

Adding Spark To Your Hadoop

Markus Dale

2015

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
 - ▶ ~ 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
 - ▶ Programmer 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

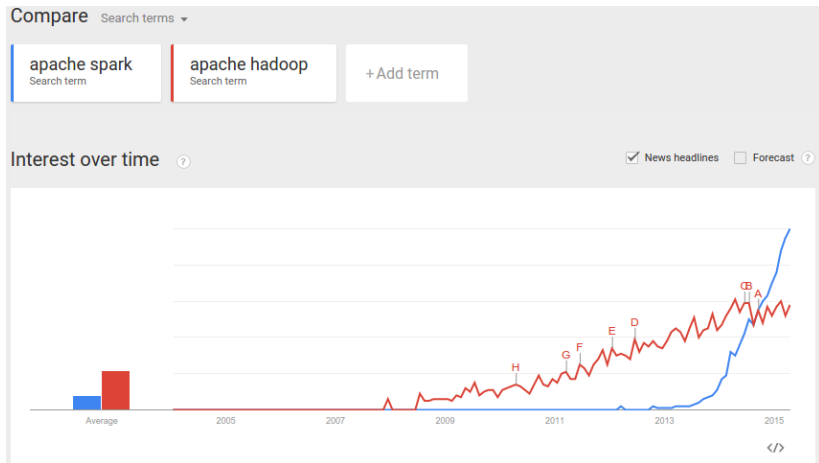


Figure : Google Trends Apache Spark/ Apache Hadoop

Apache Spark Unified Large Scale Processing System

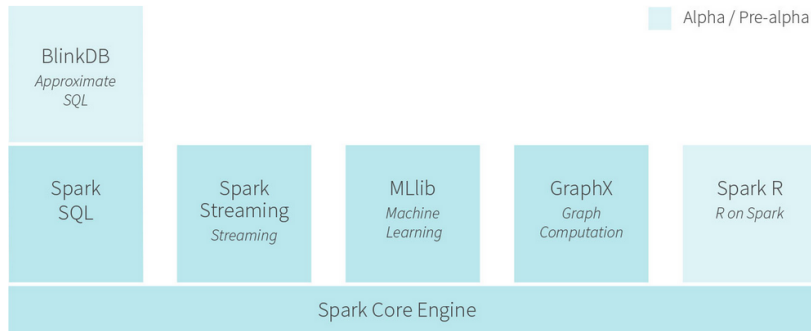


Figure : Databricks Spark Ecosystem (2015)

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 (~ 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/FolderAnalyt>

Spark Installation

- ▶ Download binary tgz from Apache Spark (match Hadoop version)
- ▶ Untar on edge node (requires java)
- ▶ 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

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
 - ▶ ~ 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

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

- 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 the `RDD` class. The methods shown are:

- `def subtract(other: RDD[T], p: Partitioner): RDD[T]`
Return an RDD with the elements from this RDD that are not in `other`.
- `def subtract(other: RDD[T], numPartitions: Int): RDD[T]`
Return an RDD with the elements from this RDD that are not in `other`.
- `def subtract(other: RDD[T]): RDD[T]`
Return an RDD with the elements from this RDD that are not in `other`.
- `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: <input type="text"/>											
▼	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>	ApplicationMaster	
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>	History	

entries	First	Previous	1	Next	Last
---------	-------	----------	---	------	------

Figure : Yarn Resource Manager

Spark Web UI - Tour

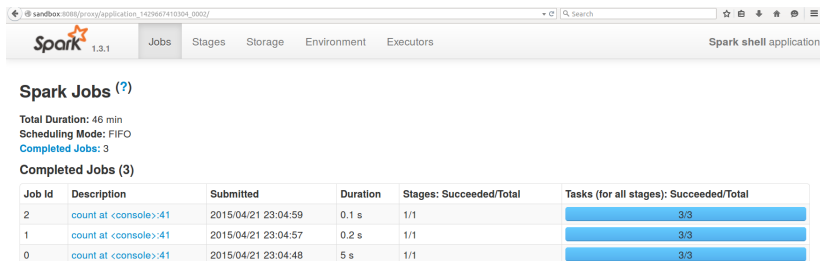


Figure : Spark Web UI

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()
```

```
>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()  
}
```


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>.