

# Lab 1 - MapReduce, HDFS, HBase, Spark

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## 1 Overview

In this lab assignment you will practice the basics of data intensive programming by setting up HDFS, HBase, Hadoop MapReduce, Spark, and Spark SQL, and implementing simple applications on them.

The assignment consists of two parts. In the first part (Sections 3-8) you practice with HDFS, HBase, and Hadoop MapReduce, and as the deliverable, you complete a code that parses given user activity data and finds top ten users based on their reputation. In the second part (Sections 9-12), you practice with Spark and Spark SQL.

We strongly recommended that you use a Linux environment for all the assignments of this course. You can either install Linux on your own machine, or use a Virtual Machine (VM) that runs a Linux installation. If you are new to Linux, we recommend using a VM so you would not need to worry about messing up your own computer. In order to run a VM, you need a Hypervisor such as VirtualBox. You can download VirtualBox from its [website](#). You can also find different ready to use Linux distribution images for VirtualBox [here](#). However, in the next section we show you how to set up a VM and install Ubuntu 18.04.5 on it.

Note that the following instructions have been tested on Ubuntu 18.04.5 LTS Desktop, a very stable and widely used distribution of Linux. Again, we strongly recommend that you use the exact versions of the platforms that are specified in these instructions.

## 2 Setting Up a VirtualBox VM

Follow these instructions to create a VirtualBox VM running Ubuntu 18.04.5 LTS.

### 2.1 Creating a VM Instance

1. Download Ubuntu 18.04.5 LTS Desktop iso from [here](#).
2. Download and install VirtualBox 6 from its [website](#).
3. Open VirtualBox and click on the **New** button to create a new VM.
4. In “Guided Mode”, give a name to your VM, for **Type** select **Linux**, for **Version** select **Ubuntu (64-bit)**, and click on **Continue**.
5. If your computer has at least 8GB of memory, increase the memory size to a recommended minimum of 4096MB.
6. For Hard disk, choose **Create a virtual hard disk now** and click on **Create**. Select **VDI (VirtualBox Disk Image)** and click on **Continue**.
7. Choose either of the options. If you have lots of storage at your disposal, selecting **Fixed size** would result in a faster experience with the VM.
8. Allocate at least 10GB of storage, and click on **Create**.

## 2.2 Installing Ubuntu 18.04.5 on the VM

1. In VirtualBox's main window, select the VM instance that you just created.
2. Select **Start** and then **Normal Start**.
3. Select the iso image that you downloaded.
4. Click on **Install Ubuntu**.
5. Choose a keyboard layout and click on **Continue**.
6. Select **Minimal installation** and uncheck all the other options.
7. Select **Erase disks and ...** and click on **Install Now**. If you are installing Ubuntu on your own machine, this is the step you should be very careful about, as careless settings might result in losing all your data. However, since we are installing Ubuntu on a VM, selecting the first option will erase the VirtualBox disk image that we just created while setting up the VM.
8. The rest of the installation steps are straight forward. Once the installation is complete, you can login to your account using the password you specified during the installation.

## 2.3 Setting Up Port Forwarding

You can use port forwarding, e.g., to work with the Jupyter notebooks on your own machine's browser if the VM's graphical environment is not very smooth.

1. Right-click on your VM and click on **Settings**.
2. On the top bar, choose **Network**.
3. Go to **Adapter 1**. Make sure **Enable Network Adapter** is checked NAT is selected.
4. Click on **Advanced** and then choose **Port Forwarding**.
5. Add your desired mappings and click on **OK**. Below you can see an example mapping for default web interfaces of NameNode, DataNode, Jupyter, and Spark.

## 3 Introduction to Part 1

In the first part of the assignment, you practice with Hadoop MapReduce, HDFS, and HBase. Section 4 and Section 5 of this document demonstrate how to install MapReduce, HDFS and HBase, and work with them, and Sections 6 and 7 show how to build and run an application with Hadoop MapReduce, and connect to HBase. Later, in Section 8, you are asked to implement a MapReduce code as the first deliverable of this assignment.

## 4 Installing Hadoop MapReduce and HDFS

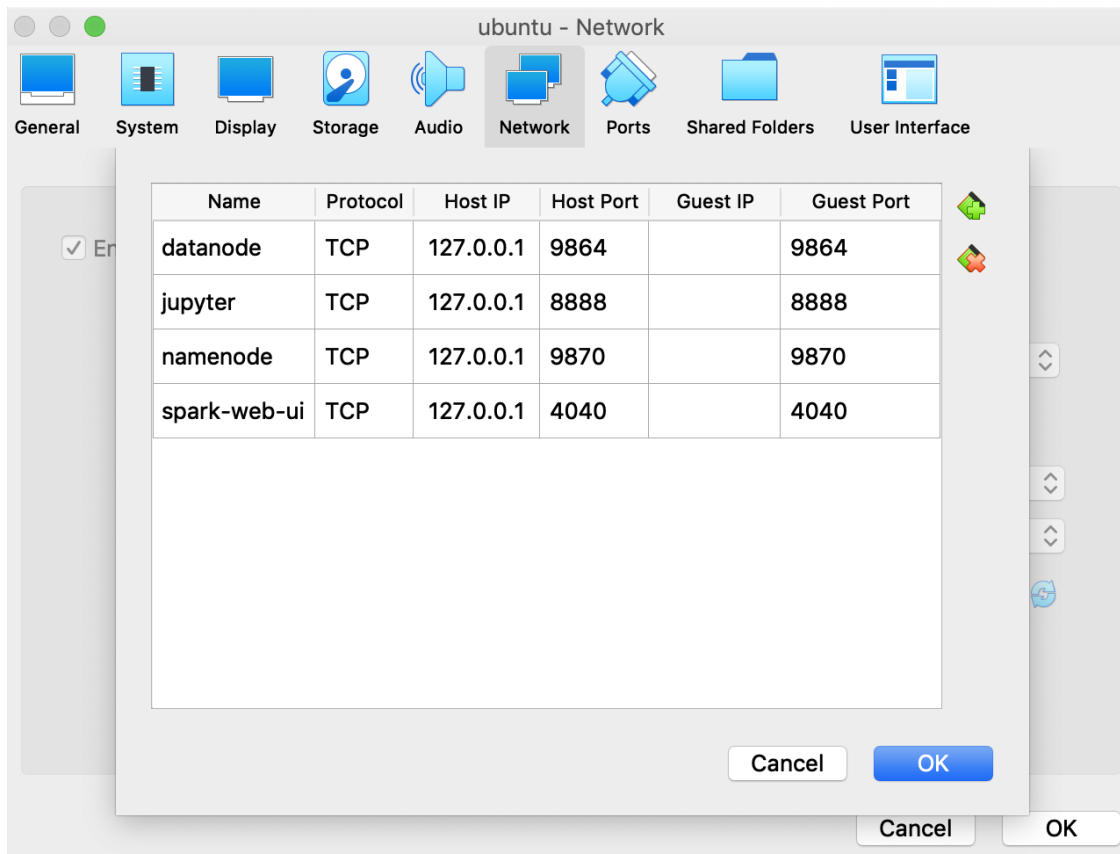
This section presents the steps you need to do to install MapReduce and HDFS.

1. Install Java SDK 8:

```
sudo apt install openjdk-8-jdk -y
```

2. Download and extract Hadoop MapReduce 3.1.2 tarball in your home directory:

```
cd ~
wget https://archive.apache.org/dist/hadoop/common/hadoop-3.1.2/hadoop-3.1.2.tar.gz
tar -xvf hadoop-3.1.2.tar.gz
```



- Set the following environment variables. The following values are just examples and you might need to change them depending on how and where you have installed/extracted JDK and Hadoop. Add the following lines to the end of `.bashrc`:

```
export JAVA_HOME="/usr/lib/jvm/java-8-openjdk-amd64"
export HADOOP_HOME="/home/dataintensive/hadoop-3.1.2"
export HADOOP_CONFIG="$HADOOP_HOME/etc/hadoop"
export PATH=$JAVA_HOME/bin:$HADOOP_HOME/bin:$HADOOP_HOME/sbin:$PATH
```

- Source `.bashrc` to apply the changes in the current shell:

```
source .bashrc
```

- Set `JAVA_HOME` in the `$HADOOP_CONFIG/hadoop-env.sh` shell script.

```
export JAVA_HOME="/usr/lib/jvm/java-8-openjdk-amd64"
```

- Make two folders on local file system, where HDFS *NameNode* and *DataNode* store their data.

- The `$HADOOP_CONFIG/core-site.xml` file contains information such as the URI of the NameNode (master), the port number used for Hadoop instance, memory allocated for file system, memory limit for storing data, and the size of read/write buffers. Open `$HADOOP_CONFIG/core-site.xml` and add the following lines.

```
<configuration>
  <property>
    <name>fs.defaultFS</name>
    <value>hdfs://127.0.0.1:9000</value>
    <description>NameNode URI</description>
  </property>
</configuration>
```

8. The `$HADOOP_CONFIG/hdfs-site.xml` file contains information such as the value of replication data, as well as the NameNode and DataNode paths on your local file system. Here, you should replace the `PATH_TO_NAMENODE` and `PATH_TO_DATANODE` with the paths you defined in step 6.

```
<configuration>
  <property>
    <name>dfs.replication</name>
    <value>1</value>
  </property>

  <property>
    <name>dfs.namenode.name.dir</name>
    <value>file://PATH_TO_NAMENODE</value>
    <description>Path on the local filesystem ...</description>
  </property>

  <property>
    <name>dfs.datanode.data.dir</name>
    <value>file://PATH_TO_DATANODE</value>
    <description>Comma separated list of paths on the local filesystem ...</description>
  </property>
</configuration>
```

9. Format the NameNode directory (DO THIS ONLY ONCE, THE FIRST TIME).

```
$HADOOP_HOME/bin/hdfs namenode -format
```

10. Start the NameNode and DataNode daemons.

```
$HADOOP_HOME/bin/hdfs --daemon start namenode
$HADOOP_HOME/bin/hdfs --daemon start datanode
```

If all the above steps are done correctly, you should see the running processing. To do so, execute the `jps` in a terminal to print out the HDFS running processes. You can also monitor the process through their web interfaces on the following addresses `http://127.0.0.1:9870` for the NameNode and `http://127.0.0.1:9864` for the DataNode. Now, let's try some HDFS commands:

- Create a new directory `/kth` on HDFS

```
$HADOOP_HOME/bin/hdfs dfs -mkdir /kth
```

- Create a file, call it `big`, on your local filesystem and upload it to HDFS under `/kth`

```
touch big
$HADOOP_HOME/bin/hdfs dfs -put big /kth
```

- View the content of `/kth` directory

```
$HADOOP_HOME/bin/hdfs dfs -ls /kth
```

- Determine the size of file `big` on HDFS

```
$HADOOP_HOME/bin/hdfs dfs -du -h /kth/big
```

- Print the first 5 lines of the file `big` to screen (the `big` file is empty, so you can add some lines of text to it before uploading it on the HDFS)

```
$HADOOP_HOME/bin/hdfs dfs -cat /kth/big | head -n 5
```

- Make a copy of the file `big` on HDFS, and call it `big_hdfscopy`

```
$HADOOP_HOME/bin/hdfs dfs -cp /kth/big /kth/big_hdfscopy
```

- Copy the file `big` to the local filesystem and name it `big_localcopy`

```
$HADOOP_HOME/bin/hdfs dfs -get /kth/big big_localcopy
```

- Check the entire HDFS filesystem for inconsistencies/problems

```
$HADOOP_HOME/bin/hdfs fsck /
```

- Delete the file `big` from HDFS

```
$HADOOP_HOME/bin/hdfs dfs -rm /kth/big
```

- Delete the folder `/kth` from HDFS

```
$HADOOP_HOME/bin/hdfs dfs -rm -r /kth
```

## 5 Installing HBase

Here, we explain how to install HBase in *pseudo-distributed* mode, where all daemons run on a single node:

1. Install the SSH-server.

```
sudo apt install openssh-server
```

2. Download and extract Apache HBase 1.4.10:

```
cd ~
wget https://archive.apache.org/dist/hbase/1.4.10/hbase-1.4.10-bin.tar.gz
tar -xvf hbase-1.4.10-bin.tar.gz
```

3. Add the following lines to `.bashrc` (and then `source` it):

```
export HBASE_HOME="/path/to/the/hbase/folder"
export HBASE_CONF="$HBASE_HOME/conf"
export PATH=$HBASE_HOME/bin:$PATH
```

4. Edit `JAVA_HOME` in `$HBASE_CONF/hbase-env.sh`.

```
export JAVA_HOME="/path/to/the/java/folder"
```

5. Make a folder on local file system, where ZooKeeper stores its data.

```
mkdir -p $HBASE_HOME/zookeeper
```

6. Edit `$HBASE_CONF/hbase-site.xml` by adding the following lines. Replace the `PATH_TO_ZOOKEEPER` with the path you built in the step 4.

```
<configuration>
  <property>
    <name>hbase.rootdir</name>
    <value>hdfs://localhost:9000/hbase</value>
  </property>

  <property>
    <name>hbase.zookeeper.property.dataDir</name>
    <value>PATH_TO_ZOOKEEPER</value>
  </property>

  <property>
    <name>hbase.cluster.distributed</name>
    <value>true</value>
  </property>
</configuration>
```

7. Start HBase with the following command. Before starting it, make sure that Hadoop NameNode and DataNode are running.

```
$HBASE_HOME/bin/start-hbase.sh
```

8. HBase creates its directory in HDFS. To see the created directory type the following command.

```
$HADOOP_HOME/bin/hdfs dfs -ls /hbase
```

9. Start and stop a backup HBase Master server (OPTIONAL ON PRODUCTION ENVIRONMENTS). This step is offered for testing and learning purposes only, because running multiple HMaster instances on the same hardware does not make sense in a production environment (in the same way that running a pseudo-distributed cluster does not make sense for production). The HMaster server controls the HBase cluster. You can start up to nine backup HMaster servers, which makes 10 total HMasters, including the primary. To start a backup HMaster, use the `$HBASE_HOME/bin/local-master-backup.sh` command. For each backup master you want to start, add a parameter representing the port offset for that master. Each HMaster uses three ports (16010, 16020, and 16030 by default). The port offset is added to these ports, so using an offset of 2, the backup HMaster would use ports 16012, 16022, and 16032. The following command starts 3 backup servers using ports 16012/16022/16032, 16013/16023/16033, and 16015/16025/16035.

```
$HBASE_HOME/bin/local-master-backup.sh start 2 3 5
```

10. To kill a backup master without killing the entire cluster, you need to find its process ID (PID). The PID is stored in a file with a name like `/tmp/hbase-USER-X-master.pid`. The only contents of the file is the PID. You can use the `kill -9` command to kill that PID. The following command will kill the master with port offset 2, but leaves the cluster running (replace `USER` with your username):

```
cat /tmp/hbase-USER-2-master.pid | xargs kill -9
```

11. Start and stop additional RegionServers (OPTIONAL ON PRODUCTION ENVIRONMENTS). The HRegionServer manages the data in its StoreFiles as directed by the HMaster. Generally, one HRegionServer runs per node in the cluster. Running multiple HRegionServers on the same system can be useful for testing in pseudo-distributed mode. The `$HBASE_HOME/bin/local-regionervers.sh` command allows you to run multiple RegionServers. It works in a similar way to the `local-master-backup.sh` command, in that each parameter you provide represents the port offset for an instance. Each RegionServer requires two ports, and the default ports are 16020 and 16030. However, the base ports for additional RegionServers are not the default ports since the default ports are used by the HMaster, which is also a RegionServer since HBase version 1.0.0. The base ports are 16200 and 16300 instead. You can run 99 additional RegionServers that are not a HMaster or backup HMaster, on a server. The following command starts four additional RegionServers, running on sequential ports starting at 16202/16302 (base ports 16200/16300 plus 2).

```
$HBASE_HOME/bin/local-regionervers.sh start 2 3 4 5
```

12. To stop a RegionServer manually, use the `$HBASE_HOME/bin/local-regionervers.sh` command with the `stop` parameter and the offset of the server to stop.

```
$HBASE_HOME/bin/local-regionervers.sh stop 3
```

Now, let's go through the following steps to create a table in HBase and test it:

- Start the HBase shell

```
$HBASE_HOME/bin/hbase shell
```

- Create a table called `test` with the column family `cf`

```
# if you copy the commands from this PDF file, note that ' is a single quotation  
create 'test', 'cf'
```

- Use the command `describe` to get the description of the table

```
describe 'test'
```

- Print the information about your table

```
list 'test'
```

- Put data into your table (the first insert is at `row1`, column `cf:a`, with a value of `value1`). Columns in HBase are comprised of a column family prefix, e.g., `cf`, followed by a colon and then a column qualifier suffix, e.g., `a`.

```
put 'test', 'row1', 'cf:a', 'value1'  
put 'test', 'row2', 'cf:b', 'value2'  
put 'test', 'row3', 'cf:c', 'value3'
```

- Scan the table for all data at once

```
scan 'test'
```

- To get a single row of data at a time, use the `get` command

```
get 'test', 'row1'
```

- If you want to delete a table or change its settings, as well as in some other situations, you need to disable the table first, using the `disable` command. You can re-enable it using the `enable` command.

```
disable 'test'  
enable 'test'
```

- To delete a table, use the `drop` command.

```
disable 'test'  
drop 'test'
```

- Exit the HBase shell

```
exit
```

## 6 Example 1: Word Count in MapReduce

*WordCount* is a simple application that counts the number of occurrences of each word in a given input set. Below we will take a look at the mapper and reducer in detail, and then we present the complete code and show how to compile and run it. The complete code and the input data are available in the given zipped file, under the folder `src/id2221/wordcount`.

### 6.1 The Mapper Class

Here is the word count mapper class:

```
public static class TokenizerMapper extends Mapper<Object, Text, Text, IntWritable> {

    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();

    public void map(Object key, Text value, Context context) throws IOException, InterruptedException {
        StringTokenizer itr = new StringTokenizer(value.toString());
        while (itr.hasMoreTokens()) {
            word.set(itr.nextToken());
            context.write(word, one);
        }
    }
}
```

The `Mapper<Object, Text, Text, IntWritable>` refers to the data type of input and output key-value pairs specific to the mapper or the `map` method, i.e., `Mapper<Input Key Type, Input Value Type, Output Key Type, Output Value Type>`. In our example, the input to a mapper is a single line, so this `Text` forms the input value. The input key would be a long value assigned by default based on the position of `Text` in input file. Our output from the mapper is of the format (word, 1) hence the data type of our output key value pair is `<Text(String), IntWritable(int)>`.

In the `map` method, the first and second parameter refer to the data type of the input key and value to the mapper. The third parameter is the output collector that does the job of taking the output data. With the output collector we need to specify the data types of the output key and value from the mapper. The fourth parameter is used to report the task status internally in Hadoop environment to avoid time outs.

The functionality of the `map` method is as follows:

1. Create an `IntWritable` variable `one` with value as 1.
2. Convert the input line in `Text` type to a `String`.
3. Use a tokenizer to split the line into words.
4. Iterate through each word and form key-value pairs as (word, one) and push it to the `output collector`.

### 6.2 The Reducer Class

Here is the word count reducer class:

```
public static class IntSumReducer extends Reducer<Text, IntWritable, Text, IntWritable> {
    private IntWritable result = new IntWritable();

    public void reduce(Text key, Iterable<IntWritable> values, Context context)
        throws IOException, InterruptedException {
        int sum = 0;
        for (IntWritable val : values) {
            sum += val.get();
        }

        result.set(sum);
        context.write(key, result);
    }
}
```



In `Reducer<Text, IntWritable, Text, IntWritable>`, the first two parameters refer to data type of input key and value to the reducer and the last two refer to data type of output key and value. Our mapper emits output as (apple, 1), (grapes, 1), (apple, 1), etc. This is the input for reducer so here the data types of key and value in Java would be `String` and `int`, the equivalent in Hadoop would be `Text` and `IntWritable`. Also we get the output as (word, num. of occurrences) so the data type of output key-value would be `<Text, IntWritable>`.

The input to reduce method from the mapper after the sort and shuffle phase would be the key with the list of associated values with it. For example here we have multiple values for a single key from our mapper like (apple, 1), (apple, 1), (apple, 1). These key-values would be fed into the reducer as (apple, [1, 1, 1]), which is a key and list of values (`Text key, Iterator<IntWritable> values`). The next parameter to the `reduce` method denotes the output collector of the reducer with the data type of output key and value.

The functionality of the `reduce` method is as follows:

1. Initialize the variable `sum` as 0.
2. Iterate through all the values with respect to a key and sum up all of them.
3. Push to the output collector, the key and the obtained sum as value.

## 6.3 The Driver Class

In addition to mapper and reducer classes, we need a *driver* class to trigger the MapReduce job in Hadoop. In the driver class we provide the name of the job, output key-value data types and the mapper and reducer classes. Below you see the complete code of the word count. Here, we assume there are two input files, `file0` and `file1`, uploaded on HDFS, and our code reads those files and counts their words. Then, we should go through the following steps to compile and run the code:

1. Start the HDFS NameNode and DataNode (if they are not running). Then create a folder `input` in HDFS, and upload the files in it.

```
$HADOOP_HOME/bin/hdfs --daemon start namenode
$HADOOP_HOME/bin/hdfs --daemon start datanode

cd src/id2221/wordcount/
$HADOOP_HOME/bin/hdfs dfs -mkdir -p input
$HADOOP_HOME/bin/hdfs dfs -put file0 input/file0
$HADOOP_HOME/bin/hdfs dfs -put file1 input/file1
$HADOOP_HOME/bin/hdfs dfs -ls input
```

2. Set the `HADOOP_CLASSPATH` environment variable.

```
export HADOOP_CLASSPATH=$(HADOOP_HOME/bin/hadoop classpath)
```

3. Change directory to the `src/id2221` folder and make a target directory, `wordcount_classes`, to keep the compiled files. Then, compile the code and make a final jar file.

```
cd src/id2221

mkdir wordcount_classes

javac -cp $HADOOP_CLASSPATH -d wordcount_classes wordcount/WordCount.java

jar -cvf wordcount.jar -C wordcount_classes/ .
```

4. Run the application

```
$HADOOP_HOME/bin/hadoop jar wordcount.jar id2221.wordcount.WordCount input output
```

5. Check the output in HDFS

```
$HADOOP_HOME/bin/hdfs dfs -ls output
$HADOOP_HOME/bin/hdfs dfs -cat output/part-r-00000
```

```

package id2221.wordcount;

import java.io.IOException;
import java.util.StringTokenizer;

import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.Mapper;
import org.apache.hadoop.mapreduce.Reducer;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;

public class WordCount {

    public static class TokenizerMapper extends Mapper<Object, Text, Text, IntWritable> {

        private final static IntWritable one = new IntWritable(1);
        private Text word = new Text();

        public void map(Object key, Text value, Context context) throws IOException, InterruptedException {
            StringTokenizer itr = new StringTokenizer(value.toString());
            while (itr.hasMoreTokens()) {
                word.set(itr.nextToken());
                context.write(word, one);
            }
        }
    }

    public static class IntSumReducer extends Reducer<Text, IntWritable, Text, IntWritable> {
        private IntWritable result = new IntWritable();

        public void reduce(Text key, Iterable<IntWritable> values, Context context)
            throws IOException, InterruptedException {
            int sum = 0;
            for (IntWritable val : values) {
                sum += val.get();
            }

            result.set(sum);
            context.write(key, result);
        }
    }

    public static void main(String[] args) throws Exception {
        Configuration conf = new Configuration();
        Job job = Job.getInstance(conf, "word count");
        job.setJarByClass(WordCount.class);

        job.setMapperClass(TokenizerMapper.class);
        job.setCombinerClass(IntSumReducer.class);
        job.setReducerClass(IntSumReducer.class);

        job.setOutputKeyClass(Text.class);
        job.setOutputValueClass(IntWritable.class);

        FileInputFormat.addInputPath(job, new Path(args[0]));
        FileOutputFormat.setOutputPath(job, new Path(args[1]));

        System.exit(job.waitForCompletion(true) ? 0 : 1);
    }
}

```

## 7 Example 2: MapReduce and HBase

Here, we show a sample MapReduce program that reads data from an HBase table, does some aggregation, and writes the output to another HBase table. The complete code is available in the zip file, under the folder `src/id2221/hbase`.

### 7.1 The Mapper Class

Here is the mapper class:

```
public static class hbaseMapper extends TableMapper<Text, IntWritable> {
    public void map(ImmutableBytesWritable rowKey, Result columns, Context context)
        throws IOException, InterruptedException {
        try {
            String inKey = new String(rowKey.get());

            String oKey = inKey.split("#")[0];

            byte[] bSales = columns.getValue(Bytes.toBytes("cf"), Bytes.toBytes("sales"));
            String sSales = new String(bSales);
            Integer sales = new Integer(sSales);

            context.write(new Text(oKey), new IntWritable(sales));
        } catch (RuntimeException e) {
            e.printStackTrace();
        }
    }
}
```

The functionality of the `map` method is as follows:

1. Get the `rowKey` and convert it to `String`.
2. Set new key having only date.
3. Get sales column in byte format first and then convert it to string (as it is stored as string from hbase shell).
4. Emit date and sales values.

### 7.2 The Reducer Class

Here is the reducer class:

```
public static class hbaseReducer extends TableReducer<Text, IntWritable, ImmutableBytesWritable> {
    public void reduce(Text key, Iterable<IntWritable> values, Context context)
        throws IOException, InterruptedException {
        try {
            int sum = 0;

            for (IntWritable sales : values) {
                Integer intSales = new Integer(sales.toString());
                sum += intSales;
            }

            Put insHBase = new Put(key.getBytes());

            insHBase.addColumn(Bytes.toBytes("cf"), Bytes.toBytes("sum"), Bytes.toBytes(sum));

            context.write(null, insHBase);
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

The functionality of the `reducer` method is as follows:

1. Initialize the variable `sum` as 0.
2. Loop through different sales vales and add it to `sum`.
3. Create HBase put `insHBase` with rowkey as date.
4. Insert `sum` value to HBase.
5. Write data to Hbase table.

## 7.3 The Driver Class

Below you can see the complete code, including the driver class, as well as how to build a table in HBase and compile and run the code. Here, we assume there are two HBase tables, named `test1` and `test2`, and our code reads a column from `test1`, aggregates the values and writes the result in `test2`.

1. Start the HBase and the HBase shell.

```
$HBASE_HOME/bin/start-hbase.sh
$HBASE_HOME/bin/hbase shell
```

2. Create the HBase tables `test1` and `test2`. For the table `test1`, the rowkey is composed of `date` and `store number` and we have `sales` value for each store. We shall do an aggregation on `date` to get total sales.

```
create 'test1', 'cf'

put 'test1', '20130101#1', 'cf:sales', '100'
put 'test1', '20130101#2', 'cf:sales', '110'
put 'test1', '20130102#1', 'cf:sales', '200'
put 'test1', '20130102#2', 'cf:sales', '210'

create 'test2', 'cf'

scan 'test1'
scan 'test2'
```

3. Set the `HADOOP_CLASSPATH` environment variable.

```
export HADOOP_CLASSPATH=$(HADOOP_HOME/bin/hadoop classpath)
export HBASE_CLASSPATH=$(HBASE_HOME/bin/hbase classpath)
export HADOOP_CLASSPATH=$HADOOP_CLASSPATH:$HBASE_CLASSPATH
```

4. Change directory to the `src/id2221` folder and make a target directory, `hbase_classes`, to keep the compiled files. Then, compile the code and make a final jar file.

```
cd src/id2221

mkdir hbase_classes

javac -cp $HADOOP_CLASSPATH -d hbase_classes hbase/HBaseMapReduce.java

jar -cvf hbaseMapReduce.jar -C hbase_classes/ .
```

5. Run the application

```
$HADOOP_HOME/bin/hadoop jar hbaseMapReduce.jar id2221.hbase.HBaseMapReduce
```

6. Check the output in HBase. The sum values are displayed as bytes (HBase stores everything as bytes), we can convert it to readable integer format in HBase shell.

```
scan 'test2'
org.apache.hadoop.hbase.util.Bytes.toInt("\x00\x00\x00\xD2".to_java_bytes)
org.apache.hadoop.hbase.util.Bytes.toInt("\x00\x00\x01\x9A".to_java_bytes)
```

```

package id2221.hbase;

import java.io.IOException;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.hbase.util.Bytes;
import org.apache.hadoop.hbase.client.Put;
import org.apache.hadoop.hbase.client.Result;
import org.apache.hadoop.hbase.client.Scan;
import org.apache.hadoop.hbase.HBaseConfiguration;
import org.apache.hadoop.hbase.mapreduce.TableMapper;
import org.apache.hadoop.hbase.mapreduce.TableReducer;
import org.apache.hadoop.hbase.mapreduce.TableMapReduceUtil;
import org.apache.hadoop.hbase.io.ImmutableBytesWritable;
import org.apache.hadoop.hbase.filter.FirstKeyOnlyFilter;

public class HBaseMapReduce {
    public static class hbaseMapper extends TableMapper<Text, IntWritable> {
        public void map(ImmutableBytesWritable rowKey, Result columns, Context context)
            throws IOException, InterruptedException {
            try {
                String inKey = new String(rowKey.get());

                String oKey = inKey.split("#")[0];

                byte[] bSales = columns.getValue(Bytes.toBytes("cf"), Bytes.toBytes("sales"));
                String sSales = new String(bSales);
                Integer sales = new Integer(sSales);

                context.write(new Text(oKey), new IntWritable(sales));
            } catch (RuntimeException e) {
                e.printStackTrace();
            }
        }
    }

    public static class hbaseReducer extends TableReducer<Text, IntWritable, ImmutableBytesWritable> {
        public void reduce(Text key, Iterable<IntWritable> values, Context context)
            throws IOException, InterruptedException {
            try {
                int sum = 0;

                for (IntWritable sales : values) {
                    Integer intSales = new Integer(sales.toString());
                    sum += intSales;
                }

                Put insHBase = new Put(key.getBytes());

                insHBase.addColumn(Bytes.toBytes("cf"), Bytes.toBytes("sum"), Bytes.toBytes(sum));

                context.write(null, insHBase);
            } catch (Exception e) {
                e.printStackTrace();
            }
        }
    }
}

```

```

public static void main(String[] args) throws Exception {
    Configuration conf = HBaseConfiguration.create();

    // define scan and define column families to scan
    Scan scan = new Scan();
    scan.addFamily(Bytes.toBytes("cf"));
    Job job = Job.getInstance(conf);
    job.setJarByClass(HBaseMapReduce.class);

    // define input hbase table
    TableMapReduceUtil.initTableMapperJob("test1", scan, hbaseMapper.class, Text.class, IntWritable.class, job);

    // define output table
    TableMapReduceUtil.initTableReducerJob("test2", hbaseReducer.class, job);
    job.waitForCompletion(true);
}
}

```

## 8 Your Assignment for Part 1

As the first part of your assignment you should complete the code in the folder `src/id2221/topten`. In this assignment, you are given a list of users, and you should print out the information of the top ten users based on their reputation. In your code, each mapper reads data from HDFS and determines the top ten records of its input split and outputs them to the reduce phase. The mappers should filter their input split to the top ten records, and the reducer is responsible for the final ten and write the result in table in HBase. The input file of the assignment is `users.xml`, which is in the folder `data/topten`. Each line contains a single user record in the format described below. The `map` method will get this file as a single String value. You will need to parse this string to extract the user's reputation. You can use the helper function `transformXmlToMap` given to you in assignment file. Be careful when processing the XML file, and skip over the rows that do not contain user data (e.g., when `Id == null`).

```

<row Id="-1" Reputation="1"
  CreationDate="2014-05-13T21:29:22.820" DisplayName="Community"
  LastAccessDate="2014-05-13T21:29:22.820"
  WebsiteUrl="http://meta.stackexchange.com/"
  Location="on the server farm" AboutMe="..;"
  Views="0" UpVotes="506"
  DownVotes="37" AccountId="-1" />

```

In the mapper class, you can use the `TreeMap` to store the processed input records. A `TreeMap` is a subclass of `Map` that sorts on key. After all the records have been processed, the top ten records in the `TreeMap` are output to the reducers in the `cleanup` method. The `cleanup` method gets called once after all key-value pairs have been through the `map` function. Use `setNumReduceTasks` to configure your job to use only one reducer, because multiple reducers would shard the data and would result in multiple top ten lists. The reducer determines its top ten records in a way that's very similar to the mapper. Because we configured our job to have one reducer using `job.setNumReduceTasks(1)` there will be one input group for this reducer that contains all the potential top ten records. The reducer iterates through all these records and stores them in a `TreeMap`. After all the values have been iterated over, the values of `Id` and `Reputation` contained in the `TreeMap` should be stored in the table `topten` in HBase. We use the columns `info:rep` and `info:id` to store them. We will build the table `topten` and the column family `info` in the HBase shell, but the columns `rep` and `id` should be created in your Java code.

Go through the following steps to compile and run the code:

1. Start the HDFS NameNode and DataNode (if they are not running). Then create a folder `input` in HDFS, and upload the files in it.

```
$HADOOP_HOME/bin/hdfs --daemon start namenode
$HADOOP_HOME/bin/hdfs --daemon start datanode

cd src/id2221/topten
$HADOOP_HOME/bin/hdfs dfs -mkdir -p topten_input
$HADOOP_HOME/bin/hdfs dfs -put data/users.xml
$HADOOP_HOME/bin/hdfs dfs -ls topten_input
```

2. Start the HBase and the HBase shell.

```
$HBASE_HOME/bin/start-hbase.sh
$HBASE_HOME/bin/hbase shell
```

3. Create the HBase table `topten` with one column family `info` to store the id and reputation of users.

```
create 'topten', 'info'
```

4. Set the environment variables.

```
export HADOOP_CLASSPATH=$(HADOOP_HOME/bin/hadoop classpath)
export HBASE_CLASSPATH=$(HBASE_HOME/bin/hbase classpath)
export HADOOP_CLASSPATH=$HADOOP_CLASSPATH:$HBASE_CLASSPATH
```

5. Change directory to the `src` folder and make a target directory, `topten_classes`, to keep the compiled files. Then, compile the code and make a final jar file.

```
cd src/id2221

mkdir topten_classes

javac -cp $HADOOP_CLASSPATH -d topten_classes topten/TopTen.java

jar -cvf topten.jar -C topten_classes/ .
```

6. Run the application

```
$HADOOP_HOME/bin/hadoop jar topten.jar id2221.topten.TopTen topten_input topten_output
```

7. Check the result in the HBase shell

```
scan 'topten'
```

## 9 Introduction to Part 2

In the second part of this assignment you will practice the basic operations of Spark (RDDs) and Spark SQL (DataFrames). We use Jupyter Notebooks for this lab assignment. Notebooks are documents that contain both the programming code, as well as human-readable text elements. Below, we first explain how to install Spark and test it, and then we go through the steps to install Jupyter Notebook on a Linux machine. Then, we show how to use this environment to do your assignment.

## 10 Installing Spark

This section includes the steps you need to go through in order to install Spark. It is assumed that you have installed Java SDK 8 as stated in Section 4.

1. Download and extract Apache Spark 2.4.3 tarball in your home directory:

```
cd ~
wget https://archive.apache.org/dist/spark/spark-2.4.3/spark-2.4.3-bin-hadoop2.7.tgz
tar -xvf spark-2.4.3-bin-hadoop2.7.tgz
```

2. Add the following lines to `.bashrc` (and then `source` it):

```
export SPARK_HOME="/path/to/the/spark/folder"
export PATH=$SPARK_HOME/bin:$PATH
```

3. Run the command `spark-shell` in a terminal. If it works, you should see something like the screenshot below:



```
Welcome to
Spark version 2.4.3

Using Scala version 2.11.12 (Java HotSpot(TM) 64-Bit Server VM, Java 1.8.0_221)
Type in expressions to have them evaluated.
Type :help for more information.

scala>
```

4. Now, we want to write a self-contained word count application using the Spark API in Scala (with SBT). This code is available in the `zip` file under the folder `src/id2221/hellospark`.

```
import org.apache.spark.sql.SparkSession

object HelloSpark {
  def main(args: Array[String]) {
    val logFile = "/path/to/a/text/file"
    val spark = SparkSession.builder.appName("Hello Spark").master("local[2]").getOrCreate()
    val sc = spark.sparkContext
    val logData = sc.textFile(logFile).cache()
    val wordCounts = logData.flatMap(line => line.split(" "))
      .map(word => (word, 1))
      .reduceByKey((a, b) => a + b)
    wordCounts.foreach(println(_))
    spark.stop()
  }
}
```

5. We also need to include a SBT configuration file, `build.sbt`, which explains that Spark is a dependency.

```
name := "Simple Project"

version := "1.0"

scalaVersion := "2.11.12"

libraryDependencies += "org.apache.spark" %% "spark-sql" % "2.4.3"
```

6. To compile and run the code you should execute the `sbt run` command. If you do not have SBT on your machine, you can install it as shown below.

```
echo "deb https://dl.bintray.com/sbt/debian /" | sudo tee -a /etc/apt/sources.list.d/sbt.list
sudo apt-key adv --keyserver hkp://keyserver.ubuntu.com:80 --recv 2EE0EA64E40A89B84B2DF73499E82A75642AC823
sudo apt-get update
sudo apt-get install sbt
```

## 11 Setting Up Jupyter Notebook for Apache Spark

Now let's set up a Jupyter Notebook environment for Apache Spark. We recommend using Apache Toree (as instructed below), but there are other options such as [spylon-kernel](#) or [Almond](#) that work with specific



Scala and Spark versions.

To install Jupyter and Apache Toret:

1. Make sure you have Python 3 installed in your environment. Ubuntu 18.04.5 comes with Python 3 pre-installed, but in case you use other environments you can setup Python easily, e.g., through installing an appropriate Anaconda distribution from the following link:  
<https://www.anaconda.com/distribution/>.

2. `pip` is the package installer for Python, and you need it to install Jupyter. On Ubuntu 18.04, you can install it by running the following command:

```
sudo apt install python3-pip
```

3. Install Jupyter Notebook:

```
pip3 install jupyter
```

4. We now have to add the path to `jupyter` executables to the `$PATH` environment variable. In our case (Ubuntu 18.04), installing packages outside a Python `venv` results in them being added to `~/.local/bin`. We now add the following lines to `.bashrc`:

```
export PIP_LIBS_BINS="/home/dataintensive/.local/bin"
export PATH=$PIP_LIBS_BINS:$PATH
```

5. Now, we need to install Apache Toret and load it into Jupyter. Apache Toret is a kernel for the Jupyter Notebook platform providing interactively access to Spark.

```
pip3 install --upgrade toree
jupyter toree install --user --python_exec='python3' --spark_home=$SPARK_HOME --spark_opts='--master=local[*]'
```

6. We can get the Notebook server running now (add the `--ip=0.0.0.0` option if you use a VM and want to work with Jupyter on your host machine through port forwarding):

```
jupyter notebook --ip=0.0.0.0
```

7. Once you run the Jupyter Notebook, you can see it on your browser on the address `localhost:8888`.

## 12 Your Assignment for Part 2

Copy the Notebooks and the `data` folder from `src/notebook` to the folder you have started the Jupyter Notebook (or, start Jupyter Notebook in `src/notebook`). Then, you should be able to see the files in Jupyter on your browser on the address `localhost:8888` (as shown below). There are three Jupyter Notebooks called `warmup.ipynb`, `spark.ipynb`, and `sparksql.ipynb`, in which the first one (`warmup.ipynb`) is just for practice, and the next two Notebooks are the ones you need to complete. The files are self-explanatory and describe what you need to do.



## 13 What to Deliver

For the first part of the assignment, you should complete the `topten.java` code, and write a short document to explain how you implemented your code and how to run it, and also show your results. For the second part of the assignment, you should complete the two Notebooks `spark.ipynb` and `sparksql.ipynb`. Please zip only the aforementioned files **in a single ZIP file** with the filename format of `lab1_groupname.zip`. Do not include the data files.