

# 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 Ecosystem
- ▶ Spark Intro
- ▶ Resilient Distributed Datasets (RDDs)

# Speaker Background

# Hadoop Ecosystem

- ▶ Based on Google GFS (2003)/MapReduce (2004) papers
- ▶ Extremely rich and robust
  - ▶ ~ 2005 Nutch/2006 Yahoo - Doug Cutting/Mike Cafarella
- ▶ HDFS/Hadoop MapReduce
- ▶ DSLs: Pig, Cascading/Scalding, Crunch, Hive (SQL)
- ▶ Graph processing: Giraph
- ▶ Real-time streaming: Storm
- ▶ Machine Learning: Apache Mahout ...

# Hadoop Challenges

- ▶ With rich ecosystem: installation, maintenance, cognitive load for each add-on framework
- ▶ MapReduce is batch only - no interactive shell
- ▶ Must write out to disk between each iteration
- ▶ No memory caching yet (Apache Tez working on complex DAGs of tasks)
- ▶ Hadoop MapReduce programming is very low-level
  - ▶ map phase - (internal shuffle/sort) - reduce phase
  - ▶ Programmer expresses logic in map/reduce

# Why Apache Spark?

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

# Apache Spark Unified Large Scale Processing System

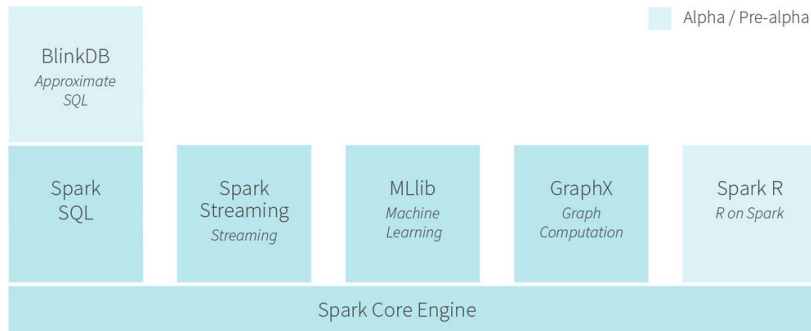


Figure : Databricks Spark Ecosystem (2015)



# 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

# RDD API

- ▶ Resilient Distributed Dataset (RDD)
- ▶ From API scala docs: "immutable, partitioned collection of elements that can be operated on in parallel"
- ▶ map, flatMap, filter, reduce...

# Enron Email Dataset and Avro MailRecord

- ▶ Downloaded 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: Create Avro record format, parse once, store (MailRecord)

# Apache Avro

- ▶ JSON - need to encode binary data
- ▶ Hadoop Writable - Java centric
- ▶ Apache Avro
- ▶ Binary serialization framework created by Doug Cutting in 2009 (Hadoop, Lucene)
- ▶ Language bindings for: 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 (~ 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;  
}
```

# 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
- ▶ emits key: userName, value: folderName for each email



# 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/FolderAnalyt>

# Spark Installation

- ▶ Bundled with Cloudera, Hortonworks, MapR distros
- ▶ Or download binary tgz from Apache Spark (match Hadoop version)
- ▶ Untar on edge node
- ▶ Set `HADOOP_CONF_DIR` environment variable or `$SPARK_HOME/conf/spark-env.sh`

# 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 via spark-submit (yarn-cluster/yarn-client master)
- ▶ 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)
- ▶ `map(f: (A) => B)`

## 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

*//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

- ▶ Used instead of Null
- ▶ Can be instance of `Some[T]` or singleton object `None`
- ▶ Can be treated as a collection

# flatMap

- ▶ ScalaDoc:

```
List[A]
```

```
...
```

```
def 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
```

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

```
> Some(tuple)  
> None
```

# Spark - SparkContext

- ▶ Automatically created by shell (sc, sqlContext)
- ▶ Or created with SparkConf for submitting a job
- ▶ accumulator and broadcast variables (~ Hadoop counters/distributed cache)
- ▶ input from HDFS or local file system (Hadoop API, textFile...)

# Spark - RDD API

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

# RDD Scaladocs

The screenshot shows the Spark RDD Scaladocs page. The left sidebar contains a navigation menu with the following items:

- display packages only
- RandomRDDs
- hide focus
- org.apache.spark.mllib.rdd
- RDDFunctions
- hide focus
- org.apache.spark.rdd
- AsyncRDDActions
- CoGroupedRDD
- DoubleRDDFunctions
- HadoopRDD
- JdbcRDD
- NewHadoopRDD
- OrderedRDDFunctions
- PairRDDFunctions
- PartitionPruningRDD
- RDD
- SequenceFileRDDFunctions
- ShuffledRDD
- UnionRDD

The main content area displays the Scala API for RDD, including the following methods:

- `def subtract(other: RDD[T], p: Partitioner): RDD[T]`  
Return an RDD with the elements from this RDD that are not in the other RDD.
- `def subtract(other: RDD[T], numPartitions: Int): RDD[T]`  
Return an RDD with the elements from this RDD that are not in the other RDD.
- `def subtract(other: RDD[T]): RDD[T]`  
Return an RDD with the elements from this RDD that are not in the other RDD.
- `def take(num: Int): Array[T]`  
Take the first num elements of the RDD.
- `def takeOrdered(num: Int)(implicit ord: Ordering[T]): Array[T]`  
Returns the first k (smallest) elements from this RDD, maintaining the ordering.
- `def takeSample(withReplacement: Boolean, num: Int, seed: Long): Array[T]`  
Return a fixed-size sampled subset of this RDD.
- `def toDebugString: String`  
A description of this RDD and its recursive dependencies.
- `def toJavaRDD(): JavaRDD[T]`

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

g	Apps Running	Apps Completed	Containers Running	Memory Used	Memory Total	Memory Reserved	VCore Used	VCore Total	VCore Reserved	Active Nodes	Decommissioned Nodes	Lost Nodes	Unhealthy Nodes	Rebooted Nodes
	1	1	2	3 GB	8 GB	0 B	2	8	0	1	0	0	0	0

Search:										
	User	Name	Application Type	Queue	StartTime	FinishTime	State	FinalStatus	Progress	Tracking UI
7410304_0002	root	Spark shell	SPARK	default	Wed, 22 Apr 2015 02:24:02 GMT	N/A	RUNNING	UNDEFINED	<div></div>	<a href="#">ApplicationMaster</a>
7410304_0001	root	Spark shell	SPARK	default	Wed, 22 Apr 2015 02:09:53 GMT	Wed, 22 Apr 2015 02:23:10 GMT	FINISHED	SUCCEEDED	<div></div>	<a href="#">History</a>

entries First Previous 1 Next Last

Figure : Yarn Resource Manager

# Spark Web UI - Tour

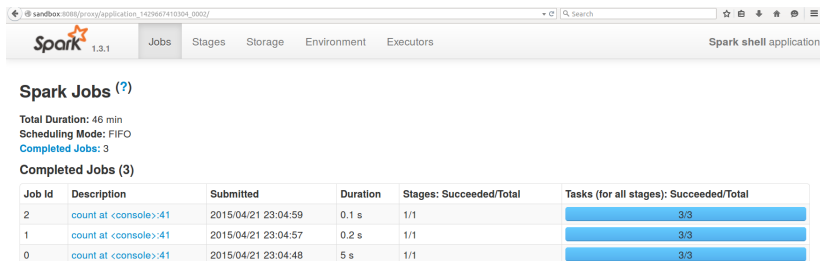


Figure : Spark Web UI

# 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()
```

```
count(), take(n)
```

# 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] =  
    folderPerUserRddExact.values
```

```
val stats = folderCounts.stats()  
> stats: org.apache.spark.util.StatCounter =  
(count: 150, mean: 22.033333, stdev: 26.773474,  
 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)  
res13: Array[Long] = Array(116, 16, 11, 3, 2, 1, 0, 1)
```

# Who has 193 folders?

- ▶ RDD - `def max()(implicit ord: Ordering[T]): T`  
`folderPerUserRddExact.max()`  
`Ordering.by(tuple => tuple._2))`  
`> res2: (String, Int) = (kean-s, 193)`

## 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()  
}
```

# 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

```
“java 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>.