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CAP 6315 Social Networks and Big Data Analytics

Homework 4

Question 1 (0.5 pts): Please use your own language to describe the following concepts:

MapReduce (including Map and Reduce): a programming model, framework, or implementation for processing and generating large data sets using a distributed computing system. It is composed of two main functions, Map, which filters and sorts key-value pairs into a usable form, and Reduce, which aggregates the key-value pairs to create intermediate output. Additionally, the data set must be read by a scanner process, moved from Mappers to Reducers by intermediate steps called shuffling and sorting, and retrieved from the Reducers by a reader process that produces usable output.

Combiner: a less powerful Reducer-like component of MapReduce that is used with a Mapper to optimize intermediate values before moving them on to Reducers. They lower network traffic and lighten the workload of the Reducers.

Hadoop Distributed File System: a program designed to store and process large sets of data using clusters of computers. The program started from research at Google, but is now open-source and managed by Apache. Also called HDFS, it is programmed in Java and built to be fault-tolerant, easy to use, and inexpensive.

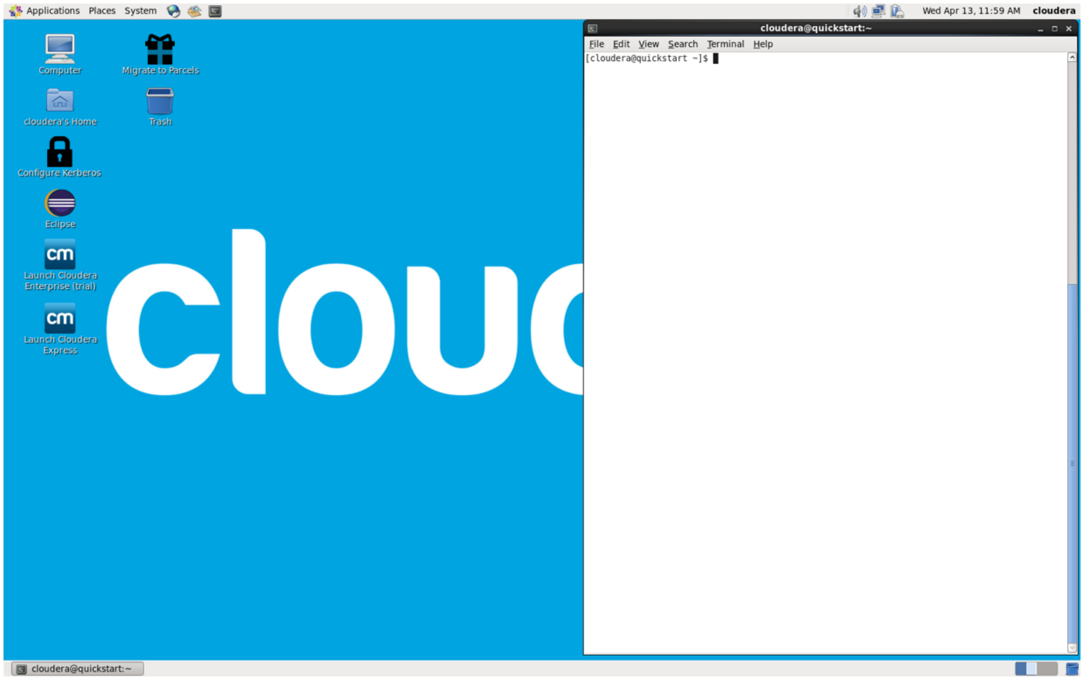
Hadoop Name Node: the control center and single point of failure of an HDFS implementation. It tracks the locations and attributes of all files in a cluster and provides the interface to add/copy/move/delete files on the file system. If the NameNode fails, the entire system is offline.

Hadoop Data Node: a server in an HDFS cluster that stores files/data. The DataNode receives its directions for file management from the NameNode, other DataNodes, or applications after they have been directed by the NameNode. DataNodes work together to coordinate data replication and create redundancy in the file system, and periodically update the NameNode on their contents.

Question 2 (1.5 pts) Hadoop Installation: Please follow the "MapReduce Programming Platform Installation Instruction" posted in the Blackboard (in the "Lectures" folder) to install Hadoop on your computer. Please report following major steps (capturing screenshots)

- **Part I:** Cloudera MapReduce Installation (0.5 pt)
- **Part II:** First MapReduce Job Task (0.5 pt)
- Pleases report the WordCount task outputs **(**0.5 pt**)**

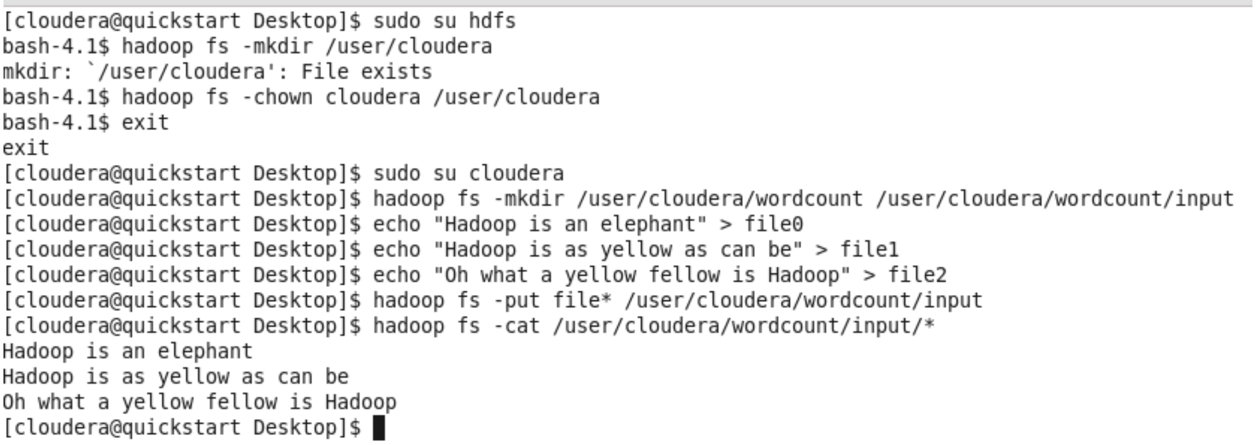
Part I results in the screenshot below. Virtual machine created with VirtualBox, terminal opened.



```
[cloudera@quickstart ~]$ 
```

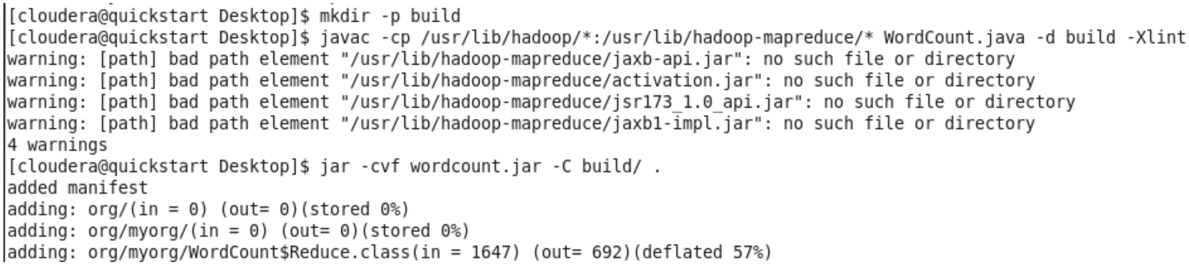
Part II results in the screenshots below.

Steps 1 and 2:



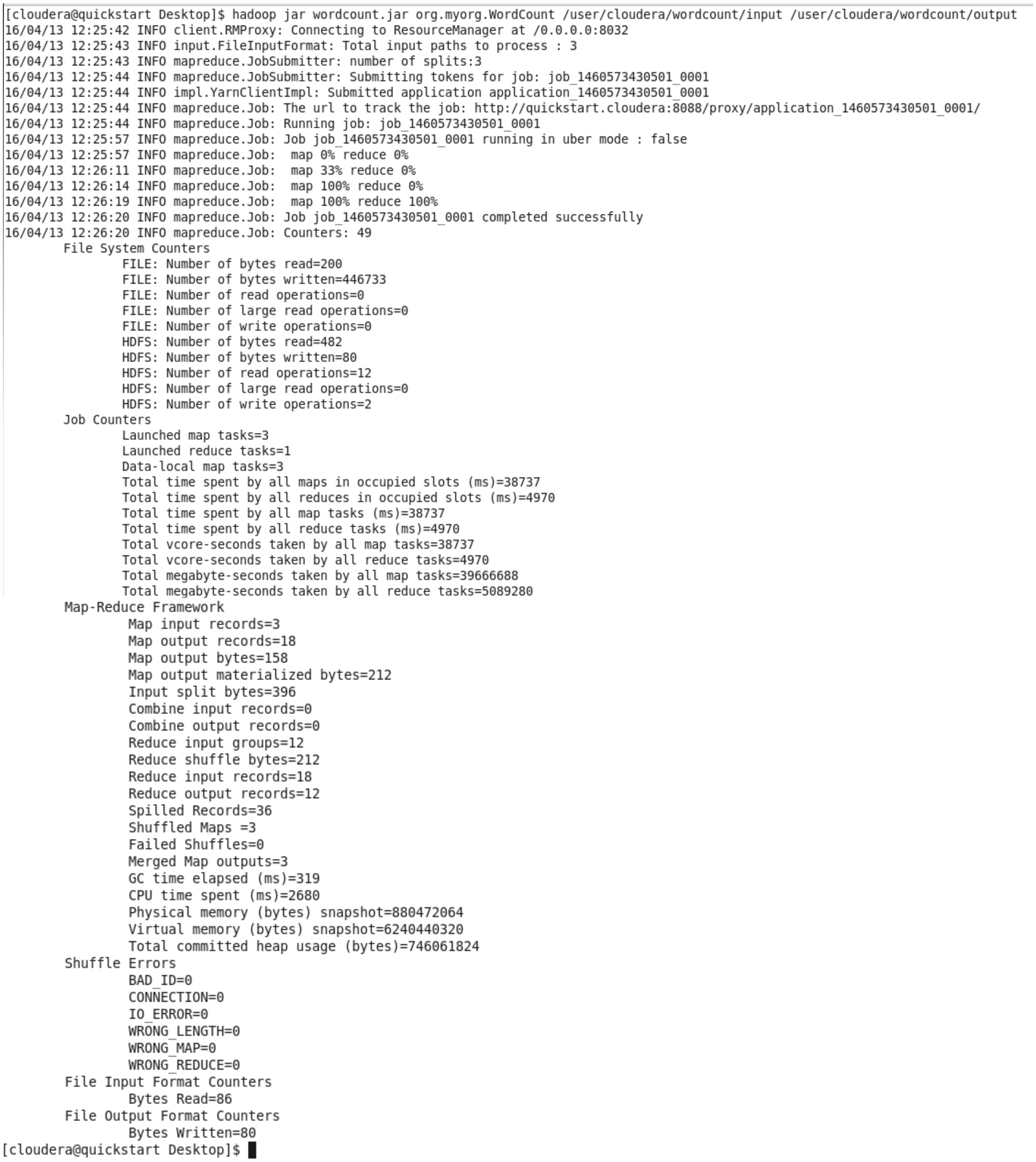
```
[cloudera@quickstart Desktop]$ sudo su hdfs
bash-4.1$ hadoop fs -mkdir /user/cloudera
mkdir: `/user/cloudera': File exists
bash-4.1$ hadoop fs -chown cloudera /user/cloudera
bash-4.1$ exit
exit
[cloudera@quickstart Desktop]$ sudo su cloudera
[cloudera@quickstart Desktop]$ hadoop fs -mkdir /user/cloudera/wordcount /user/cloudera/wordcount/input
[cloudera@quickstart Desktop]$ echo "Hadoop is an elephant" > file0
[cloudera@quickstart Desktop]$ echo "Hadoop is as yellow as can be" > file1
[cloudera@quickstart Desktop]$ echo "Oh what a yellow fellow is Hadoop" > file2
[cloudera@quickstart Desktop]$ hadoop fs -put file* /user/cloudera/wordcount/input
[cloudera@quickstart Desktop]$ hadoop fs -cat /user/cloudera/wordcount/input/*
Hadoop is an elephant
Hadoop is as yellow as can be
Oh what a yellow fellow is Hadoop
[cloudera@quickstart Desktop]$ 
```

Steps 3 and 4:



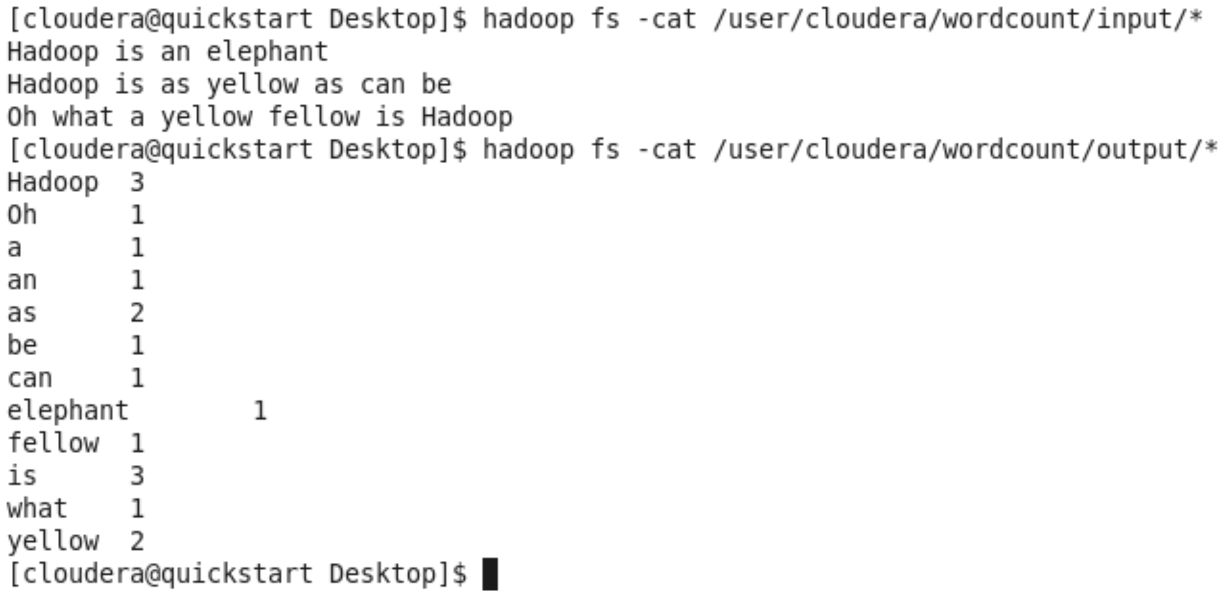
```
[cloudera@quickstart Desktop]$ mkdir -p build
[cloudera@quickstart Desktop]$ javac -cp /usr/lib/hadoop/*:/usr/lib/hadoop-mapreduce/* WordCount.java -d build -Xlint
warning: [path] bad path element "/usr/lib/hadoop-mapreduce/jaxb-api.jar": no such file or directory
warning: [path] bad path element "/usr/lib/hadoop-mapreduce/activation.jar": no such file or directory
warning: [path] bad path element "/usr/lib/hadoop-mapreduce/jsr173_1.0_api.jar": no such file or directory
warning: [path] bad path element "/usr/lib/hadoop-mapreduce/jaxb1-impl.jar": no such file or directory
4 warnings
[cloudera@quickstart Desktop]$ jar -cvf wordcount.jar -C build/ .
added manifest
adding: org/(in = 0) (out= 0)(stored 0%)
adding: org/myorg/(in = 0) (out= 0)(stored 0%)
adding: org/myorg/WordCount$Reduce.class(in = 1647) (out= 692)(deflated 57%)
```

Output from running .jar file:



```
[cloudera@quickstart Desktop]$ hadoop jar wordcount.jar org.myorg.WordCount /user/cloudera/wordcount/input /user/cloudera/wordcount/output
16/04/13 12:25:42 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/13 12:25:43 INFO input.FileInputFormat: Total input paths to process : 3
16/04/13 12:25:43 INFO mapreduce.JobSubmitter: number of splits:3
16/04/13 12:25:44 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1460573430501_0001
16/04/13 12:25:44 INFO impl.YarnClientImpl: Submitted application application_1460573430501_0001
16/04/13 12:25:44 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1460573430501_0001/
16/04/13 12:25:44 INFO mapreduce.Job: Running job: job_1460573430501_0001
16/04/13 12:25:57 INFO mapreduce.Job: Job job_1460573430501_0001 running in uber mode : false
16/04/13 12:25:57 INFO mapreduce.Job:  map 0% reduce 0%
16/04/13 12:26:11 INFO mapreduce.Job:  map 33% reduce 0%
16/04/13 12:26:14 INFO mapreduce.Job:  map 100% reduce 0%
16/04/13 12:26:19 INFO mapreduce.Job:  map 100% reduce 100%
16/04/13 12:26:20 INFO mapreduce.Job: Job job_1460573430501_0001 completed successfully
16/04/13 12:26:20 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=200
                FILE: Number of bytes written=446733
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=482
                HDFS: Number of bytes written=80
                HDFS: Number of read operations=12
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=3
                Launched reduce tasks=1
                Data-local map tasks=3
                Total time spent by all maps in occupied slots (ms)=38737
                Total time spent by all reduces in occupied slots (ms)=4970
                Total time spent by all map tasks (ms)=38737
                Total time spent by all reduce tasks (ms)=4970
                Total vcore-seconds taken by all map tasks=38737
                Total vcore-seconds taken by all reduce tasks=4970
                Total megabyte-seconds taken by all map tasks=39666688
                Total megabyte-seconds taken by all reduce tasks=5089280
        Map-Reduce Framework
                Map input records=3
                Map output records=18
                Map output bytes=158
                Map output materialized bytes=212
                Input split bytes=396
                Combine input records=0
                Combine output records=0
                Reduce input groups=12
                Reduce shuffle bytes=212
                Reduce input records=18
                Reduce output records=12
                Spilled Records=36
                Shuffled Maps =3
                Failed Shuffles=0
                Merged Map outputs=3
                GC time elapsed (ms)=319
                CPU time spent (ms)=2680
                Physical memory (bytes) snapshot=880472064
                Virtual memory (bytes) snapshot=6240440320
                Total committed heap usage (bytes)=746061824
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=86
        File Output Format Counters
                Bytes Written=80
[cloudera@quickstart Desktop]$ 
```

Step 5 complete, wordcount program run with provided inputs:

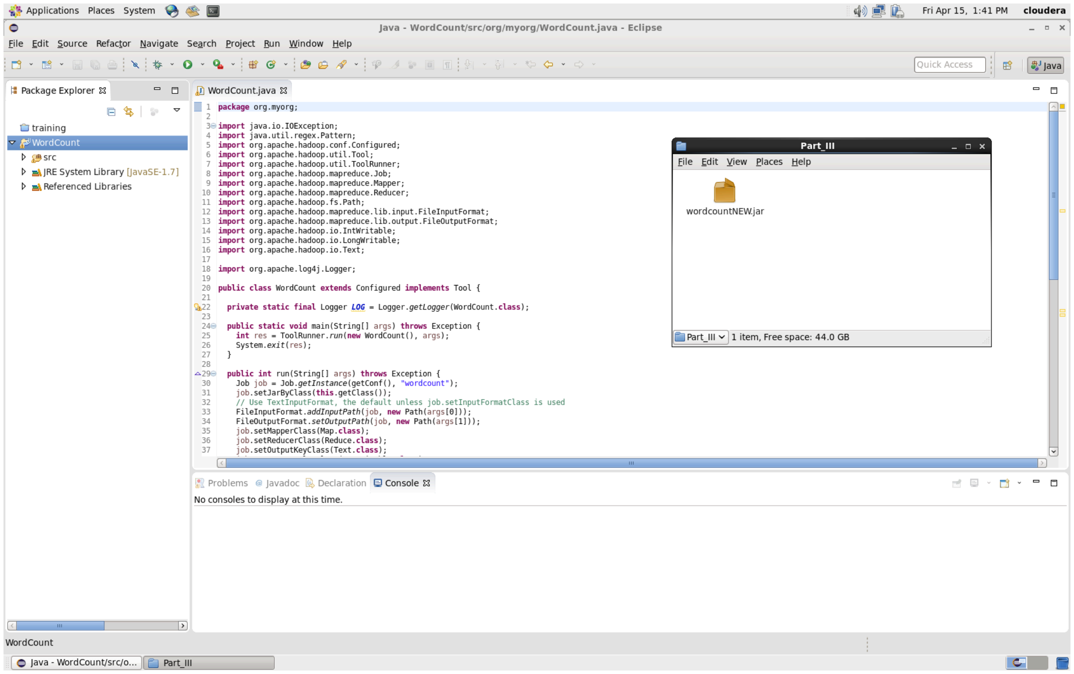


```
[cloudera@quickstart Desktop]$ hadoop fs -cat /user/cloudera/wordcount/input/*
Hadoop is an elephant
Hadoop is as yellow as can be
Oh what a yellow fellow is Hadoop
[cloudera@quickstart Desktop]$ hadoop fs -cat /user/cloudera/wordcount/output/*
Hadoop  3
Oh      1
a       1
an      1
as      2
be      1
can     1
elephant        1
fellow  1
is      3
what    1
yellow  2
[cloudera@quickstart Desktop]$ 
```

Question 3 (2 pts) Eclipse Hadoop project development: Please follow the installation instruction Part III (**Part III:** Eclipse MapReduce programming platform) to create a WordCount Eclipse Project. You can use WordCount.java file downloaded from the Cloudera website (please refer to the instruction for details). After that, please report the following major steps (capturing screenshots)

- Report that you have created an Eclipse WordCount project (0.5 pt)
- Report that you can compile the WordCount project and output JAR file (0.5 pt)
- Run WordCound.jar as a MapReduce task, and report the output (1 pt)

1. & 2. The WordCount project is created in Eclipse and the .jar file is output (called wordcountNEW):

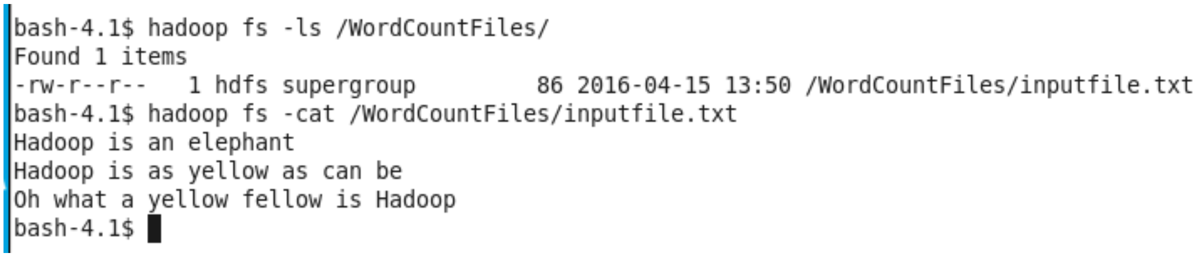


```
package org.myorg;

import java.io.IOException;
import java.util.regex.Pattern;
import org.apache.hadoop.conf.Configured;
import org.apache.hadoop.util.Tool;
import org.apache.hadoop.util.ToolRunner;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.Mapper;
import org.apache.hadoop.mapreduce.Reducer;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;

import org.apache.log4j.Logger;

public class WordCount extends Configured implements Tool {

  private static final Logger LOG = Logger.getLogger(WordCount.class);

  public static void main(String[] args) throws Exception {
    int res = ToolRunner.run(new WordCount(), args);
    System.exit(res);
  }

  public int run(String[] args) throws Exception {
    Job job = Job.getInstance(getConf(), "wordcount");
    job.setJarByClass(this.getClass());
    // Use TextInputFormat, the default unless job.setInputFormatClass is used
    FileInputFormat.addInputPath(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));
    job.setMapperClass(Map.class);
    job.setReducerClass(Reduce.class);
    job.setOutputKeyClass(Text.class);
```

1 item, Free space: 44.0 GB

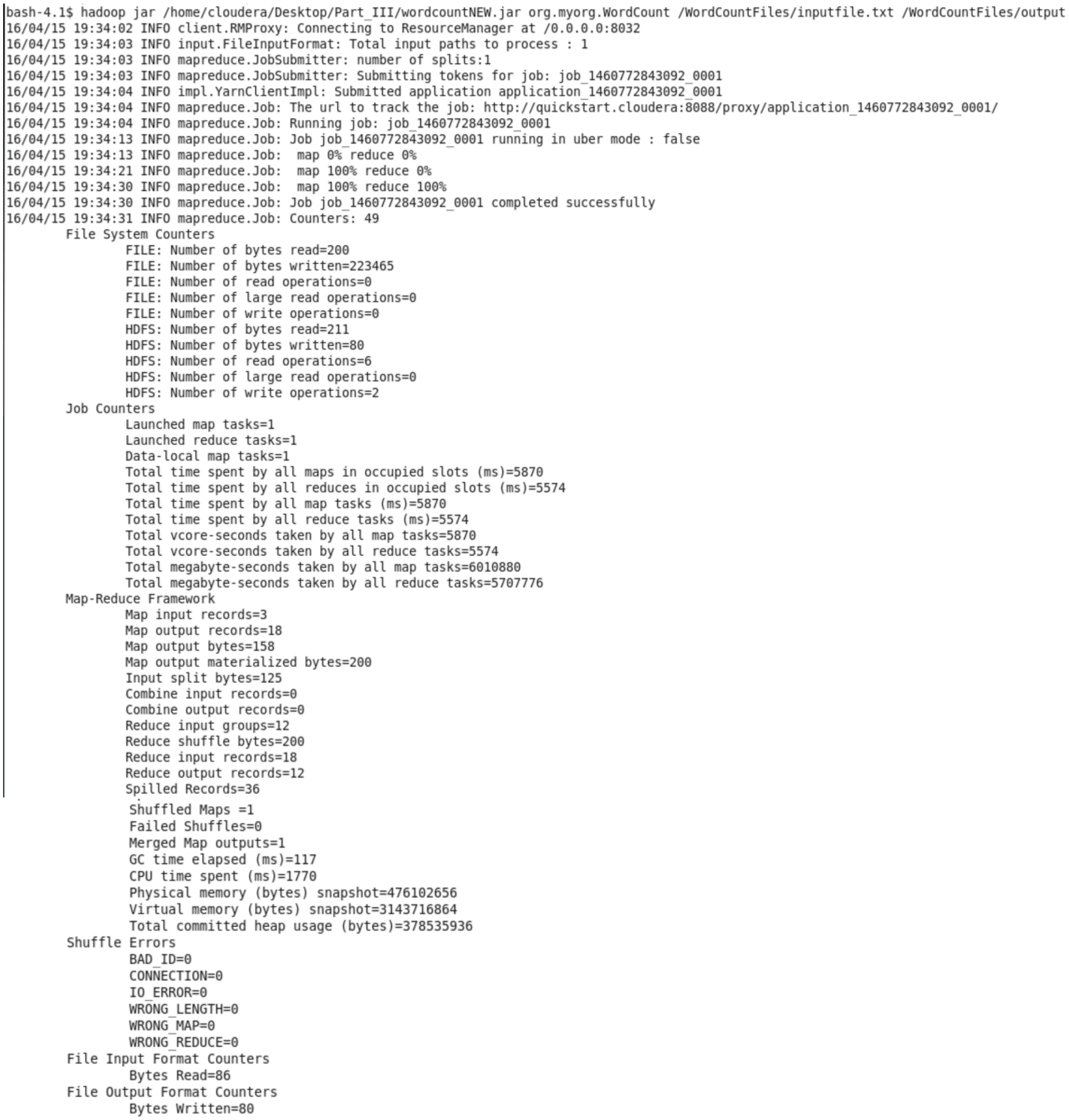
No consoles to display at this time.

Input file to be used with wordcountNEW.jar is moved into the HDFS:



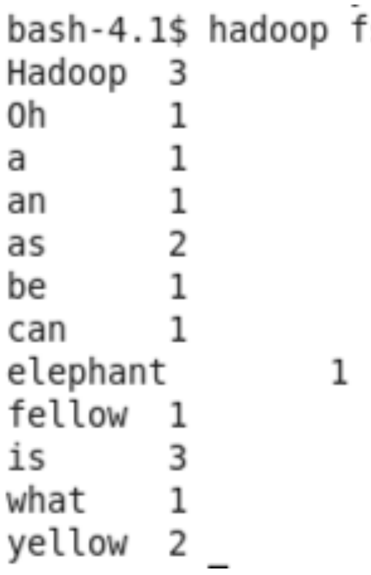
```
bash-4.1$ hadoop fs -ls /WordCountFiles/
Found 1 items
-rw-r--r--   1 hdfs supergroup         86 2016-04-15 13:50 /WordCountFiles/inputfile.txt
bash-4.1$ hadoop fs -cat /WordCountFiles/inputfile.txt
Hadoop is an elephant
Hadoop is as yellow as can be
Oh what a yellow fellow is Hadoop
bash-4.1$ █
```

3. The MapReduce task is run via wordcountNEW.jar:



```
bash-4.1$ hadoop jar /home/cloudera/Desktop/Part_III/wordcountNEW.jar org.myorg.WordCount /WordCountFiles/inputfile.txt /WordCountFiles/output
16/04/15 19:34:02 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/15 19:34:03 INFO input.FileInputFormat: Total input paths to process : 1
16/04/15 19:34:03 INFO mapreduce.JobSubmitter: number of splits:1
16/04/15 19:34:03 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1460772843092_0001
16/04/15 19:34:04 INFO impl.YarnClientImpl: Submitted application application_1460772843092_0001
16/04/15 19:34:04 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1460772843092_0001/
16/04/15 19:34:04 INFO mapreduce.Job: Running job: job_1460772843092_0001
16/04/15 19:34:13 INFO mapreduce.Job: Job job_1460772843092_0001 running in uber mode : false
16/04/15 19:34:13 INFO mapreduce.Job:  map 0% reduce 0%
16/04/15 19:34:21 INFO mapreduce.Job:  map 100% reduce 0%
16/04/15 19:34:30 INFO mapreduce.Job:  map 100% reduce 100%
16/04/15 19:34:30 INFO mapreduce.Job: Job job_1460772843092_0001 completed successfully
16/04/15 19:34:31 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=200
                FILE: Number of bytes written=223465
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=211
                HDFS: Number of bytes written=80
                HDFS: Number of read operations=6
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=1
                Launched reduce tasks=1
                Data-local map tasks=1
                Total time spent by all maps in occupied slots (ms)=5870
                Total time spent by all reduces in occupied slots (ms)=5574
                Total time spent by all map tasks (ms)=5870
                Total time spent by all reduce tasks (ms)=5574
                Total vcore-seconds taken by all map tasks=5870
                Total vcore-seconds taken by all reduce tasks=5574
                Total megabyte-seconds taken by all map tasks=6010880
                Total megabyte-seconds taken by all reduce tasks=5707776
        Map-Reduce Framework
                Map input records=3
                Map output records=18
                Map output bytes=158
                Map output materialized bytes=200
                Input split bytes=125
                Combine input records=0
                Combine output records=0
                Reduce input groups=12
                Reduce shuffle bytes=200
                Reduce input records=18
                Reduce output records=12
                Spilled Records=36
                Shuffled Maps =1
                Failed Shuffles=0
                Merged Map outputs=1
                GC time elapsed (ms)=117
                CPU time spent (ms)=1770
                Physical memory (bytes) snapshot=476102656
                Virtual memory (bytes) snapshot=3143716864
                Total committed heap usage (bytes)=378535936
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=86
        File Output Format Counters
                Bytes Written=80
```

The final results are output:

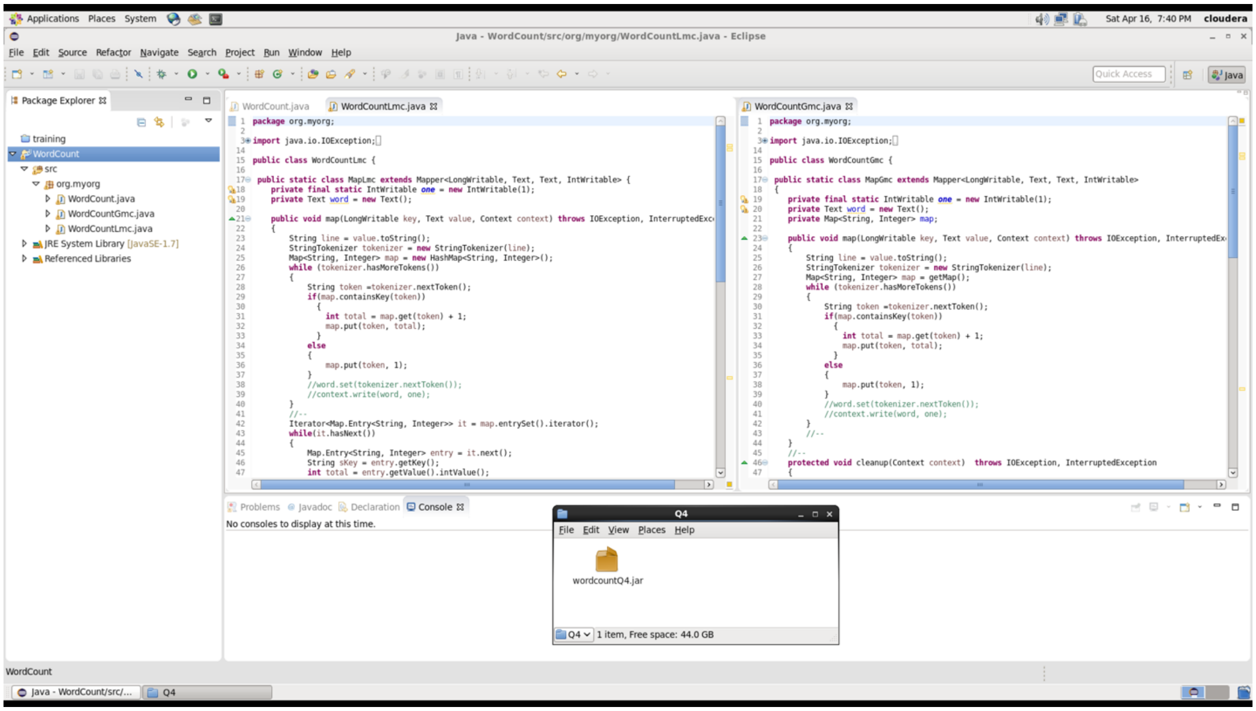


```
bash-4.1$ hadoop fs -cat /WordCountFiles/output/*
Hadoop  3
Oh      1
a       1
an      1
as      2
be      1
can     1
elephant        1
fellow  1
is      3
what    1
yellow  2 _
```

Question 4 (3 pts) Mapper functions: In the attached "WordCountLmc.java" and "WordCountGmc.java", the mapper functions create associate array to maintain key-value pair status. The difference is that WordCountLmc uses local in-mapper-combing, and WordCountGmc uses global in-mapper-combing.

- Please modify your Hadoop Project in Question 3, to create a new project "WordCountLmc", which uses local in-mapper-combing to count word frequency. Please use "genesis.txt", "luke.txt", and "kings.txt" as input (place all three files in a folder named "input"), and report the running results of the project. (1 pt)
- Please modify your Hadoop Project in Question 3, to create a new project "WordCountGmc", which uses global in-mapper-combing to count word frequency. Please use "genesis.txt", "luke.txt", and "kings.txt" as input (place all three files in a folder named "input"), and report the running results of the project. (1 pt)
- Please compare running results from three MapReduce Tasks, WordCount, WordCountLmc, and WordCountGmc. Analyze and report the differences (i.e. Explain the benefits of in-mapper-combining, and explain how local and global in-mapper-combing achieve the efficiency gain) (1 pt)

1. The WordCountLmc.java and WordCountGmc.java code is added to the project and a new .jar file is created:



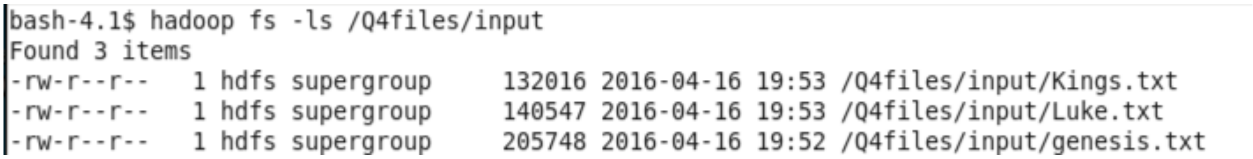
```
package org.myorg;

import java.io.IOException;

public class WordCountLmc {

 public static class MapLmc extends Mapper<LongWritable, Text, Text, IntWritable> {
    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();

    public void map(LongWritable key, Text value, Context context) throws IOException, InterruptedExc
    {
        String line = value.toString();
        StringTokenizer tokenizer = new StringTokenizer(line);
        Map<String, Integer> map = new HashMap<String, Integer>();
        while (tokenizer.hasMoreTokens())
        {
            String token =tokenizer.nextToken();
            if(map.containsKey(token))
              {
                int total = map.get(token) + 1;
                map.put(token, total);
              }
            else
            {
                map.put(token, 1);
            }
            //word.set(tokenizer.nextToken());
            //context.write(word, one);
        }
        //--
        Iterator<Map.Entry<String, Integer>> it = map.entrySet().iterator();
        while(it.hasNext())
        {
            Map.Entry<String, Integer> entry = it.next();
            String sKey = entry.getKey();
            int total = entry.getValue().intValue();
```

```
package org.myorg;

import java.io.IOException;

public class WordCountGmc {

 public static class MapGmc extends Mapper<LongWritable, Text, Text, IntWritable>
 {
    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();
    private Map<String, Integer> map;

    public void map(LongWritable key, Text value, Context context) throws IOException, InterruptedEx
    {
        String line = value.toString();
        StringTokenizer tokenizer = new StringTokenizer(line);
        Map<String, Integer> map = getMap();
        while (tokenizer.hasMoreTokens())
        {
            String token =tokenizer.nextToken();
            if(map.containsKey(token))
              {
                int total = map.get(token) + 1;
                map.put(token, total);
              }
            else
            {
                map.put(token, 1);
            }
            //word.set(tokenizer.nextToken());
            //context.write(word, one);
        }
        //--
    }
    //--
    protected void cleanup(Context context)  throws IOException, InterruptedException
    {
```

No consoles to display at this time.

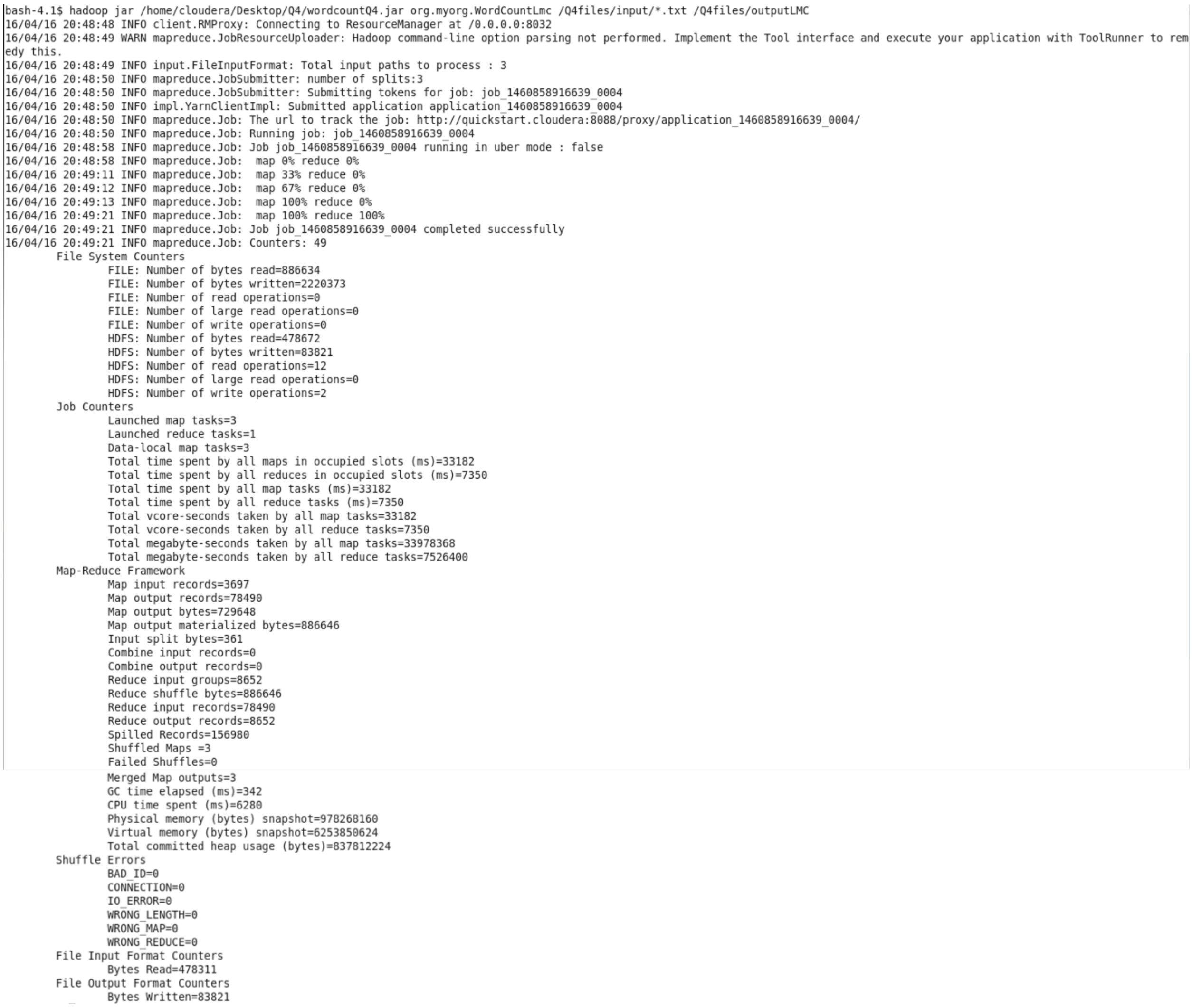
1 item, Free space: 44.0 GB

The text files are copied into the HDFS:



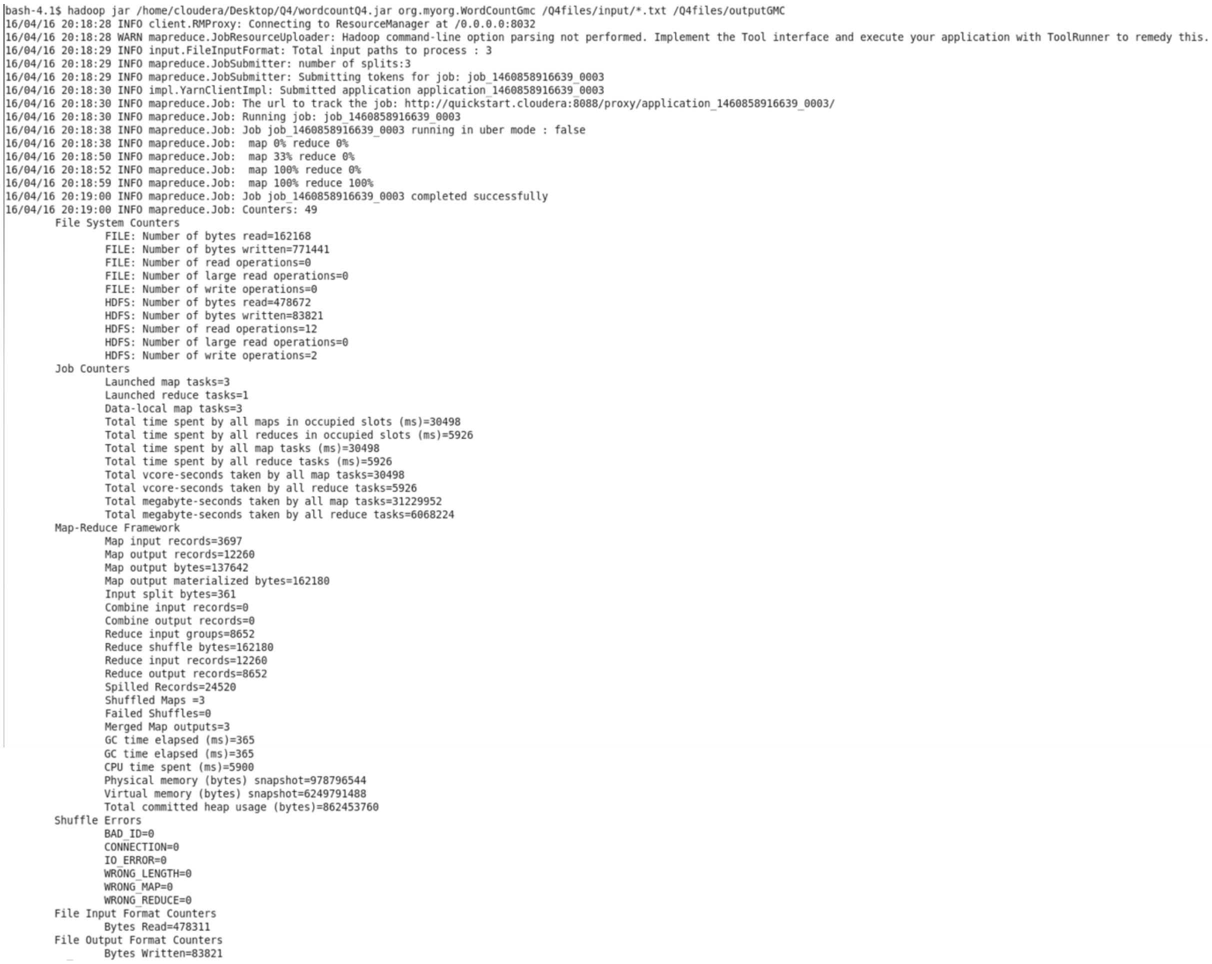
```
bash-4.1$ hadoop fs -ls /Q4files/input
Found 3 items
-rw-r--r--   1 hdfs supergroup     132016 2016-04-16 19:53 /Q4files/input/Kings.txt
-rw-r--r--   1 hdfs supergroup     140547 2016-04-16 19:53 /Q4files/input/Luke.txt
-rw-r--r--   1 hdfs supergroup     205748 2016-04-16 19:52 /Q4files/input/genesis.txt
```

1. The WordCountLmc.java program is run. Output is too large to display in the console, run results:



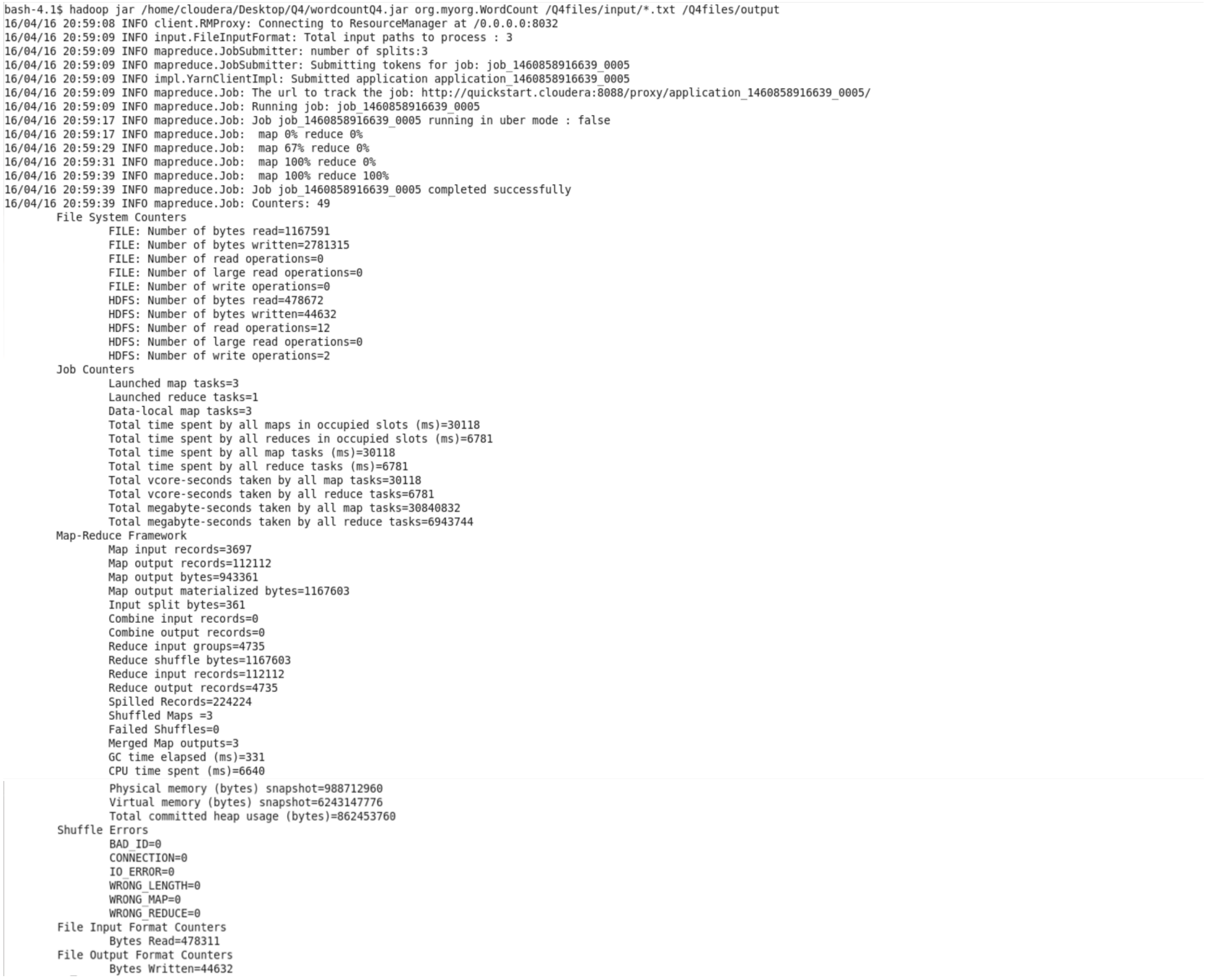
```
bash-4.1$ hadoop jar /home/cloudera/Desktop/Q4/wordcountQ4.jar org.myorg.WordCountLmc /Q4files/input/*.txt /Q4files/outputLMC
16/04/16 20:48:48 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/16 20:48:49 WARN mapreduce.JobResourceUploader: Hadoop command-line option parsing not performed. Implement the Tool interface and execute your application with ToolRunner to rem
edy this.
16/04/16 20:48:49 INFO input.FileInputFormat: Total input paths to process : 3
16/04/16 20:48:50 INFO mapreduce.JobSubmitter: number of splits:3
16/04/16 20:48:50 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1460858916639_0004
16/04/16 20:48:50 INFO impl.YarnClientImpl: Submitted application application_1460858916639_0004
16/04/16 20:48:50 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1460858916639_0004/
16/04/16 20:48:50 INFO mapreduce.Job: Running job: job_1460858916639_0004
16/04/16 20:48:58 INFO mapreduce.Job: Job job_1460858916639_0004 running in uber mode : false
16/04/16 20:48:58 INFO mapreduce.Job:  map 0% reduce 0%
16/04/16 20:49:11 INFO mapreduce.Job:  map 33% reduce 0%
16/04/16 20:49:12 INFO mapreduce.Job:  map 67% reduce 0%
16/04/16 20:49:13 INFO mapreduce.Job:  map 100% reduce 0%
16/04/16 20:49:21 INFO mapreduce.Job:  map 100% reduce 100%
16/04/16 20:49:21 INFO mapreduce.Job: Job job_1460858916639_0004 completed successfully
16/04/16 20:49:21 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=886634
                FILE: Number of bytes written=2220373
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=478672
                HDFS: Number of bytes written=83821
                HDFS: Number of read operations=12
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=3
                Launched reduce tasks=1
                Data-local map tasks=3
                Total time spent by all maps in occupied slots (ms)=33182
                Total time spent by all reduces in occupied slots (ms)=7350
                Total time spent by all map tasks (ms)=33182
                Total time spent by all reduce tasks (ms)=7350
                Total vcore-seconds taken by all map tasks=33182
                Total vcore-seconds taken by all reduce tasks=7350
                Total megabyte-seconds taken by all map tasks=33978368
                Total megabyte-seconds taken by all reduce tasks=7526400
        Map-Reduce Framework
                Map input records=3697
                Map output records=78490
                Map output bytes=729648
                Map output materialized bytes=886646
                Input split bytes=361
                Combine input records=0
                Combine output records=0
                Reduce input groups=8652
                Reduce shuffle bytes=886646
                Reduce input records=78490
                Reduce output records=8652
                Spilled Records=156980
                Shuffled Maps =3
                Failed Shuffles=0
                Merged Map outputs=3
                GC time elapsed (ms)=342
                CPU time spent (ms)=6280
                Physical memory (bytes) snapshot=978268160
                Virtual memory (bytes) snapshot=6253850624
                Total committed heap usage (bytes)=837812224
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=478311
        File Output Format Counters
                Bytes Written=83821
```

2. The WordCountGmc.java program is run. Again, output is too large to display in the console, run results:



```
bash-4.1$ hadoop jar /home/cloudera/Desktop/Q4/wordcountQ4.jar org.myorg.WordCountGmc /Q4files/input/*.txt /Q4files/outputGMC
16/04/16 20:18:28 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/16 20:18:28 WARN mapreduce.JobResourceUploader: Hadoop command-line option parsing not performed. Implement the Tool interface and execute your application with ToolRunner to remedy this.
16/04/16 20:18:29 INFO input.FileInputFormat: Total input paths to process : 3
16/04/16 20:18:29 INFO mapreduce.JobSubmitter: number of splits:3
16/04/16 20:18:29 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1460858916639_0003
16/04/16 20:18:30 INFO impl.YarnClientImpl: Submitted application application_1460858916639_0003
16/04/16 20:18:30 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1460858916639_0003/
16/04/16 20:18:30 INFO mapreduce.Job: Running job: job_1460858916639_0003
16/04/16 20:18:38 INFO mapreduce.Job: Job job_1460858916639_0003 running in uber mode : false
16/04/16 20:18:38 INFO mapreduce.Job:  map 0% reduce 0%
16/04/16 20:18:50 INFO mapreduce.Job:  map 33% reduce 0%
16/04/16 20:18:52 INFO mapreduce.Job:  map 100% reduce 0%
16/04/16 20:18:59 INFO mapreduce.Job:  map 100% reduce 100%
16/04/16 20:19:00 INFO mapreduce.Job: Job job_1460858916639_0003 completed successfully
16/04/16 20:19:00 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=162168
                FILE: Number of bytes written=771441
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=478672
                HDFS: Number of bytes written=83821
                HDFS: Number of read operations=12
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=3
                Launched reduce tasks=1
                Data-local map tasks=3
                Total time spent by all maps in occupied slots (ms)=30498
                Total time spent by all reduces in occupied slots (ms)=5926
                Total time spent by all map tasks (ms)=30498
                Total time spent by all reduce tasks (ms)=5926
                Total vcore-seconds taken by all map tasks=30498
                Total vcore-seconds taken by all reduce tasks=5926
                Total megabyte-seconds taken by all map tasks=31229952
                Total megabyte-seconds taken by all reduce tasks=6068224
        Map-Reduce Framework
                Map input records=3697
                Map output records=12260
                Map output bytes=137642
                Map output materialized bytes=162180
                Input split bytes=361
                Combine input records=0
                Combine output records=0
                Reduce input groups=8652
                Reduce shuffle bytes=162180
                Reduce input records=12260
                Reduce output records=8652
                Spilled Records=24520
                Shuffled Maps =3
                Failed Shuffles=0
                Merged Map outputs=3
                GC time elapsed (ms)=365
                GC time elapsed (ms)=365
                CPU time spent (ms)=5900
                Physical memory (bytes) snapshot=978796544
                Virtual memory (bytes) snapshot=6249791488
                Total committed heap usage (bytes)=862453760
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=478311
        File Output Format Counters
                Bytes Written=83821
```

3. WordCount.java is run on the current dataset for comparison:



```
bash-4.1$ hadoop jar /home/cloudera/Desktop/Q4/wordcountQ4.jar org.myorg.WordCount /Q4files/input/*.txt /Q4files/output
16/04/16 20:59:08 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/16 20:59:09 INFO input.FileInputFormat: Total input paths to process : 3
16/04/16 20:59:09 INFO mapreduce.JobSubmitter: number of splits:3
16/04/16 20:59:09 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1460858916639_0005
16/04/16 20:59:09 INFO impl.YarnClientImpl: Submitted application application_1460858916639_0005
16/04/16 20:59:09 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1460858916639_0005/
16/04/16 20:59:09 INFO mapreduce.Job: Running job: job_1460858916639_0005
16/04/16 20:59:17 INFO mapreduce.Job: Job job_1460858916639_0005 running in uber mode : false
16/04/16 20:59:17 INFO mapreduce.Job:  map 0% reduce 0%
16/04/16 20:59:29 INFO mapreduce.Job:  map 67% reduce 0%
16/04/16 20:59:31 INFO mapreduce.Job:  map 100% reduce 0%
16/04/16 20:59:39 INFO mapreduce.Job:  map 100% reduce 100%
16/04/16 20:59:39 INFO mapreduce.Job: Job job_1460858916639_0005 completed successfully
16/04/16 20:59:39 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=1167591
                FILE: Number of bytes written=2781315
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=478672
                HDFS: Number of bytes written=44632
                HDFS: Number of read operations=12
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=3
                Launched reduce tasks=1
                Data-local map tasks=3
                Total time spent by all maps in occupied slots (ms)=30118
                Total time spent by all reduces in occupied slots (ms)=6781
                Total time spent by all map tasks (ms)=30118
                Total time spent by all reduce tasks (ms)=6781
                Total vcore-seconds taken by all map tasks=30118
                Total vcore-seconds taken by all reduce tasks=6781
                Total megabyte-seconds taken by all map tasks=30840832
                Total megabyte-seconds taken by all reduce tasks=6943744
        Map-Reduce Framework
                Map input records=3697
                Map output records=112112
                Map output bytes=943361
                Map output materialized bytes=1167603
                Input split bytes=361
                Combine input records=0
                Combine output records=0
                Reduce input groups=4735
                Reduce shuffle bytes=1167603
                Reduce input records=112112
                Reduce output records=4735
                Spilled Records=224224
                Shuffled Maps =3
                Failed Shuffles=0
                Merged Map outputs=3
                GC time elapsed (ms)=331
                CPU time spent (ms)=6640
                Physical memory (bytes) snapshot=988712960
                Virtual memory (bytes) snapshot=6243147776
                Total committed heap usage (bytes)=862453760
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=478311
        File Output Format Counters
                Bytes Written=44632
```

Without a combiner, each token will emit a key-value pair for the reducers to sum, which is a major inefficiency in the MapReduce program. By using a local in-mapper combiner, an associative array is created inside the map method to collect and count tokens. This means that the reducers will not have to sum tokens, but only words, which can be a much smaller task. Further optimization can be made by moving the associative array out of the map method and into the mapper cleanup method. In this case, the mapper emits the key-value word counts only once – upon its task completion. With a large number of mappers and reducers, this greatly reduces shuffling overhead, but could create a space issue if the array grows too large.

In my program execution, the most observable differences between the three implementations was in the file system read & write space, and CPU time, as shown below:

	Read bytes	Written bytes	CPU time
No optimization	1,167,591	2,781,315	6,640
Local	886,634	2,220,373	6,280
Global	162,168	771,441	5,900

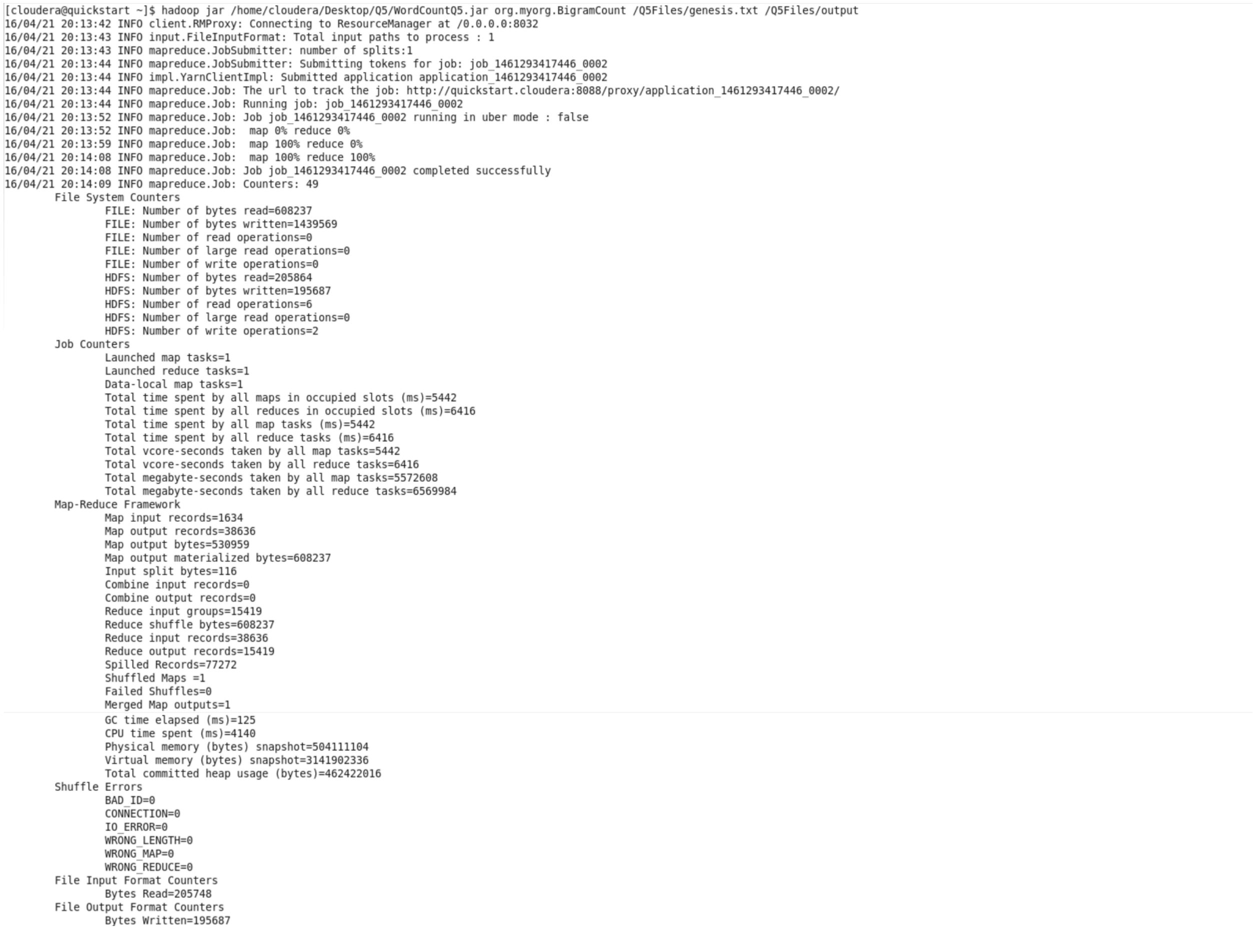
By using in-mapper combining, the efficiency improved somewhat for the local version, and substantially for the global version. This is due to the lower frequency of emissions shuffled to the reducers.

Question 5 (1.5 pt) Bigram Counting MapReduce Task: Given a sentence, a bigram denotes a unit consists of two consecutive words of the sentence. For example, given a sentence "I am a student at FAU", there are five bigrams: (I am), (am a) (a student) (student at) (at FAU). Bigrams are used to preserve the context information in the sentence.

Please deign a MapReduce task, which takes "genesis.txt" as the input, and count the frequency of all bigrams (excluding punctuations).

- Please submit your java file [1.0 pt]
- Please use "genesis.txt" as input, and report the final counting results [0.5 pt]

1. The BigramCount.java file is attached to the homework submission on Blackboard. The provided WordCount.java file was modified slightly to count bigrams. Rather than scanning through the file and emitting a key-value for each word, the map method emits a key-value for each bigram. This uses the provided regular expression for splitting the lines of text and an additional regular expression to check that only alphanumeric characters are contained in each word. Each line is tokenized and iterated through via a for loop, as in WordCount, but the loop also tracks a previous word in addition to the current word. If both the previous word and the current word are valid, a bigram is found.
2. The output text file, BigramCountOutput.txt, is attached to the homework submission on Blackboard as well. This file is too long to add to this document, but the run logs are shown below.



```
[cloudera@quickstart ~]$ hadoop jar /home/cloudera/Desktop/Q5/WordCountQ5.jar org.myorg.BigramCount /Q5Files/genesis.txt /Q5Files/output
16/04/21 20:13:42 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/04/21 20:13:43 INFO input.FileInputFormat: Total input paths to process : 1
16/04/21 20:13:43 INFO mapreduce.JobSubmitter: number of splits:1
16/04/21 20:13:44 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1461293417446_0002
16/04/21 20:13:44 INFO impl.YarnClientImpl: Submitted application application_1461293417446_0002
16/04/21 20:13:44 INFO mapreduce.Job: The url to track the job: http://quickstart.cloudera:8088/proxy/application_1461293417446_0002/
16/04/21 20:13:44 INFO mapreduce.Job: Running job: job_1461293417446_0002
16/04/21 20:13:52 INFO mapreduce.Job: Job job_1461293417446_0002 running in uber mode : false
16/04/21 20:13:52 INFO mapreduce.Job:  map 0% reduce 0%
16/04/21 20:13:59 INFO mapreduce.Job:  map 100% reduce 0%
16/04/21 20:14:08 INFO mapreduce.Job:  map 100% reduce 100%
16/04/21 20:14:08 INFO mapreduce.Job: Job job_1461293417446_0002 completed successfully
16/04/21 20:14:09 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=608237
                FILE: Number of bytes written=1439569
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=205864
                HDFS: Number of bytes written=195687
                HDFS: Number of read operations=6
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Launched map tasks=1
                Launched reduce tasks=1
                Data-local map tasks=1
                Total time spent by all maps in occupied slots (ms)=5442
                Total time spent by all reduces in occupied slots (ms)=6416
                Total time spent by all map tasks (ms)=5442
                Total time spent by all reduce tasks (ms)=6416
                Total vcore-seconds taken by all map tasks=5442
                Total vcore-seconds taken by all reduce tasks=6416
                Total megabyte-seconds taken by all map tasks=5572608
                Total megabyte-seconds taken by all reduce tasks=6569984
        Map-Reduce Framework
                Map input records=1634
                Map output records=38636
                Map output bytes=530959
                Map output materialized bytes=608237
                Input split bytes=116
                Combine input records=0
                Combine output records=0
                Reduce input groups=15419
                Reduce shuffle bytes=608237
                Reduce input records=38636
                Reduce output records=15419
                Spilled Records=77272
                Shuffled Maps =1
                Failed Shuffles=0
                Merged Map outputs=1
                GC time elapsed (ms)=125
                CPU time spent (ms)=4140
                Physical memory (bytes) snapshot=504111104
                Virtual memory (bytes) snapshot=3141902336
                Total committed heap usage (bytes)=462422016
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=205748
        File Output Format Counters
                Bytes Written=195687
```