CS 553 Cloud Computing Programming Assignment 2

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Overview:

The objective of this assignment is to perform Terasort operation using C, Hadoop and Spark. The main goal behind this is to compare the results obtained from each of this methods and build a conclusion out of it.

Runtime Environment Settings

Amazon Web Services EC2
AMI - Ubuntu Server 16.04 LTS (HVM), SSD Volume Type- ami-45ead225

Hadoop 2.6.5
Spark 2.2.0
Java 1.8.0_151
Shared-Memory:
EC2 instance type : i3.large
Hadoop:
EC2 instance type : (master node)i3.large (slave node)i3.large
Spark:
EC2 instance type : (headnode)i3.large (worker node)i3.large
MPI: Open MPI 3.0.4, starcluster 1

Installation Steps of Virtual Cluster

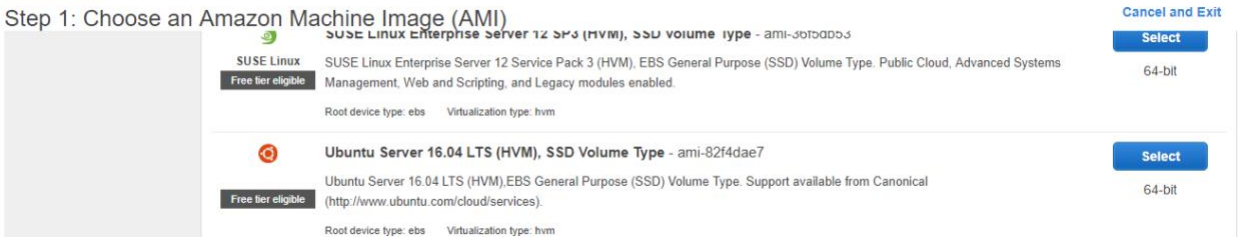
1. 1 node
1) log in to the AWS, choose EC2
2) launch instance
3) choose Ubuntu Server 14.04 LTS (HVM), SSD Volume Type - ami-3d50120d
4) choose i3.large
5) choose spot instance
6) create a new security group, with rules: SSH, All TCP(Anywhere), All ICMP(Anywhere)

2. 1 node
1) choose i3.4xlarge
2) choose spot instance
3) create an image of instance established in 1st step.
4) use the same configuration

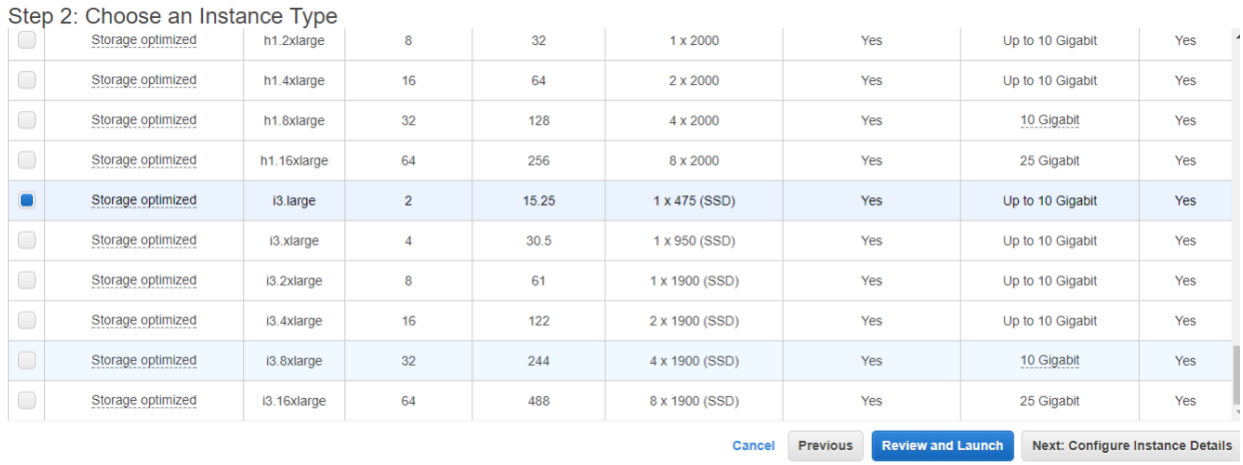
3. 8 nodes
1) finish the step of 1 node
2) create an image of instance established in 1 node
3) create another 7 nodes use the AMI just created
4) use the same configuration

➔ Create an instance on Amazon AWS:

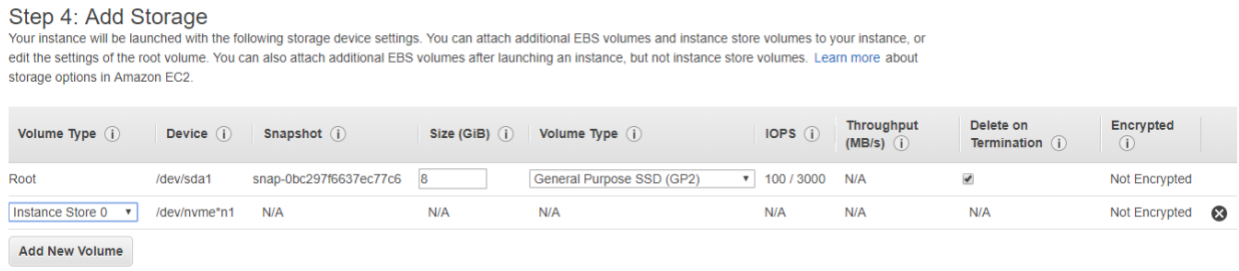
1. Choose Amazon Machine Image:



2. Choose Instance type

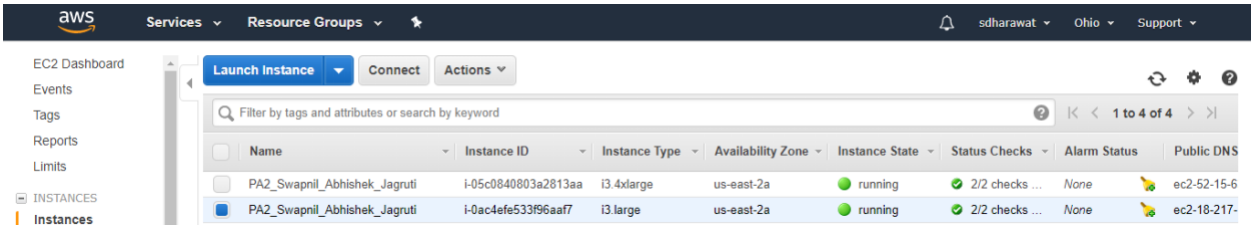


3. Edit Storage



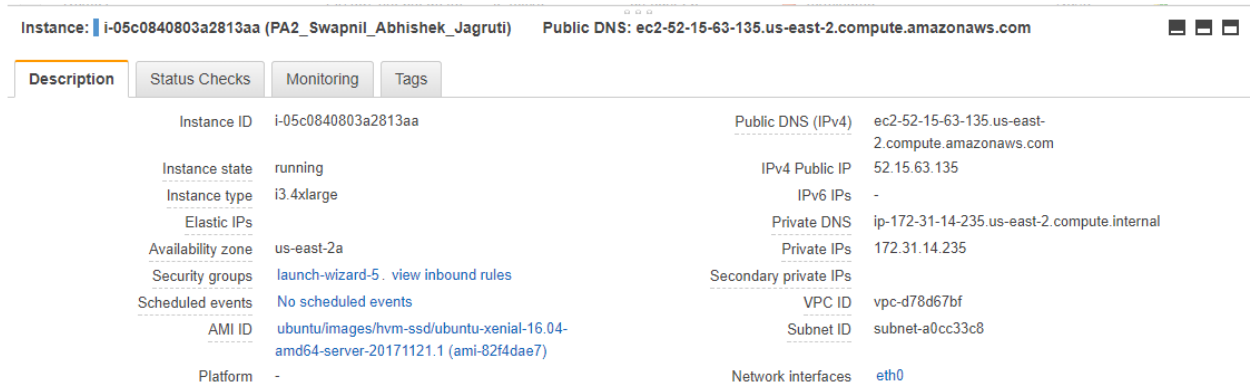
We have changed the storage to 1862GB
The screenshot is just an example

Instances created are:

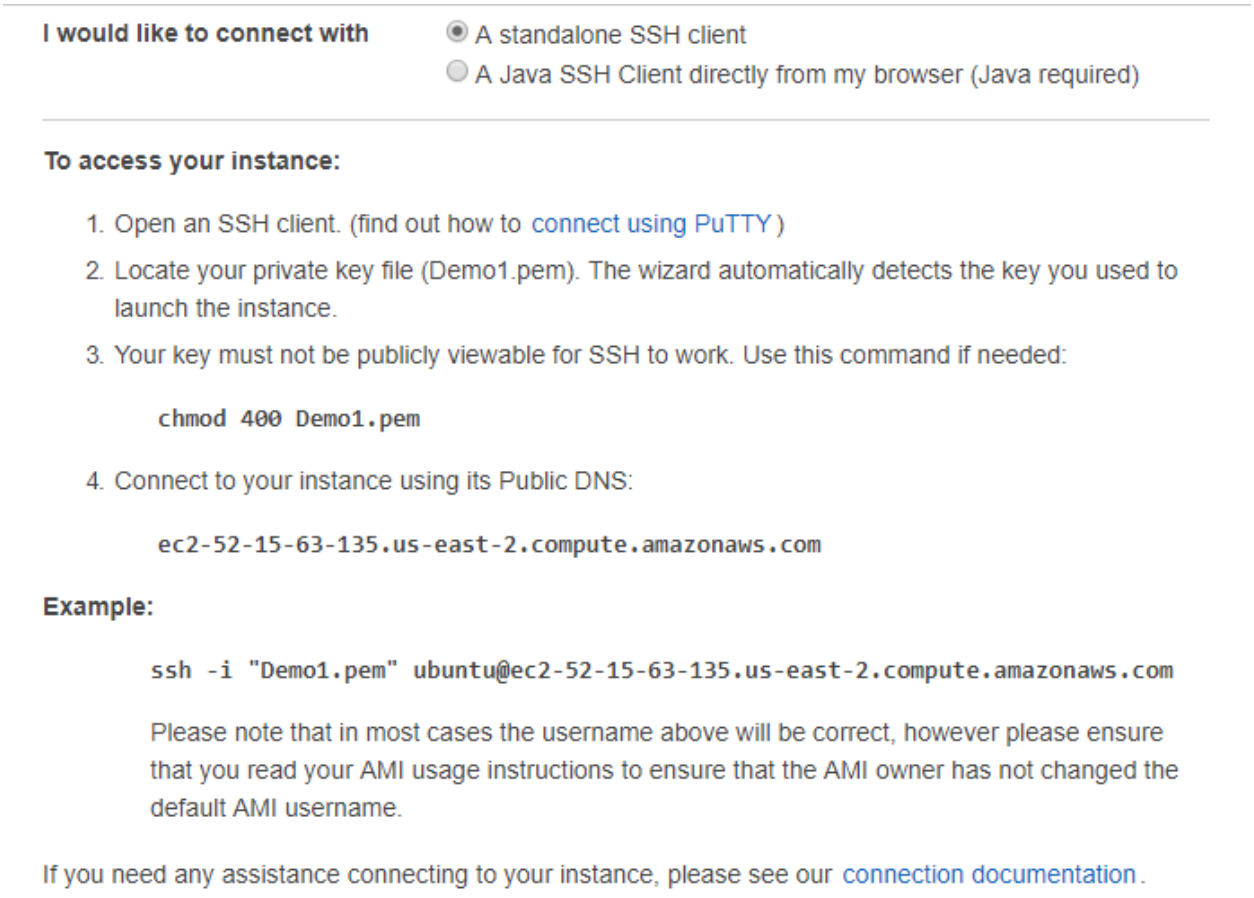


i3.large

i3.4xlarge



Connect to instance using ssh:



ssh -i "Keyname.pem" public DNS

For eg:
ssh -i "Demo1.pem" ubuntu@ec2-18-217-183-207.us-east-2.compute.amazonaws.com

Transfer file from local system to AWS instance:

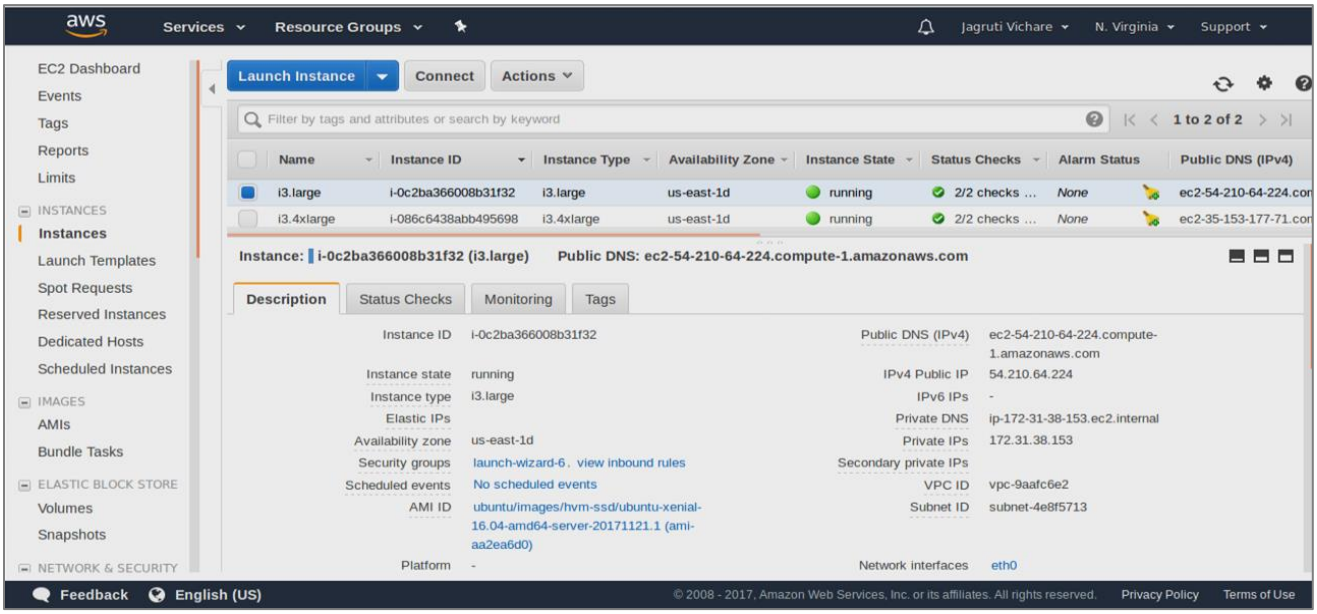
scp -i Keyname.pem filename.ext publicDNS:~/
For eg:
scp -i Demo1.pem SparkSort.py ubuntu@ec2-18-217-183-207.us-east-2.compute.amazonaws.com:~/

```
Swapnil@DESKTOP-CAH45E8 MINGW64 /c/Studies/Cloud Computing/Assignment 2
$ ssh -i "Demo1.pem" ubuntu@ec2-52-15-63-135.us-east-2.compute.amazonaws.com
Welcome to Ubuntu 16.04.3 LTS (GNU/Linux 4.4.0-1041-aws x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:     https://landscape.canonical.com
 * Support:        https://ubuntu.com/advantage

  Get cloud support with Ubuntu Advantage Cloud Guest:
    http://www.ubuntu.com/business/services/cloud

13 packages can be updated.
8 updates are security updates.


Last login: Sun Dec  3 22:11:33 2017 from 208.59.146.145
ubuntu@ip-172-31-14-235:~$
```

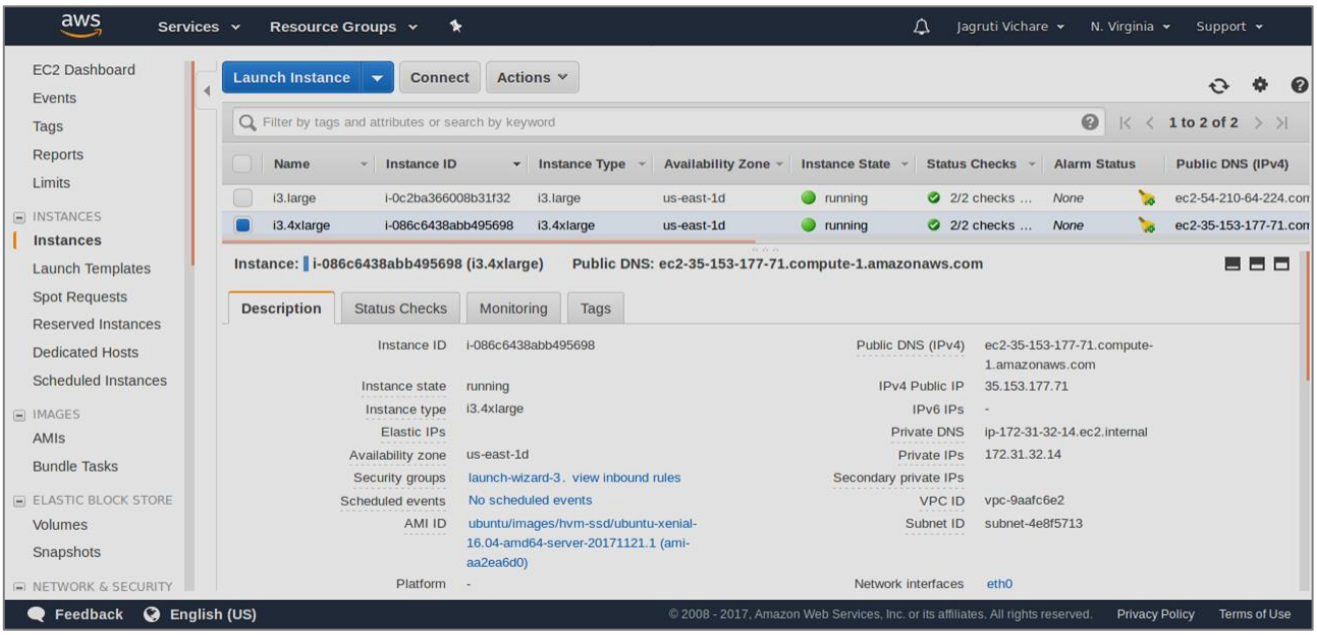
Shared Memory Terasort:

We are making use of external sort algorithm for shared memory terasort.
We have programmed the code using C language.
We have generated data using Gensort
128Gb of data is being used as an input in this part
This is performed on virtual cluster1 of i3.large and i3.4xlarge configurations.

I3.large



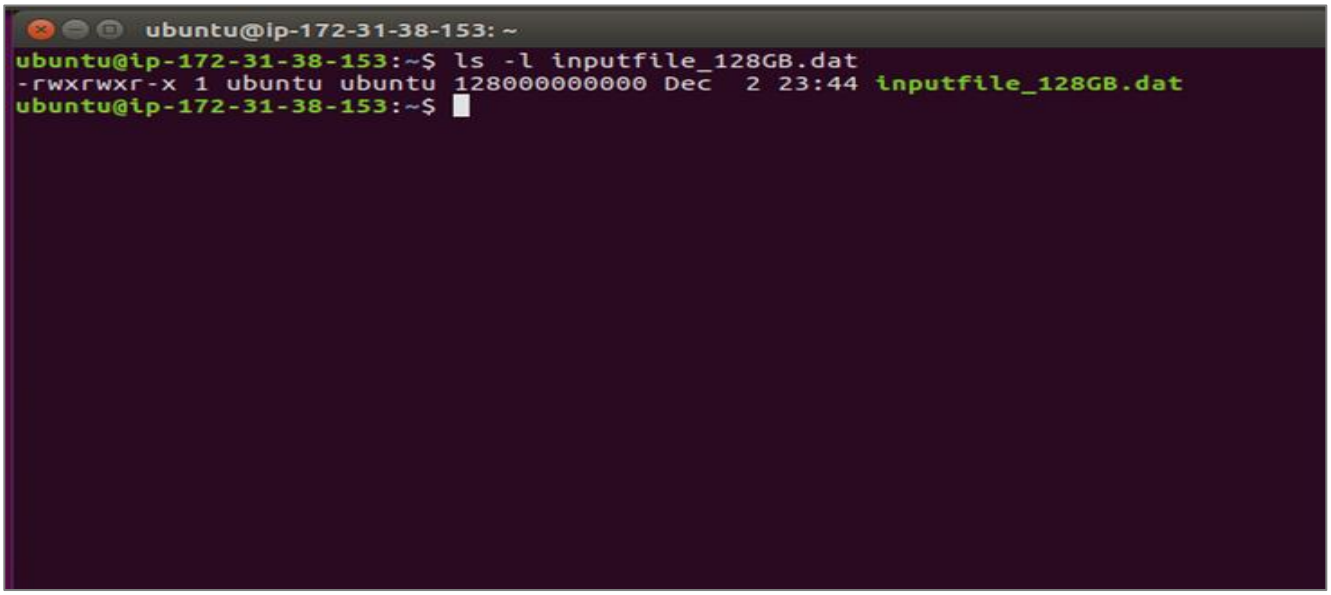
i3.4xlarge



Performance

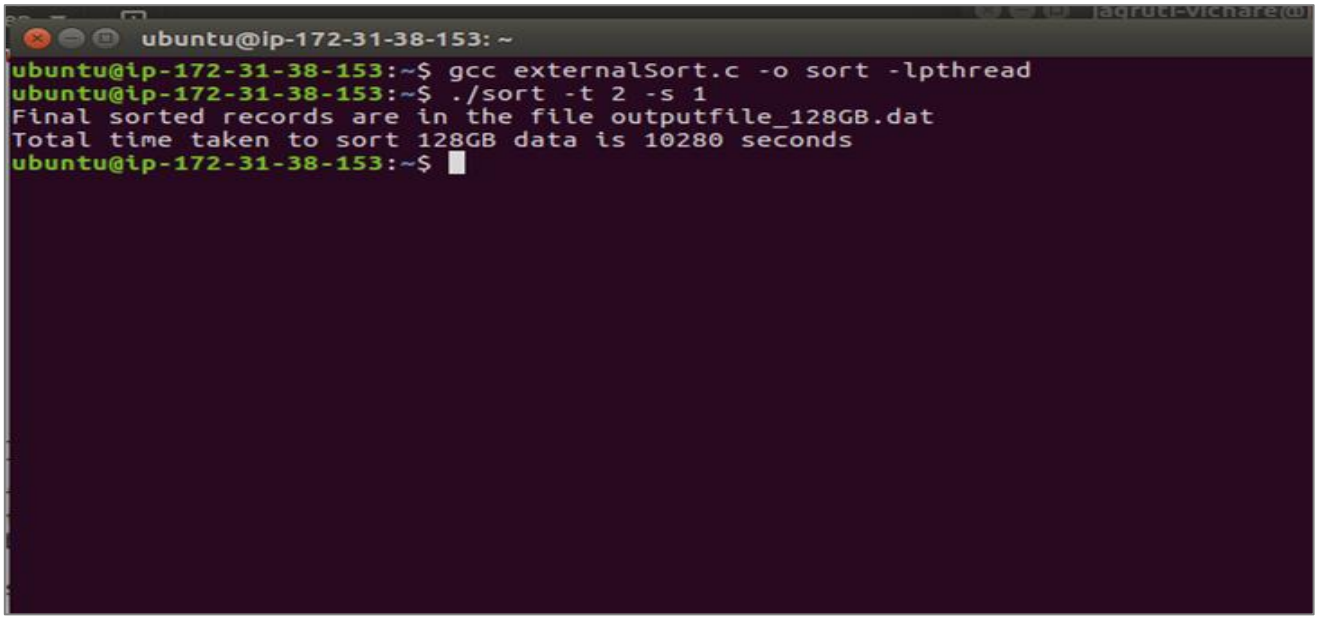
Externsl sort with 128GB dataset

Input File Size



Here an input file of 128 GB is given. The shared memory terasort is supposed to take this dataset as an input to perform operations on it.

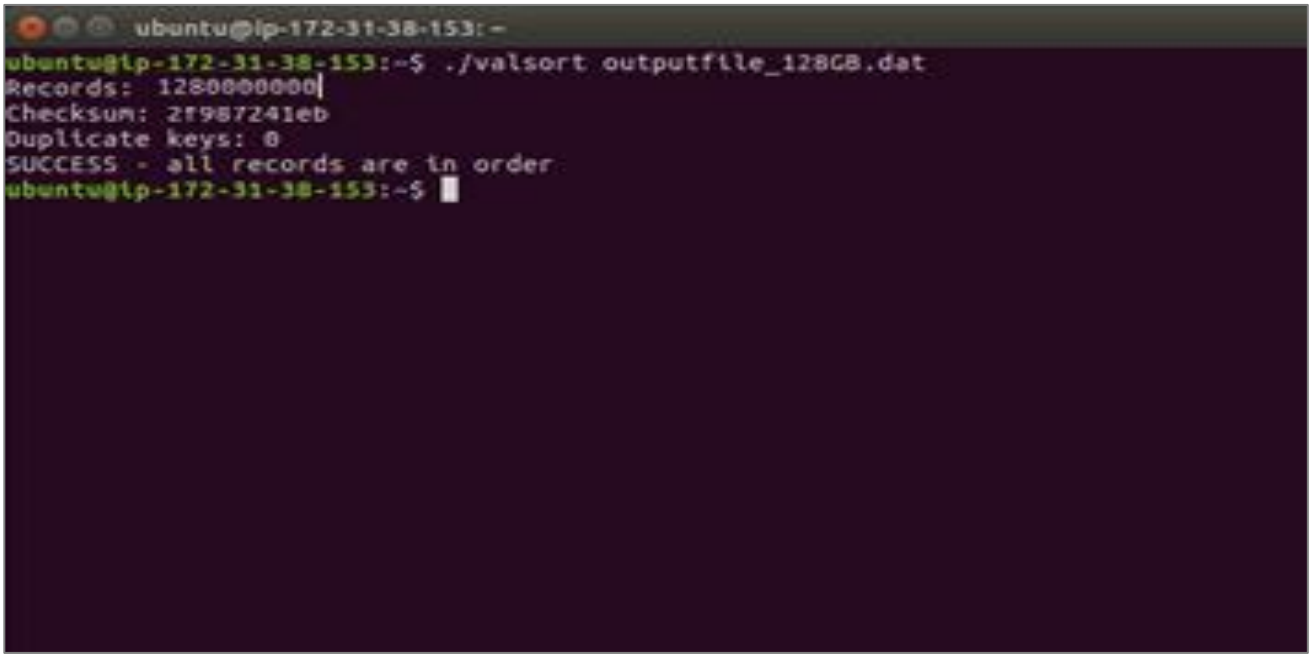
128 GB sort Result



The screenshot above displays the sorting result of 128 GB of dataset
As we can see the details are as follows:
The dataset has been sorted and stored in the output file
The total time taken for sorting is 10280 seconds.

This time shows that shared memory terasort performs good with the small datasets in one node.

Validation of result using Valsort



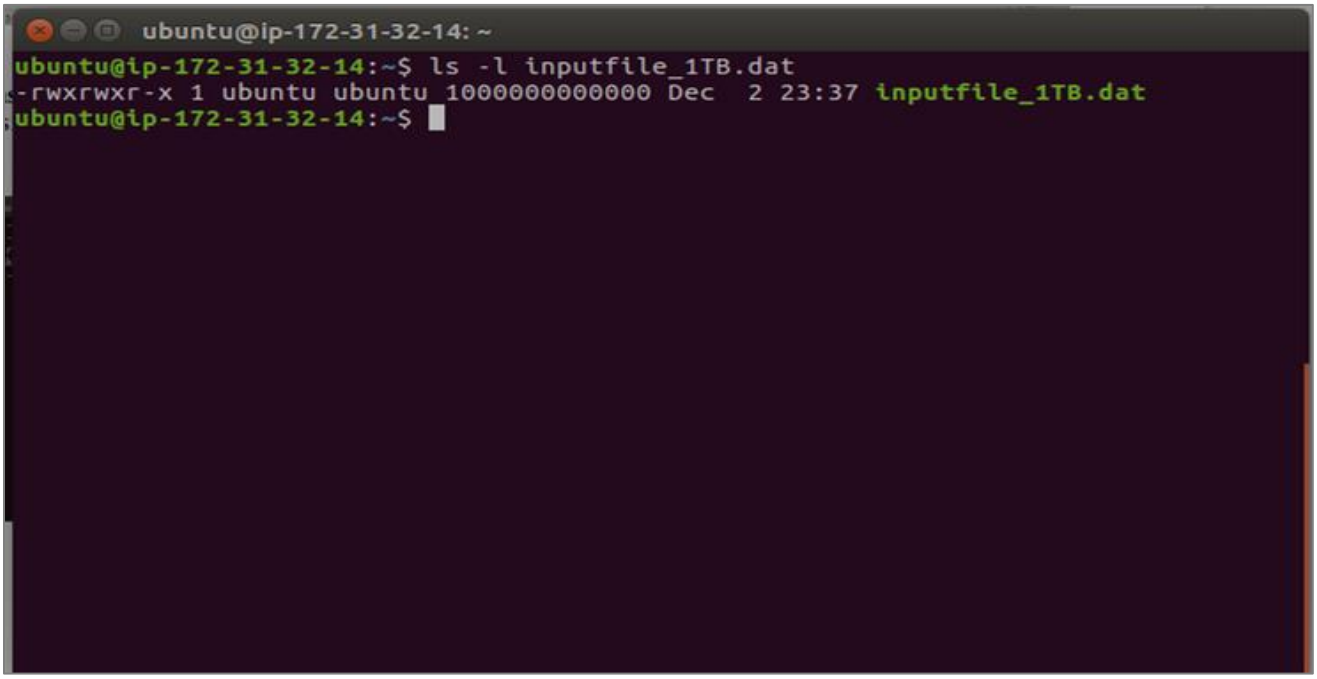
The screenshot above shows that a total of 1280000000 records are created which has to be validated.
The validation is performed after the sorting of data to check if the files are in place or not.
This step ensures that no data is lost in the process of sorting

As we can see in the image that a checksum is generated and it shows that it has no duplicate keys.
After this the code displays a message saying that all records are found to be in order and that the sorting was successful.

Similarly we will carry out all the operations for 1TB of dataset with same steps just the different dataset.

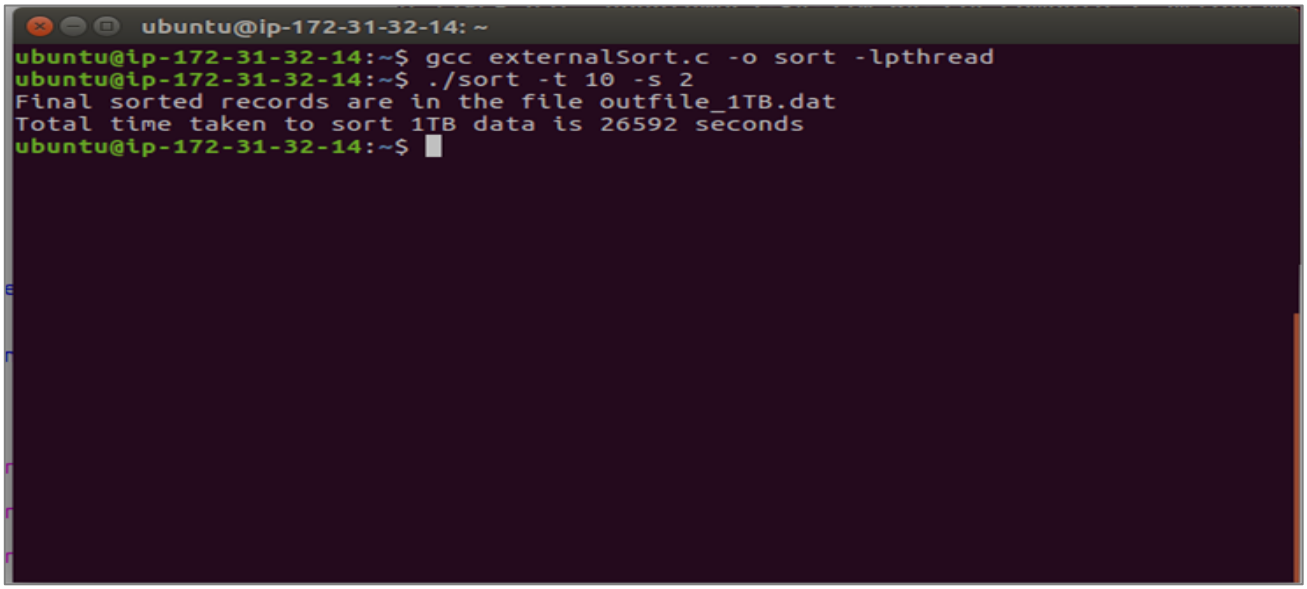
External Sort with 1 TB Dataset

Input File Size



As we can see from the screenshot, it shows that 1 TB of dataset is provided to the code as input.

1 TB sort Result



The screenshot above shows that the result has been generated for the 1TB dataset and the data has been sorted and stored in an output file

The total time taken for the sorting process to complete is 26592 seconds.
That still is a good time because it is computed on a single node
It shows that the time taken for sorting is 7.3 hours.

Validation of Result using Valsort

The image in the screenshot shows that the number of records generated is 10000000000 and has no duplicate keys.

The command displays a success message at the end which says that all the records are found to be in order and also that the operation is completed as desired.

Hadoop Terasort:

Referred this :

➔ https://janzhou.org/2014/how-to-compile-hadoop.html

How to compile and generate jar files:

```
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# ls
container-executor  Hadoop.java  input128    rcc                      yarn.cmd
hadoop              hdfs         mapred      test-container-executor
hadoop.cmd          hdfs.cmd     mapred.cmd  yarn
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# javac -classpath ${HADOOP_CLASSPATH} Hado
op.java
javac: no source files
Usage: javac <options> <source files>
use -help for a list of possible options
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin#
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# export HADOOP_CLASSPATH=$JAVA_HOME/lib/to
ols.jar
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# cd ..
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5# bin/hadoop com.sun.tools.javac.Main bin/Hadoo
p.java
/usr/lib/jvm/java-8-oracle/jre/bin/java
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5# jar -cvf bin/Hadoop.jar bin/Hadoop
bin/Hadoop : no such file or directory
added manifest
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5# cd bin/
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# ls
container-executor  Hadoop.jar                  hdfs      mapred.cmd              yarn.cmd
hadoop              Hadoop.java                 hdfs.cmd  rcc
Hadoop.class        Hadoop$SortingMapper.class  input128  test-container-executor
hadoop.cmd          Hadoop$SortingReducer.class mapred    yarn
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# rm Hadoop.jar
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# ls
container-executor  Hadoop.java                 hdfs.cmd    rcc
hadoop              Hadoop$SortingMapper.class  input128    test-container-executor
Hadoop.class        Hadoop$SortingReducer.class mapred      yarn
hadoop.cmd          hdfs                        mapred.cmd  yarn.cmd
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# jar cvf Hadoop.jar Hadoop.class Hadoop\$S
ortingMapper.class Hadoop\$SortingReducer.class
added manifest
adding: Hadoop.class(in = 1925) (out= 1025)(deflated 46%)
adding: Hadoop$SortingMapper.class(in = 1558) (out= 644)(deflated 58%)
adding: Hadoop$SortingReducer.class(in = 1644) (out= 704)(deflated 57%)
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin# ls
container-executor  Hadoop.jar                  hdfs      mapred.cmd              yarn.cmd
hadoop              Hadoop.java                 hdfs.cmd  rcc
Hadoop.class        Hadoop$SortingMapper.class  input128  test-container-executor
hadoop.cmd          Hadoop$SortingReducer.class mapred    yarn
root@ip-172-31-14-235:/home/ubuntu/hadoop-2.6.5/bin#
```

Hadoop Setup on i3.large and i3.4xlarge:

1. Login to new EC2 instance i3.large or i3.4xlarge(or any other instance you create)

2. Login as root user and install all base packages:
   sudo su
   sudo apt-get install python-software-properties
   sudo add-apt-repository ppa:webupd8team/java
   sudo apt-get update
   sudo apt-get install oracle-java8-installer

3. Check the java version just to be sure you've installed proper version for java:
   java –version

4. Download latest stable Hadoop using wget

   wget http://www.trieuvan.com/apache/hadoop/common/hadoop-2.6.5/hadoop-2.6.5.tar.gz

   tar xzf hadoop-2.6.5.tar.gz

5. Create a directory to store all data for hadoop.
   mkdir hadoopdata

6. Add the Hadoop related environment variables in your bash file.
   Vi ~/.bashrc

   Copy and paste these environment variables.

   ```
   export HADOOP_HOME=/home/ubuntu/hadoop-2.6.5
   export HADOOP_COMMON_LIB_NATIVE_DIR=$HADOOP_HOME/lib/native
   export HADOOP_OPTS="-Djava.library.path=$HADOOP_HOME/lib"
   export JAVA_HOME=/usr/lib/jvm/java-8-oracle
   PATH=$PATH:$JAVA_HOME/bin:$HADOOP_HOME/bin:$HADOOP_HOME/sbin
   ```

7. Refresh the bash settings by using this command:

   source ~/.bashrc

8. We'll setup hadoop for password less ssh access:

   ssh-keygen -t rsa -P ''
   cat $HOME/.ssh/id_rsa.pub >> $HOME/.ssh/authorized_keys

   check password less ssh access to localhost:

   ssh localhost

   and then exit.

9. Now, we've got to set the hadoop config files, has to be changed in order.

   The files changed are:

   a. core-site.xml

```
<configuration>
<property>
<name>hadoop.tmp.dir</name>
<value>/home/ubuntu/hadooptmp/hadoop-${user.name}</value>
<description>A base for other temporary directories.</description>
</property>
<property>
<name>fs.default.name</name>
<value>hdfs://localhost:9000</value>
</property></configuration>
~
```

   b. Hadoop-env.sh

```
# The java implementation to use.
export JAVA_HOME=/usr/lib/jvm/java-8-oracle

# The jsvc implementation to use. Jsvc is required to run secure datanodes
# that bind to privileged ports to provide authentication of data transfer
# protocol.  Jsvc is not required if SASL is configured for authentication of
# data transfer protocol using non-privileged ports.
#export JSVC_HOME=${JSVC_HOME}

export HADOOP_CONF_DIR=${HADOOP_CONF_DIR:-"/etc/hadoop"}
```

c. yarn.site.xml

```
<!-- Site specific YARN configuration properties -->
<configuration>
<property>
<name>yarn.nodemanager.aux-services</name>
<value>mapreduce_shuffle</value>
</property>
</configuration>
~
```

d. hdfs-site.xml

```
<configuration>
<property>
<name>dfs.replication</name>
<value>1</value>
</property>
<property><name>dfs.name.dir</name>
<value>file:///home/ubuntu/hadoopdata/hdfs/namenode</value>
</property>
<property>
<name>dfs.data.dir</name>
<value>file:///home/ubuntu/hadoopdata/hdfs/datanode</value>
</property>
</configuration>
~
```

e. mapred-site.xmi

```
<configuration>
<property>

<name>mapred.job.tracker</name>
<value>localhost:9001</value>
</property>

</configuration>
~
```

10. Now we format HDFS filesystem via NameNode:

    hdfs namenode –format

11. Start all services:

    start-all.sh

    We can check for hadoop processes/daemons running on hadoop with Java Virtual Machine Process Status Tool

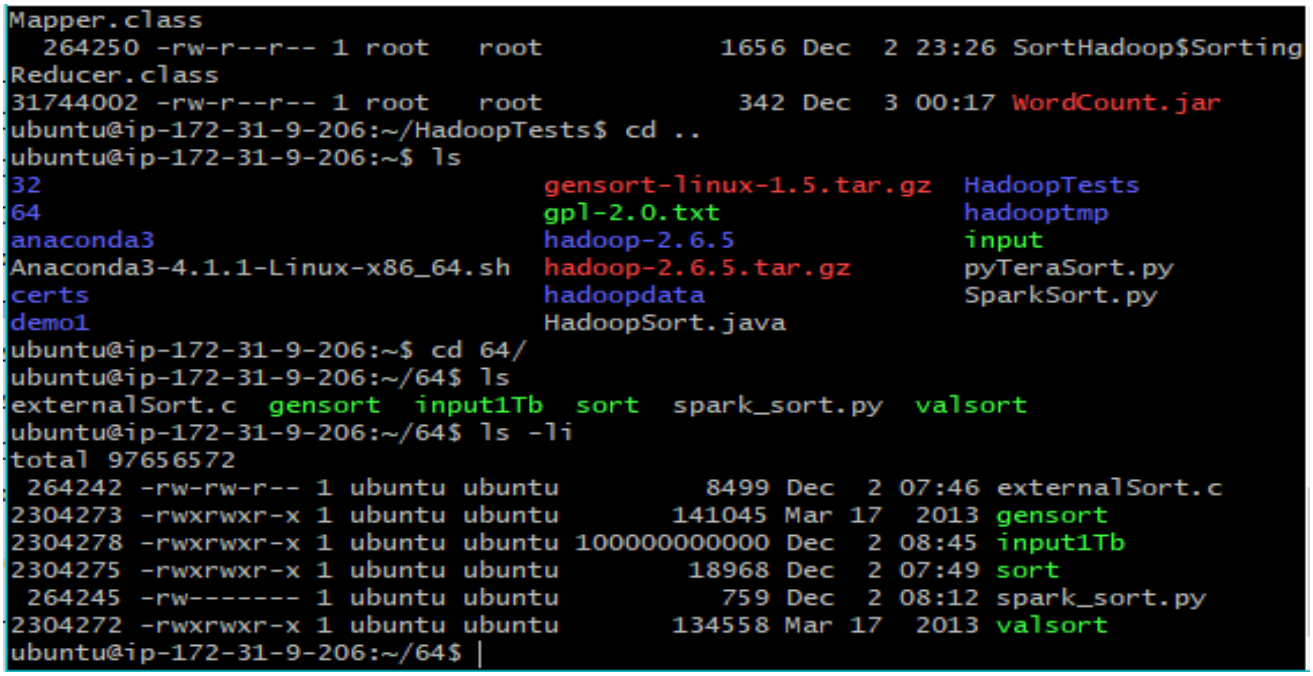
    Command:

    jps

Hadoop with 128GB dataset:

```
64                              gpl-2.0.txt               hadooptmp
anaconda3                       hadoop-2.6.5              input
Anaconda3-4.1.1-Linux-x86_64.sh hadoop-2.6.5.tar.gz       pyTeraSort.py
certs                           hadoopdata                SparkSort.py
demo1                           HadoopSort.java
ubuntu@ip-172-31-9-206:~$  HadoopTests/
-bash: HadoopTests/: Is a directory
ubuntu@ip-172-31-9-206:~$ cd HadoopTests/
ubuntu@ip-172-31-9-206:~/HadoopTests$ ls
hadoop.jar      SortHadoop.class                  WordCount.jar
hadoopsort.jar  SortHadoop$SortingMapper.class
input128        SortHadoop$SortingReducer.class
ubuntu@ip-172-31-9-206:~/HadoopTests$ ls -li
total 125000036
  264252 -rw-r--r-- 1 root   root           1496 Dec  2 23:31 hadoop.jar
31744003 -rw-r--r-- 1 root   root           3154 Dec  3 00:18 hadoopsort.jar
 2304274 -rwxrwxr-x 1 ubuntu ubuntu 128000000000 Dec  2 08:29 input128
  264251 -rw-r--r-- 1 root   root           1941 Dec  2 23:26 SortHadoop.class
  256053 -rw-r--r-- 1 root   root           1570 Dec  2 23:26 SortHadoop$Sorting
Mapper.class
  264250 -rw-r--r-- 1 root   root           1656 Dec  2 23:26 SortHadoop$Sorting
Reducer.class
31744002 -rw-r--r-- 1 root   root            342 Dec  3 00:17 WordCount.jar
ubuntu@ip-172-31-9-206:~/HadoopTests$
```

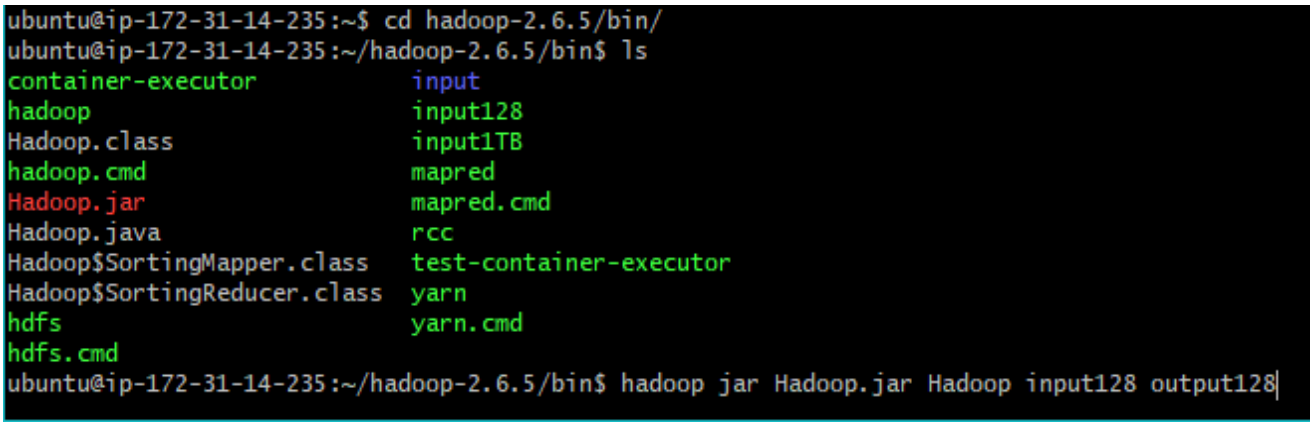
Hadoop with 1TB Dataset:



Performance

Hadoop Sort Execution

For 128 GB dataset



```
INFO input.FileInputFormat: Total input paths to process : 1
INFO mapreduce.JobSubmitter: number of splits:75
INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1459023141669_0001
INFO impl.YarnClientImpl: Submitted application application_1459023141669_0001
INFO mapreduce.Job: The url to track the job: http://master:8088/proxy/application_1459023141669_0001/
INFO mapreduce.Job: Running job: job_1459023141669_0001
INFO mapreduce.Job: Job job_1459023141669_0001 running in uber mode : false
INFO mapreduce.Job:  map 0% reduce 0%
INFO mapreduce.Job:  map 1% reduce 0%
INFO mapreduce.Job:  map 2% reduce 0%
INFO mapreduce.Job:  map 3% reduce 0%
INFO mapreduce.Job:  map 4% reduce 0%
INFO mapreduce.Job:  map 5% reduce 0%
INFO mapreduce.Job:  map 6% reduce 0%
INFO mapreduce.Job:  map 7% reduce 0%
INFO mapreduce.Job:  map 8% reduce 0%
INFO mapreduce.Job:  map 9% reduce 0%
INFO mapreduce.Job:  map 10% reduce 0%
INFO mapreduce.Job:  map 11% reduce 0%
INFO mapreduce.Job:  map 12% reduce 0%
INFO mapreduce.Job:  map 13% reduce 0%
INFO mapreduce.Job:  map 14% reduce 0%
INFO mapreduce.Job:  map 15% reduce 0%
INFO mapreduce.Job:  map 16% reduce 0%
INFO mapreduce.Job:  map 17% reduce 0%
INFO mapreduce.Job:  map 18% reduce 0%
INFO mapreduce.Job:  map 19% reduce 0%
INFO mapreduce.Job:  map 20% reduce 0%
INFO mapreduce.Job:  map 21% reduce 0%
INFO mapreduce.Job:  map 22% reduce 1%
INFO mapreduce.Job:  map 22% reduce 2%
INFO mapreduce.Job:  map 22% reduce 3%
INFO mapreduce.Job:  map 22% reduce 4%
INFO mapreduce.Job:  map 24% reduce 4%
INFO mapreduce.Job:  map 24% reduce 5%
INFO mapreduce.Job:  map 25% reduce 5%
```

```
INFO mapreduce.Job:  map 46% reduce 15%
INFO mapreduce.Job:  map 47% reduce 15%
INFO mapreduce.Job:  map 49% reduce 15%
INFO mapreduce.Job:  map 50% reduce 15%
INFO mapreduce.Job:  map 51% reduce 15%
INFO mapreduce.Job:  map 52% reduce 15%
INFO mapreduce.Job:  map 53% reduce 15%
INFO mapreduce.Job:  map 54% reduce 15%
INFO mapreduce.Job:  map 55% reduce 15%
INFO mapreduce.Job:  map 56% reduce 15%
INFO mapreduce.Job:  map 57% reduce 15%
INFO mapreduce.Job:  map 58% reduce 15%
INFO mapreduce.Job:  map 58% reduce 16%
INFO mapreduce.Job:  map 59% reduce 16%
INFO mapreduce.Job:  map 60% reduce 16%
INFO mapreduce.Job:  map 61% reduce 16%
INFO mapreduce.Job:  map 62% reduce 16%
INFO mapreduce.Job:  map 63% reduce 16%
INFO mapreduce.Job:  map 64% reduce 16%
INFO mapreduce.Job:  map 64% reduce 17%
INFO mapreduce.Job:  map 65% reduce 17%
INFO mapreduce.Job:  map 65% reduce 18%
INFO mapreduce.Job:  map 65% reduce 19%
INFO mapreduce.Job:  map 65% reduce 20%
INFO mapreduce.Job:  map 66% reduce 20%
INFO mapreduce.Job:  map 67% reduce 20%
INFO mapreduce.Job:  map 68% reduce 20%
INFO mapreduce.Job:  map 69% reduce 20%
INFO mapreduce.Job:  map 69% reduce 21%
INFO mapreduce.Job:  map 69% reduce 22%
INFO mapreduce.Job:  map 69% reduce 23%
INFO mapreduce.Job:  map 70% reduce 23%
INFO mapreduce.Job:  map 71% reduce 23%
INFO mapreduce.Job:  map 72% reduce 23%
INFO mapreduce.Job:  map 73% reduce 23%
INFO mapreduce.Job:  map 74% reduce 23%
INFO mapreduce.Job:  map 75% reduce 23%
INFO mapreduce.Job:  map 76% reduce 23%
INFO mapreduce.Job:  map 77% reduce 23%
```

```
INFO mapreduce.Job:  map 100% reduce 76%
INFO mapreduce.Job:  map 100% reduce 77%
INFO mapreduce.Job:  map 100% reduce 78%
INFO mapreduce.Job:  map 100% reduce 79%
INFO mapreduce.Job:  map 100% reduce 80%
INFO mapreduce.Job:  map 100% reduce 81%
INFO mapreduce.Job:  map 100% reduce 82%
INFO mapreduce.Job:  map 100% reduce 83%
INFO mapreduce.Job:  map 100% reduce 84%
INFO mapreduce.Job:  map 100% reduce 85%
INFO mapreduce.Job:  map 100% reduce 86%
INFO mapreduce.Job:  map 100% reduce 87%
INFO mapreduce.Job:  map 100% reduce 88%
INFO mapreduce.Job:  map 100% reduce 89%
INFO mapreduce.Job:  map 100% reduce 90%
INFO mapreduce.Job:  map 100% reduce 91%
INFO mapreduce.Job:  map 100% reduce 92%
INFO mapreduce.Job:  map 100% reduce 93%
INFO mapreduce.Job:  map 100% reduce 94%
INFO mapreduce.Job:  map 100% reduce 95%
INFO mapreduce.Job:  map 100% reduce 96%
INFO mapreduce.Job:  map 100% reduce 97%
INFO mapreduce.Job:  map 100% reduce 98%
INFO mapreduce.Job:  map 100% reduce 99%
INFO mapreduce.Job:  map 100% reduce 100%
INFO mapreduce.Job: Job job_1459023141669_0001 completed successfully
```

Output:

Head -5 output 128

```
  !&S3/]]  00000000000000000000000002145D78  8888BBBBDDDD1111CCCC55556666BBBB1111EEEEDDDD22229999
  !,=U#,9  00000000000000000000000019072E3  33332222FFFFBBBB0000FFFFAAAA666655553333DDDD3333CCCC
  !0f[ITd  0000000000000000000000003CAAB4B  9999FFFF555533337777CCCC4444BBBB7777EEEEBBBBDDDD4444
  !f6Suy2  0000000000000000000000003ABFD84  EEEE555555556666AAAA5555BBBBDDDD00001111666600000DDDD
  #%NIpq.  0000000000000000000000003B36FB9  1111000033334444111166666666AAAAAAAA00001111CCCCEEEE
```

The above screenshots are a collection of operations performed in the Hadoop Map Reduce method. As the theory says Hadoop is a method which performs sorting in many steps,
It reads data from cluster, perform an operation, write results to the cluster, read updated data from the cluster, perform next operation, write next result to cluster.
So the whole series of operations can be seen in our screenshot in the form of percentages.

The whole sorting process is divided in percentages from 0 to 100.

The last screenshot displays the output of the dataset sorted by Hadoop.

For 1 TB Dataset

```
ubuntu@ip-172-31-14-235:~$ ls
32                              gensort-linux-1.5.tar.gz  hadoop-2.6.5.tar.gz
64                              gpl-2.0.txt               hadoopdata
Anaconda3-4.1.1-Linux-x86_64.sh hadoop-2.6.5              hadooptmp
ubuntu@ip-172-31-14-235:~$ cd hadoop-2.6.5/
ubuntu@ip-172-31-14-235:~/hadoop-2.6.5$ cd bin/
ubuntu@ip-172-31-14-235:~/hadoop-2.6.5/bin$ ls
container-executor           input
hadoop                       input128
Hadoop.class                 input1TB
hadoop.cmd                   mapred
Hadoop.jar                   mapred.cmd
Hadoop.java                  rcc
Hadoop$SortingMapper.class   test-container-executor
Hadoop$SortingReducer.class  yarn
hdfs                         yarn.cmd
hdfs.cmd
ubuntu@ip-172-31-14-235:~/hadoop-2.6.5/bin$ hadoop jar Hadoop.jar Hadoop input1TB output1TB
```

```
INFO input.FileInputFormat: Total input paths to process : 1
INFO mapreduce.JobSubmitter: number of splits:75
INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1459023141669_0001
INFO impl.YarnClientImpl: Submitted application application_1459023141669_0001
INFO mapreduce.Job: The url to track the job: http://master:8088/proxy/application_1459023141669_0001/
INFO mapreduce.Job: Running job: job_1459023141669_0001
INFO mapreduce.Job: Job job_1459023141669_0001 running in uber mode : false
INFO mapreduce.Job:  map 0% reduce 0%
INFO mapreduce.Job:  map 1% reduce 0%
INFO mapreduce.Job:  map 2% reduce 0%
INFO mapreduce.Job:  map 3% reduce 0%
INFO mapreduce.Job:  map 4% reduce 0%
INFO mapreduce.Job:  map 5% reduce 0%
INFO mapreduce.Job:  map 6% reduce 0%
INFO mapreduce.Job:  map 7% reduce 0%
INFO mapreduce.Job:  map 8% reduce 0%
INFO mapreduce.Job:  map 9% reduce 0%
INFO mapreduce.Job:  map 10% reduce 0%
INFO mapreduce.Job:  map 11% reduce 0%
INFO mapreduce.Job:  map 12% reduce 0%
INFO mapreduce.Job:  map 13% reduce 0%
INFO mapreduce.Job:  map 14% reduce 0%
INFO mapreduce.Job:  map 15% reduce 0%
INFO mapreduce.Job:  map 16% reduce 0%
INFO mapreduce.Job:  map 17% reduce 0%
INFO mapreduce.Job:  map 18% reduce 0%
INFO mapreduce.Job:  map 19% reduce 0%
INFO mapreduce.Job:  map 20% reduce 0%
INFO mapreduce.Job:  map 21% reduce 0%
INFO mapreduce.Job:  map 22% reduce 1%
INFO mapreduce.Job:  map 22% reduce 2%
INFO mapreduce.Job:  map 22% reduce 3%
INFO mapreduce.Job:  map 22% reduce 4%
INFO mapreduce.Job:  map 24% reduce 4%
INFO mapreduce.Job:  map 24% reduce 5%
INFO mapreduce.Job:  map 25% reduce 5%
```

```
INFO mapreduce.Job:  map 46% reduce 15%
INFO mapreduce.Job:  map 47% reduce 15%
INFO mapreduce.Job:  map 49% reduce 15%
INFO mapreduce.Job:  map 50% reduce 15%
INFO mapreduce.Job:  map 51% reduce 15%
INFO mapreduce.Job:  map 52% reduce 15%
INFO mapreduce.Job:  map 53% reduce 15%
INFO mapreduce.Job:  map 54% reduce 15%
INFO mapreduce.Job:  map 55% reduce 15%
INFO mapreduce.Job:  map 56% reduce 15%
INFO mapreduce.Job:  map 57% reduce 15%
INFO mapreduce.Job:  map 58% reduce 15%
INFO mapreduce.Job:  map 58% reduce 16%
INFO mapreduce.Job:  map 59% reduce 16%
INFO mapreduce.Job:  map 60% reduce 16%
INFO mapreduce.Job:  map 61% reduce 16%
INFO mapreduce.Job:  map 62% reduce 16%
INFO mapreduce.Job:  map 63% reduce 16%
INFO mapreduce.Job:  map 64% reduce 16%
INFO mapreduce.Job:  map 64% reduce 17%
INFO mapreduce.Job:  map 65% reduce 17%
INFO mapreduce.Job:  map 65% reduce 18%
INFO mapreduce.Job:  map 65% reduce 19%
INFO mapreduce.Job:  map 65% reduce 20%
INFO mapreduce.Job:  map 66% reduce 20%
INFO mapreduce.Job:  map 67% reduce 20%
INFO mapreduce.Job:  map 68% reduce 20%
INFO mapreduce.Job:  map 69% reduce 20%
INFO mapreduce.Job:  map 69% reduce 21%
INFO mapreduce.Job:  map 69% reduce 22%
INFO mapreduce.Job:  map 69% reduce 23%
INFO mapreduce.Job:  map 70% reduce 23%
INFO mapreduce.Job:  map 71% reduce 23%
INFO mapreduce.Job:  map 72% reduce 23%
INFO mapreduce.Job:  map 73% reduce 23%
INFO mapreduce.Job:  map 74% reduce 23%
INFO mapreduce.Job:  map 75% reduce 23%
INFO mapreduce.Job:  map 76% reduce 23%
INFO mapreduce.Job:  map 77% reduce 23%
```

```
INFO mapreduce.Job:  map 100% reduce 76%
INFO mapreduce.Job:  map 100% reduce 77%
INFO mapreduce.Job:  map 100% reduce 78%
INFO mapreduce.Job:  map 100% reduce 79%
INFO mapreduce.Job:  map 100% reduce 80%
INFO mapreduce.Job:  map 100% reduce 81%
INFO mapreduce.Job:  map 100% reduce 82%
INFO mapreduce.Job:  map 100% reduce 83%
INFO mapreduce.Job:  map 100% reduce 84%
INFO mapreduce.Job:  map 100% reduce 85%
INFO mapreduce.Job:  map 100% reduce 86%
INFO mapreduce.Job:  map 100% reduce 87%
INFO mapreduce.Job:  map 100% reduce 88%
INFO mapreduce.Job:  map 100% reduce 89%
INFO mapreduce.Job:  map 100% reduce 90%
INFO mapreduce.Job:  map 100% reduce 91%
INFO mapreduce.Job:  map 100% reduce 92%
INFO mapreduce.Job:  map 100% reduce 93%
INFO mapreduce.Job:  map 100% reduce 94%
INFO mapreduce.Job:  map 100% reduce 95%
INFO mapreduce.Job:  map 100% reduce 96%
INFO mapreduce.Job:  map 100% reduce 97%
INFO mapreduce.Job:  map 100% reduce 98%
INFO mapreduce.Job:  map 100% reduce 99%
INFO mapreduce.Job:  map 100% reduce 100%
INFO mapreduce.Job: Job job_1459023141669_0001 completed successfully
```

Output:

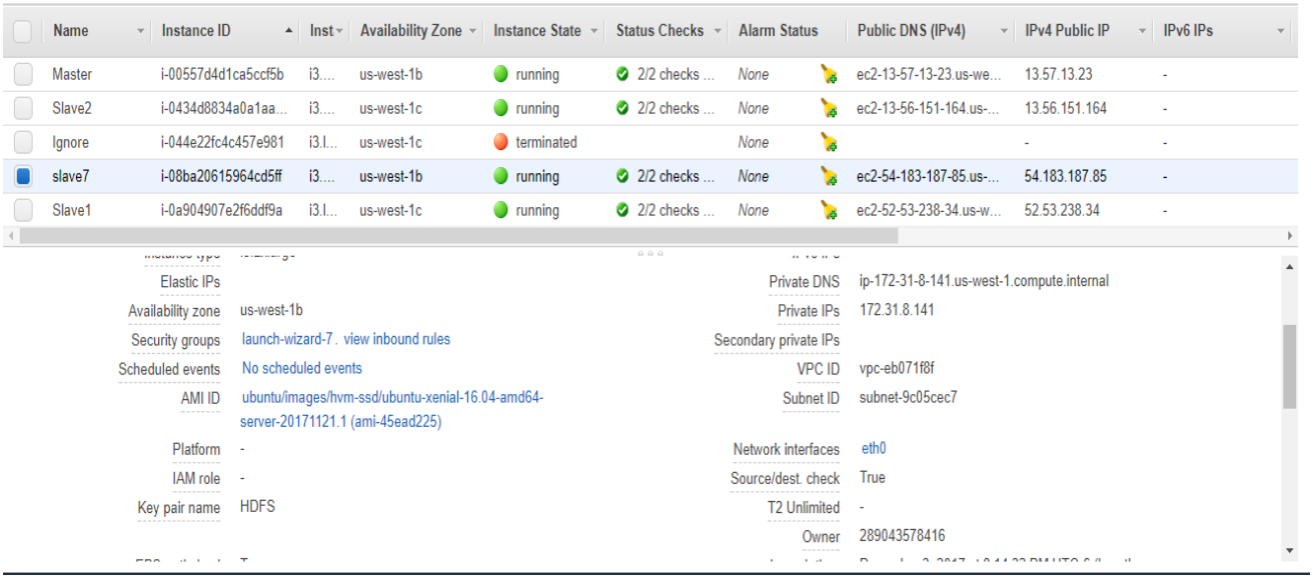
Head -5 output 1 TB

```
  "O!uve  00000000000000000000000001228D4  77778888000022224444DDDDDDDDEEEE00000000CCCC7777DDDD
  PMd32=  00000000000000000000000003440CC1  FFFFEEEE6666CCCCBBBB9999333335555DDDDDDDD7777888866666
  ^3CO],  00000000000000000000000000158C5C5  5555AAAA9999EEEE8888222229999CCCCDDDD6666555544442222
!&S3/]]  00000000000000000000000002145D78  8888BBBBDDDD1111CCCC55556666BBBB1111EEEEDDDD22229999
!,=U#,9  00000000000000000000000019072E3  33332222FFFFBBBB0000FFFFAAAA666655553333DDDD3333CCCC
```

Compute Time: 618 Minutes (10.3 hours)

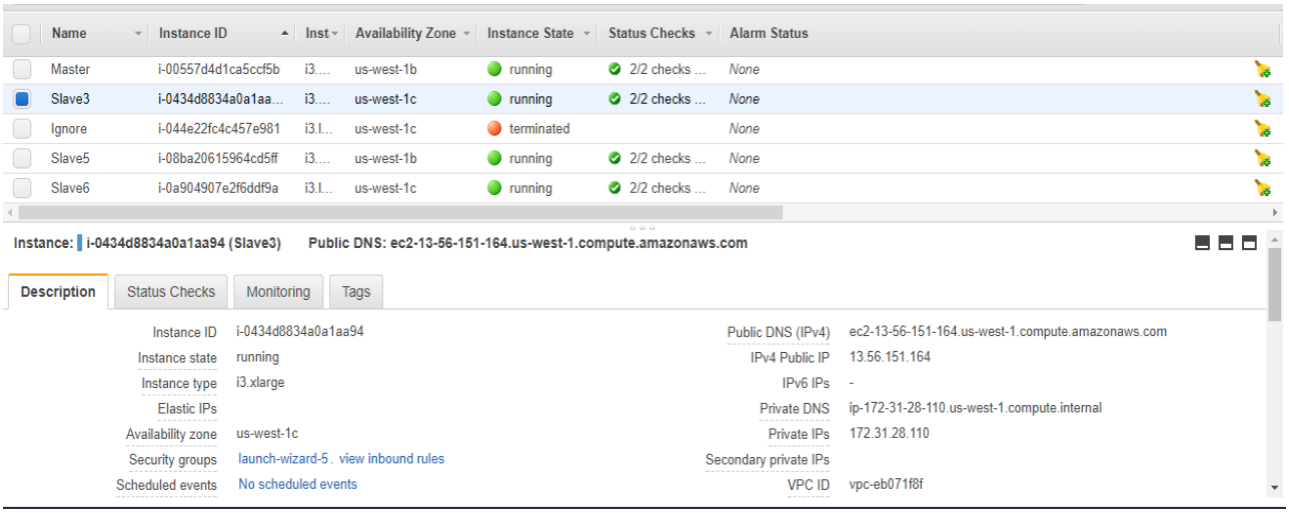
Launching 8 nodes for forming a Virtual Cluster of i3.large instance:

Private Ips are stored in etc/hadoop/slaves file for slave node and etc/hadoop/masters file for master node
Master - 172.31.6.227
Slave1- 172.31.27.17
Slave2- 172.31.29.179
Slave3- 172.31.28.110
Slave4- 172.31.7.134
Slave5- 172.31.25.127
Slave6- 172.31.12.24
Slave7-172.31.8.141



Name	Instance ID	Inst	Availability Zone	Instance State	Status Checks	Alarm Status	Public DNS (IPv4)	IPv4 Public IP	IPv6 IPs
Master	i-00557d4d1ca5ccf5b	i3....	us-west-1b	running	2/2 checks ...	None	ec2-13-57-13-23.us-we...	13.57.13.23	-
Slave2	i-0434d8834a0a1aa...	i3....	us-west-1c	running	2/2 checks ...	None	ec2-13-56-151-164.us-...	13.56.151.164	-
Ignore	i-044e22fc4c457e981	i3.l...	us-west-1c	terminated		None		-	-
slave7	i-08ba20615964cd5ff	i3....	us-west-1b	running	2/2 checks ...	None	ec2-54-183-187-85.us-...	54.183.187.85	-
Slave1	i-0a904907e2f6ddf9a	i3.l...	us-west-1c	running	2/2 checks ...	None	ec2-52-53-238-34.us-w...	52.53.238.34	-

Elastic IPs		Private DNS	ip-172-31-8-141.us-west-1.compute.internal
Availability zone	us-west-1b	Private IPs	172.31.8.141
Security groups	launch-wizard-7. view inbound rules	Secondary private IPs	
Scheduled events	No scheduled events	VPC ID	vpc-eb071f8f
AMI ID	ubuntu/images/hvm-ssd/ubuntu-xenial-16.04-amd64-server-20171121.1 (ami-45ead225)	Subnet ID	subnet-9c05cec7
Platform	-	Network interfaces	eth0
IAM role	-	Source/dest. check	True
Key pair name	HDFS	T2 Unlimited	-
		Owner	289043578416



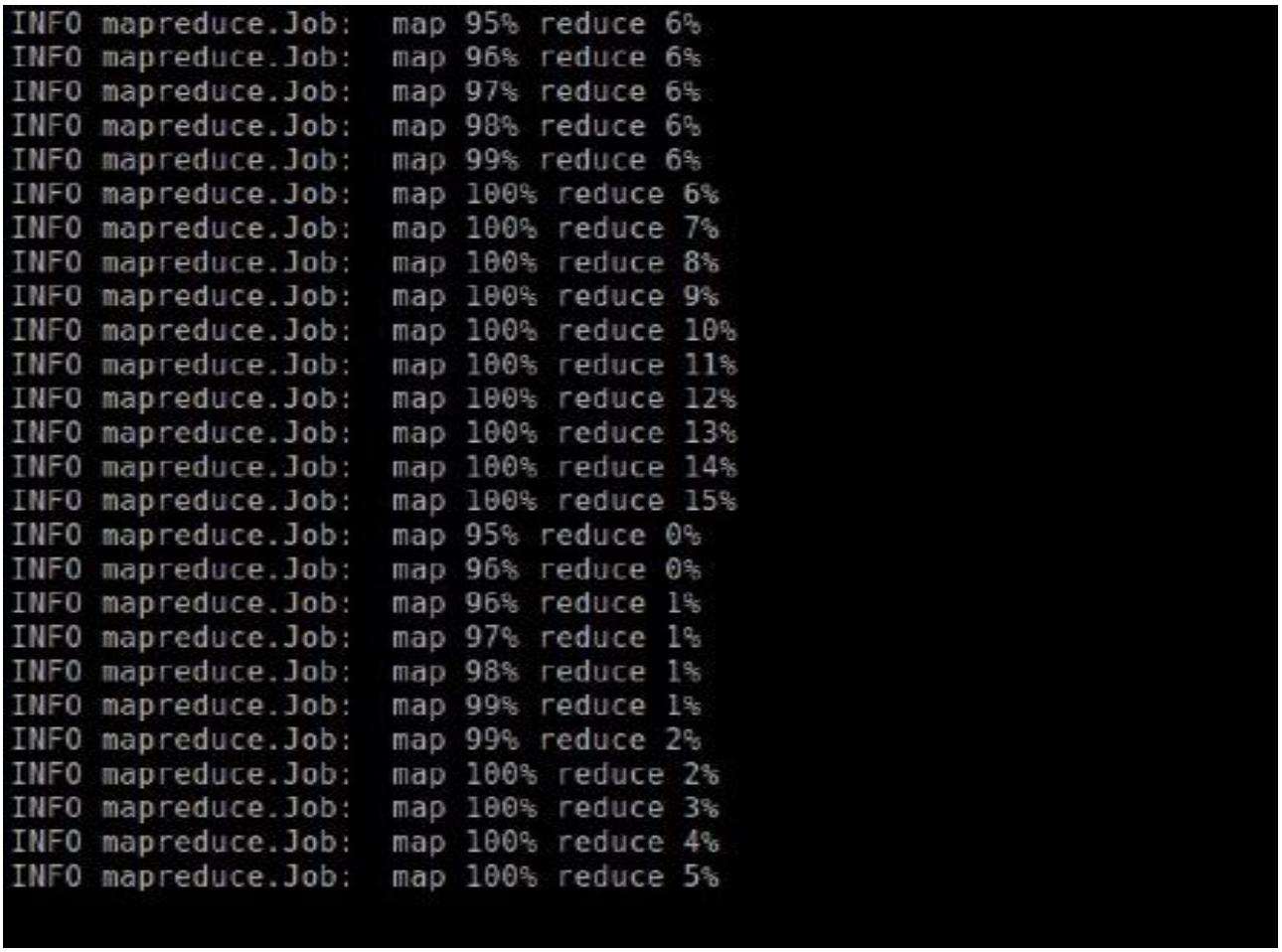
Name	Instance ID	Inst	Availability Zone	Instance State	Status Checks	Alarm Status
Master	i-00557d4d1ca5ccf5b	i3....	us-west-1b	running	2/2 checks ...	None
Slave3	i-0434d8834a0a1aa...	i3....	us-west-1c	running	2/2 checks ...	None
Ignore	i-044e22fc4c457e981	i3.l...	us-west-1c	terminated		None
Slave5	i-08ba20615964cd5ff	i3....	us-west-1b	running	2/2 checks ...	None
Slave6	i-0a904907e2f6ddf9a	i3.l...	us-west-1c	running	2/2 checks ...	None

Instance: i-0434d8834a0a1aa94 (Slave3) Public DNS: ec2-13-56-151-164.us-west-1.compute.amazonaws.com

Description | Status Checks | Monitoring | Tags

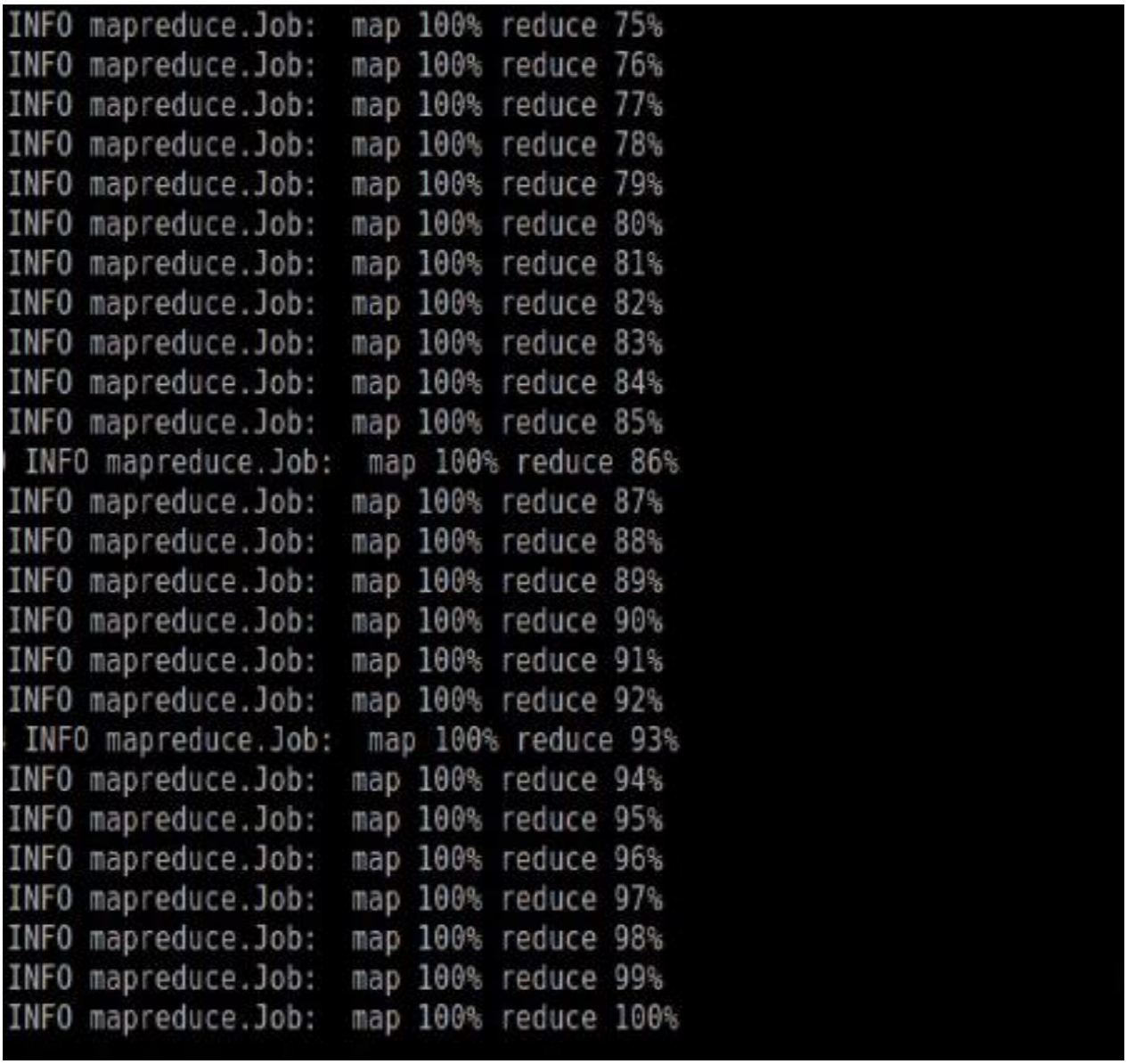
Instance ID	i-0434d8834a0a1aa94	Public DNS (IPv4)	ec2-13-56-151-164.us-west-1.compute.amazonaws.com
Instance state	running	IPv4 Public IP	13.56.151.164
Instance type	i3.xlarge	IPv6 IPs	-
Elastic IPs		Private DNS	ip-172-31-28-110.us-west-1.compute.internal
Availability zone	us-west-1c	Private IPs	172.31.28.110
Security groups	launch-wizard-5. view inbound rules	Secondary private IPs	
Scheduled events	No scheduled events	VPC ID	vpc-eb071f8f

```
INFO mapreduce.Job: Running job: job_1459040042109_0001
INFO mapreduce.Job: Job job_1459040042109_0001 running in uber mode :

INFO mapreduce.Job:  map 0% reduce 0%
INFO mapreduce.Job:  map 1% reduce 0%
INFO mapreduce.Job:  map 2% reduce 0%
INFO mapreduce.Job:  map 3% reduce 0%
INFO mapreduce.Job:  map 4% reduce 0%
INFO mapreduce.Job:  map 5% reduce 0%
INFO mapreduce.Job:  map 6% reduce 0%
INFO mapreduce.Job:  map 7% reduce 0%
INFO mapreduce.Job:  map 8% reduce 0%
INFO mapreduce.Job:  map 9% reduce 0%
INFO mapreduce.Job:  map 10% reduce 0%
INFO mapreduce.Job:  map 11% reduce 0%
INFO mapreduce.Job:  map 12% reduce 0%
INFO mapreduce.Job:  map 13% reduce 0%
INFO mapreduce.Job:  map 14% reduce 0%
INFO mapreduce.Job:  map 15% reduce 0%
INFO mapreduce.Job:  map 16% reduce 0%
INFO mapreduce.Job:  map 17% reduce 0%
INFO mapreduce.Job:  map 18% reduce 0%
INFO mapreduce.Job:  map 19% reduce 0%
INFO mapreduce.Job:  map 20% reduce 0%
INFO mapreduce.Job:  map 21% reduce 0%
INFO mapreduce.Job:  map 22% reduce 0%
INFO mapreduce.Job:  map 23% reduce 0%
INFO mapreduce.Job:  map 24% reduce 0%
```



Here in the above screenshot you can see that Maps 100% but Reduces 15% and gets into that loop again which was a problem, I first thought it was something wrong with the code, but I just had to insert the numbers of mappers and reducers in Mapred-site.xml in etc/hadoop and then it just worked.

Check the next screenshot!



And the time elapsed(Compute time) comes out to be: 477.53 minutes(7.95hrs)

Spark Terasort:

Spark Setup on i3.large and i3.4xlarge:

1. Download and Install python :

   wget http://repo.continuum.io/archive/Anaconda3-4.1.1-Linux-x86_64.sh

   bash Anaconda3–4.1.1-Linux-x86_64.sh

2. To know what version has been installed:

   which python

3. Installing Scala:

   sudo apt-get install scala

   To check whether is has been installed properly or not:

   scala –version

4. Install Spark:

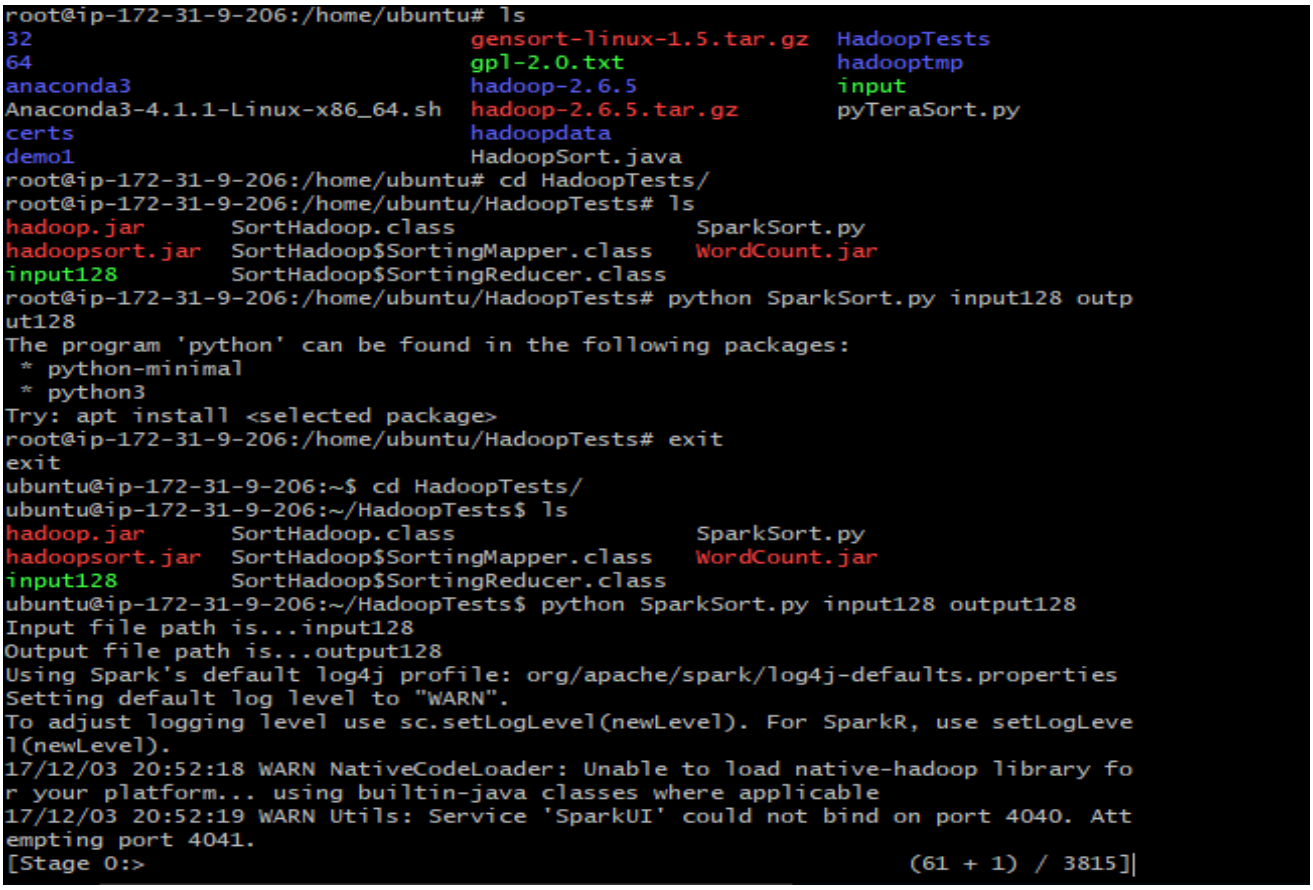
   wget http://archive.apache.org/dist/spark/spark-2.0.0/spark-2.0.0-bin-hadoop2.7.tgz

   sudo tar -zxvf spark-2.0.0-bin-hadoop2.7.tgz

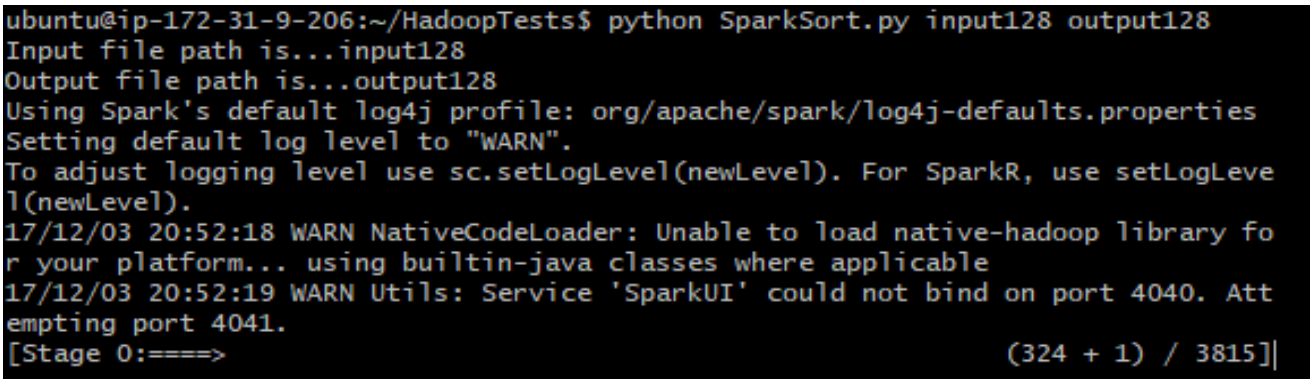
5. We've got to let python know where spark is:

   export PATH=$SPARK_HOME:$PATH
   export PYTHONPATH=$SPARK_HOME/python:$PYTHONPATH

Sparksort on 128 GB of dataset:



Stage 0 of execution:



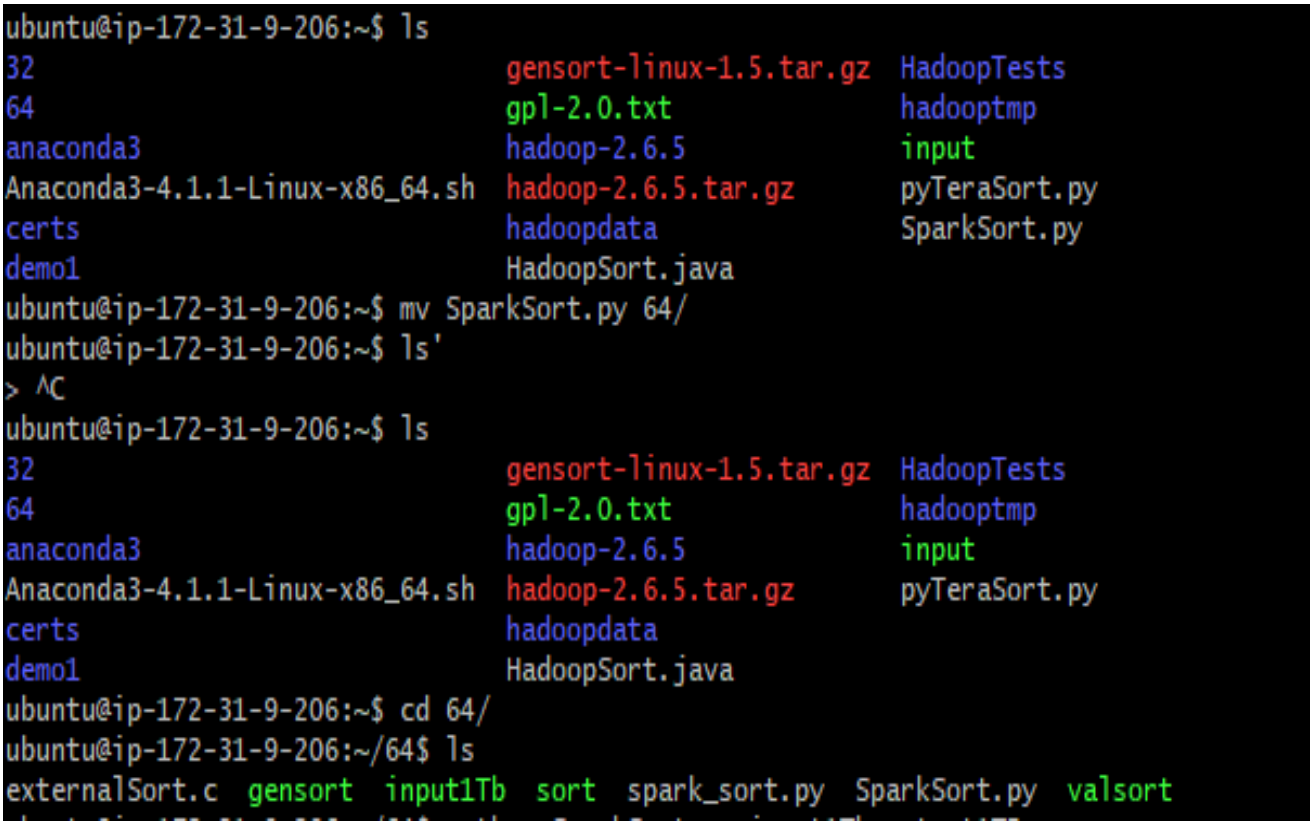
```
ubuntu@ip-172-31-9-206:~/HadoopTests$ python SparkSort.py input128 output128
Input file path is...input128
Output file path is...output128
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLeve
l(newLevel).
17/12/03 20:52:18 WARN NativeCodeLoader: Unable to load native-hadoop library fo
r your platform... using builtin-java classes where applicable
17/12/03 20:52:19 WARN Utils: Service 'SparkUI' could not bind on port 4040. Att
empting port 4041.
[Stage 0:======================>                          (1722 + 1) / 3815]
```

Stage 1 of execution:

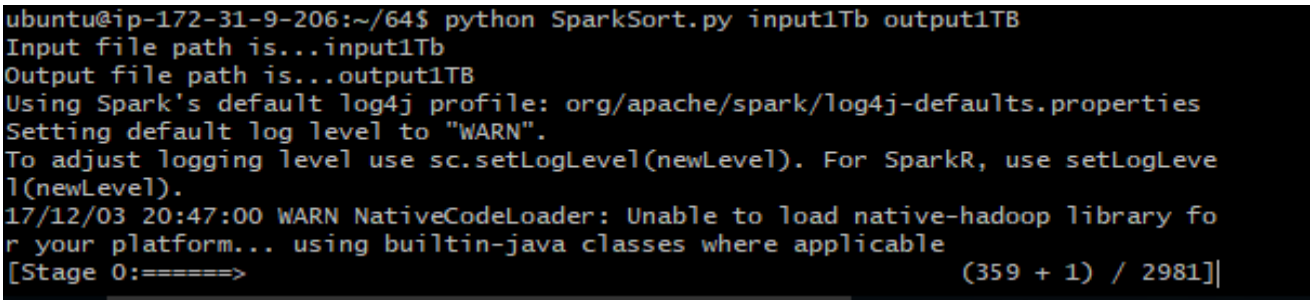
```
ubuntu@ip-172-31-9-206:~/HadoopTests$ python SparkSort.py input128 output128
Input file path is...input128
Output file path is...output128
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLeve
l(newLevel).
17/12/03 20:52:18 WARN NativeCodeLoader: Unable to load native-hadoop library fo
r your platform... using builtin-java classes where applicable
17/12/03 20:52:19 WARN Utils: Service 'SparkUI' could not bind on port 4040. Att
empting port 4041.
[Stage 0:================================>                (2282 + 1) / 3815]
```

This shows that the number of parts in which the dataset was divided is 3815
The operation is divided in 3 stages basically because the operation is performed on the whole dataset at once.
First stage reads the data from the dataset, the second stage performs the sorting operation on the data and then the third operation stored the processed data back in the output folder.

Sparksort on 1 TB dataset:



Stage 0 of execution:



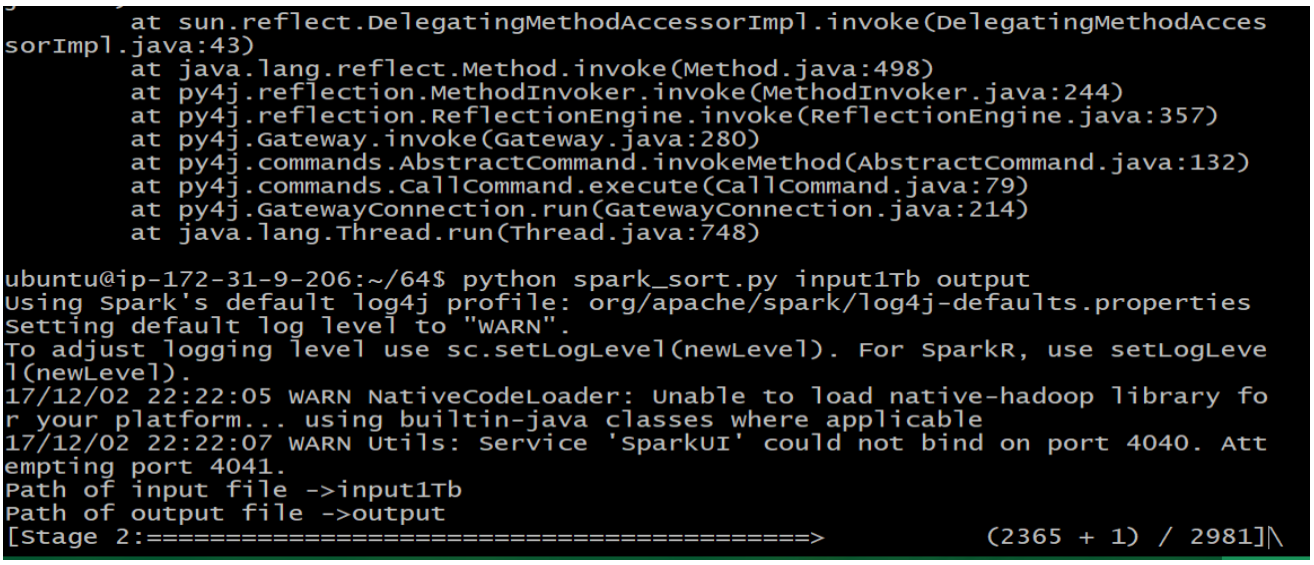
```
ubuntu@ip-172-31-9-206:~/64$ python SparkSort.py input1Tb output1TB
Input file path is...input1Tb
Output file path is...output1TB
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLeve
l(newLevel).
17/12/03 20:47:00 WARN NativeCodeLoader: Unable to load native-hadoop library fo
r your platform... using builtin-java classes where applicable
[Stage 0:==========>                                              (561 + 1) / 2981]
```

```
ubuntu@ip-172-31-9-206:~/64$ python SparkSort.py input1Tb output1TB
Input file path is...input1Tb
Output file path is...output1TB
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLeve
l(newLevel).
17/12/03 20:47:00 WARN NativeCodeLoader: Unable to load native-hadoop library fo
r your platform... using builtin-java classes where applicable
[Stage 0:=========================================>        (2503 + 1) / 2981]
```

Stage 1 of execution:

```
ubuntu@ip-172-31-9-206:~/64$ python SparkSort.py input1Tb output1TB
Input file path is...input1Tb
Output file path is...output1TB
Using Spark's default log4j profile: org/apache/spark/log4j-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLeve
l(newLevel).
17/12/03 20:47:00 WARN NativeCodeLoader: Unable to load native-hadoop library fo
r your platform... using builtin-java classes where applicable
[Stage 1:=>                                                       (103 + 1) / 2981]
```

Stage 2 of Execution:



The screenshot above displays a collection of different operations and all of them connects to one operation of sorting.
As said above the operations are divided in three stages that collectively gives us an output and stores in the desired format in the folder.

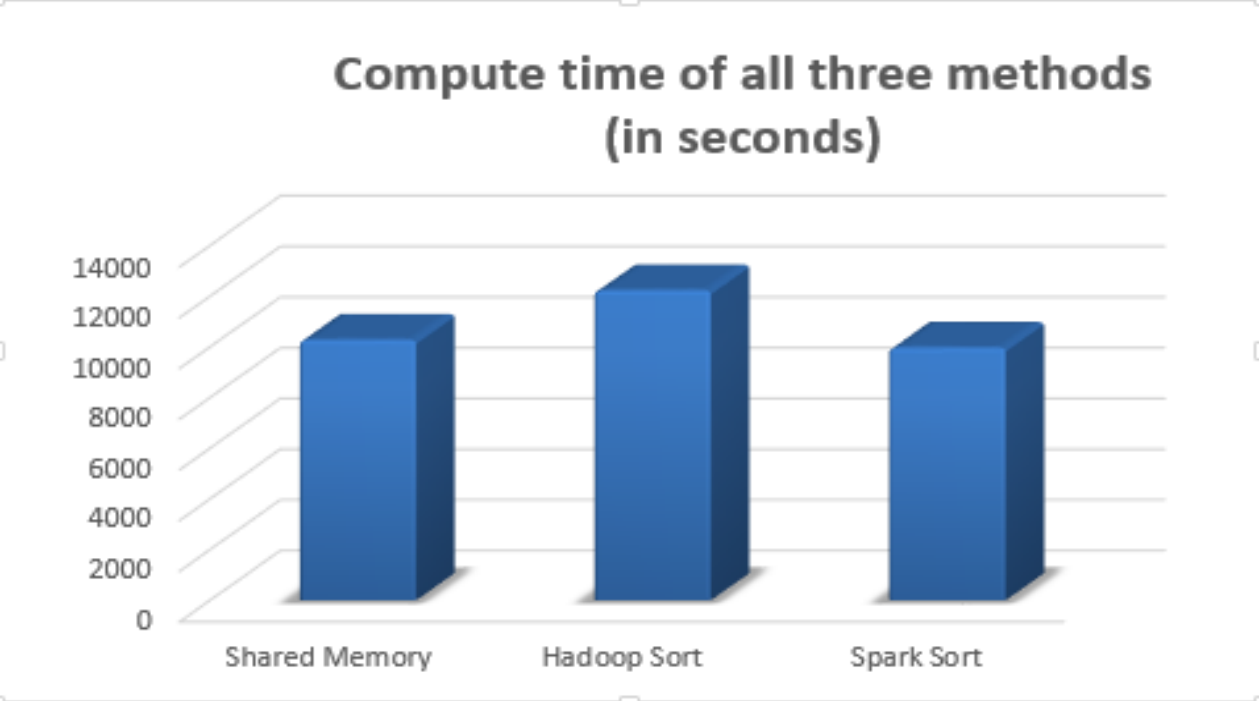
1) Performance:

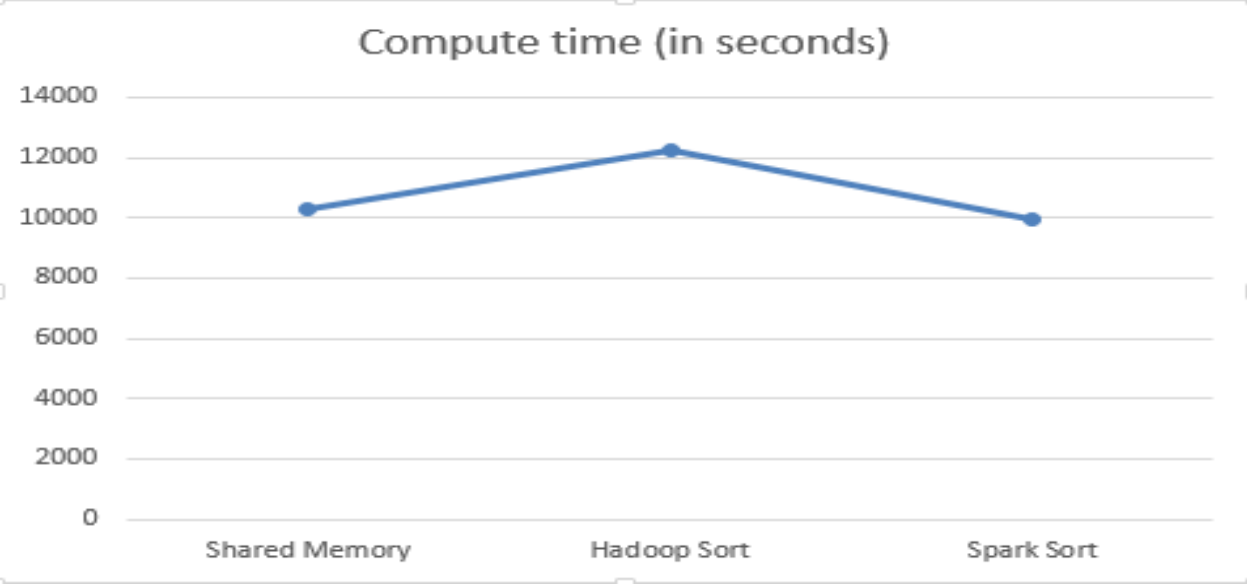
Table 1: Performance evaluation of TeraSort

Experiment (instance/dataset)	Shared Memory Terasort	Hadoop Terasort	Spark Terasort	MPI Terasort
Compute Time (sec) [1xi3.large 128GB]	10280 sec	12235 sec	9972 sec	-
Data Read (GB) [1xi3.large 128GB]	125 GB	120 GB	122 GB	-
Data Write (GB) [1xi3.large 128GB]	126 GB	120 GB	122 GB	-
I/O Throughput (MB/sec) [1xi3.large 128GB]	112.412 MB/sec	85.7 MB/sec	105.15 MB/sec	-
Compute Time (sec) [1xi3.4xlarge 1TB]	26592 sec	37080 sec	25391 sec	-
Data Read (GB) [1xi3.4xlarge 1TB]	920 GB	920 GB	920 GB	-
Data Write (GB) [1xi3.4xlarge 1TB]	920 GB	920 GB	920 GB	-
I/O Throughput (MB/sec) [1xi3.4xlarge 1TB]	315.45 MB/sec	226 MB/sec	330 Mb/sec	-
Compute Time (sec) [8xi3.large 1TB]	N/A	28652 sec	24649 sec	-
Data Read (GB) [8xi3.large 1TB]	N/A	920 GB	920 GB	-
Data Write (GB) [8xi3.large 1TB]	N/A	920 GB	920GB	-
I/O Throughput (MB/sec) [8xi3.large 1TB]	N/A	263.04 MB/sec	305.75 MB/sec	-
Speedup (weak scale)	2.80619	1.163	0.926	-
Efficiency (weak scale)	2.58677	1.290	1.030	-

Performance Report:

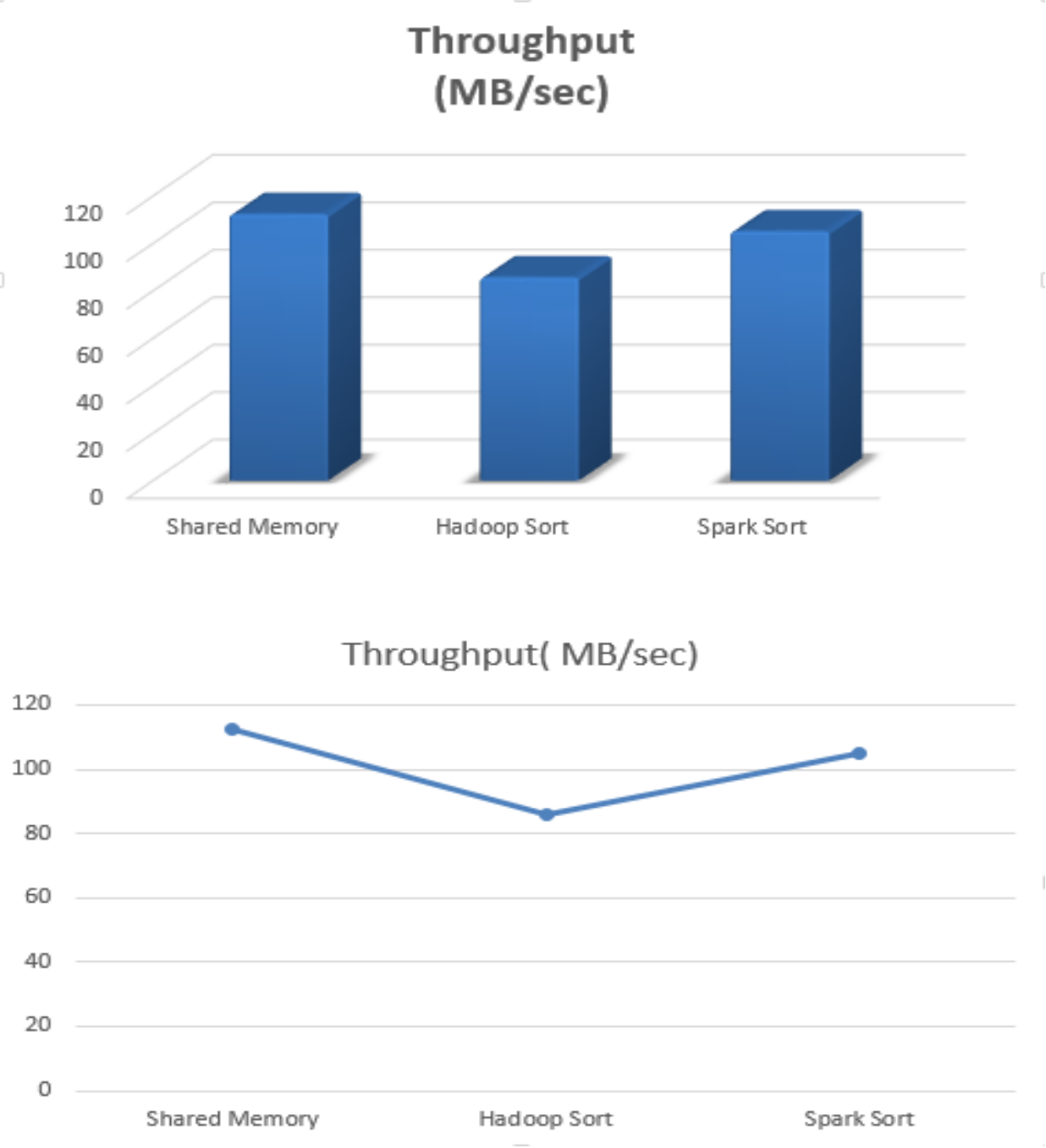
For 128 GB
Compute time comparison





It is visible from the graph that Spark Sort takes the least time of all and after that the shared memory sort is efficient. Hadoop sort is not at all efficient to be run on a single node. And that shared memory performs as good as spark on a small dataset and when it comes to the single node then the performance of shared memory is very good comparatively.

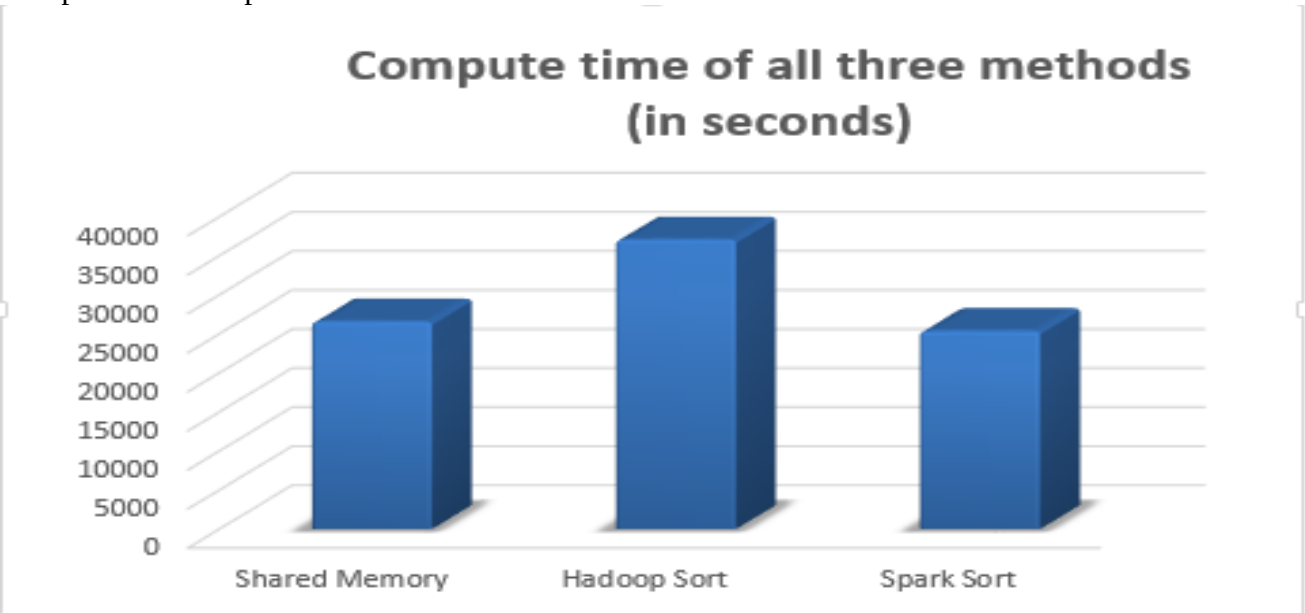
Throughput Comparison

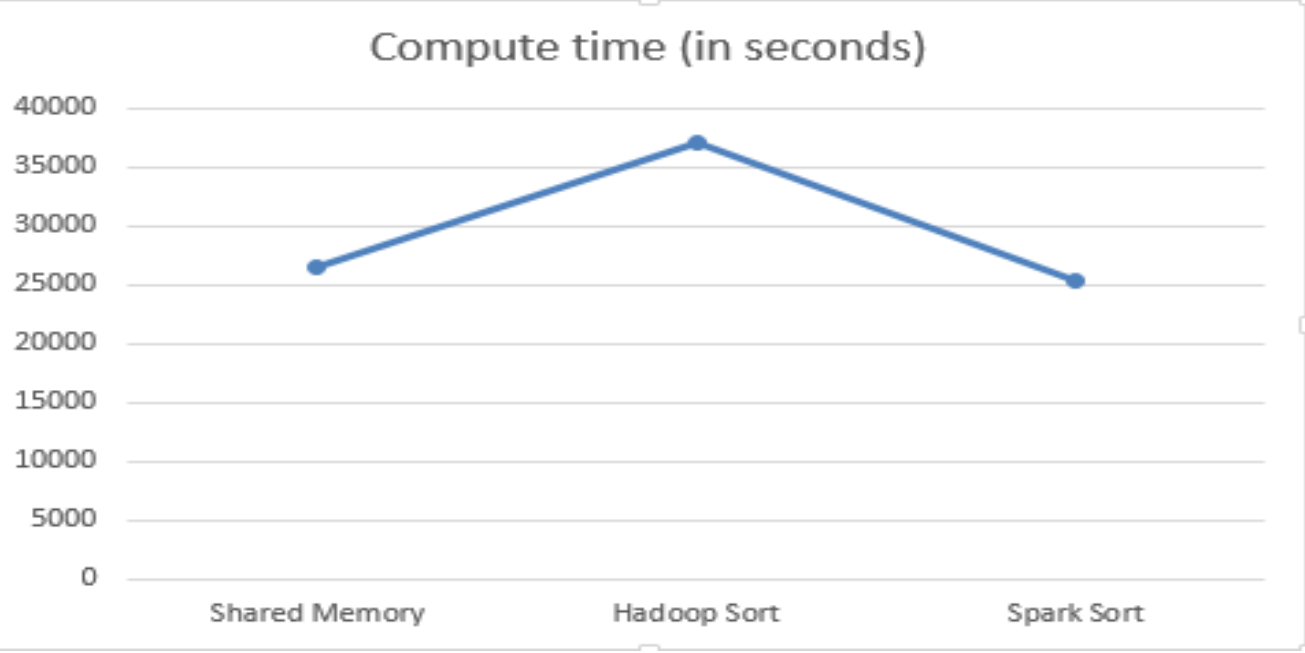


As we can see from the graph, the throughput of shared memory sorting is the best amongst all. Since the sorting is done on a single node so the shared memory outperforms all other sorting methods.

For 1 TB Dataset: (instance type i3.4xlarge)

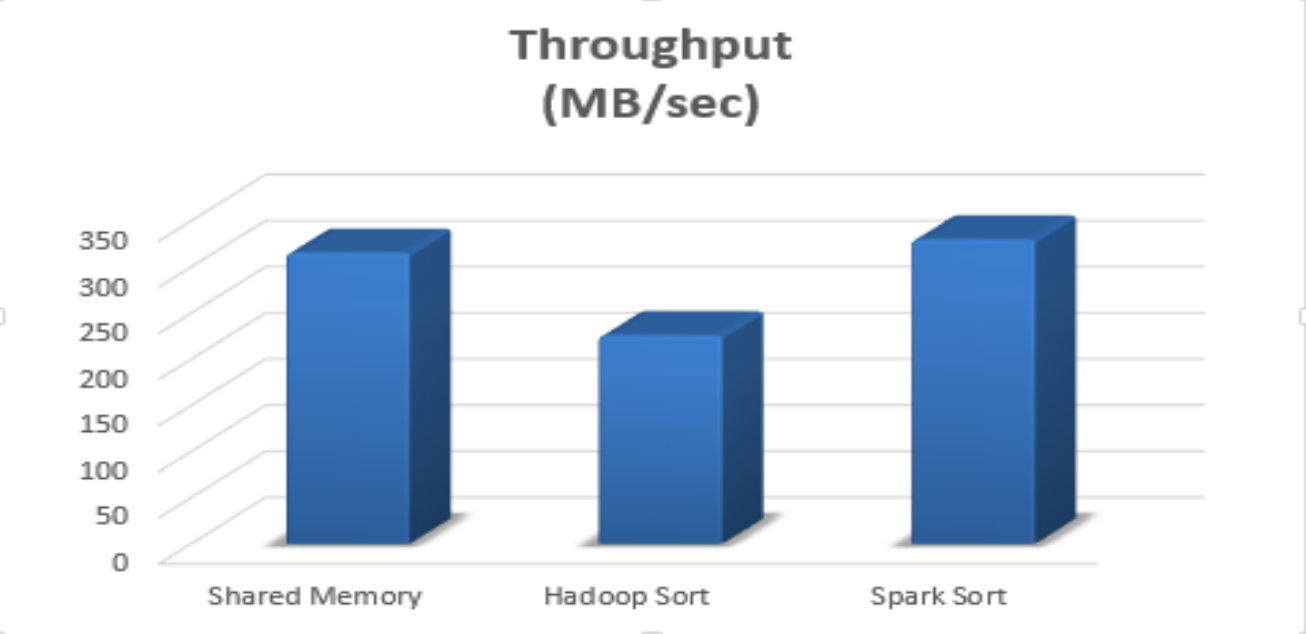
Compute time comparison:

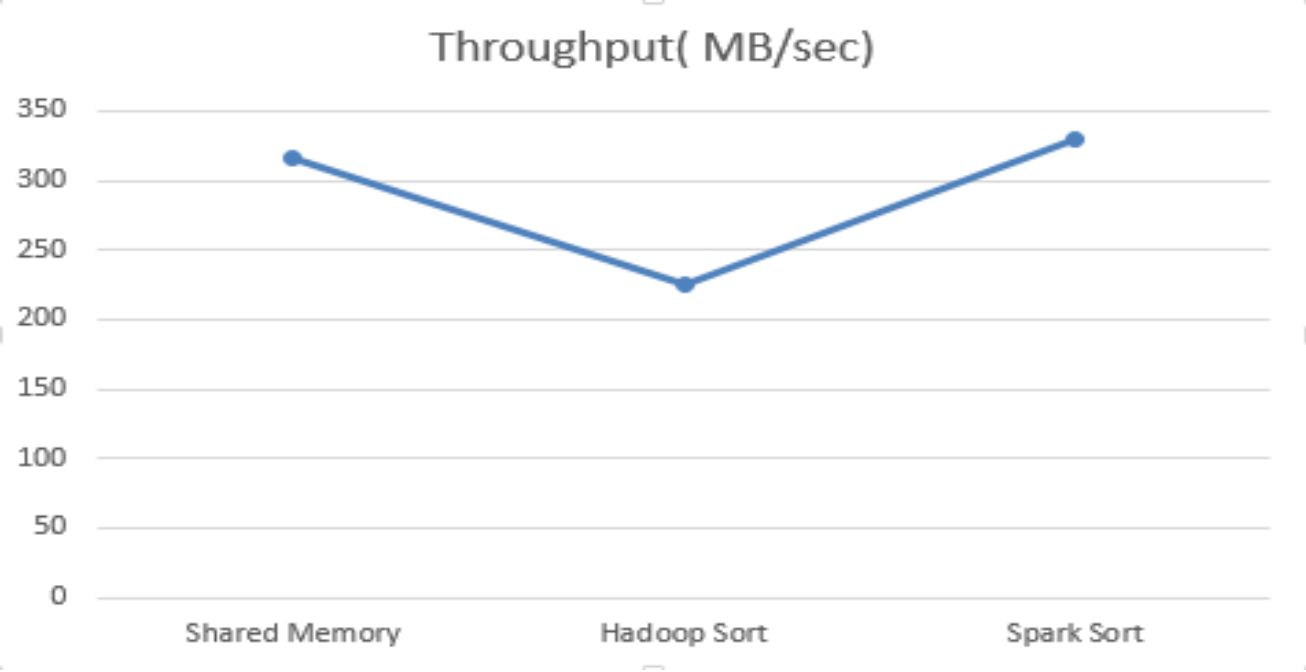




The Compute time for spark is the least in this case as seen from the graph.
The spark sort is efficient for performing sorting operations on bigger datasets with higher number of nodes.

Throughput comparison:



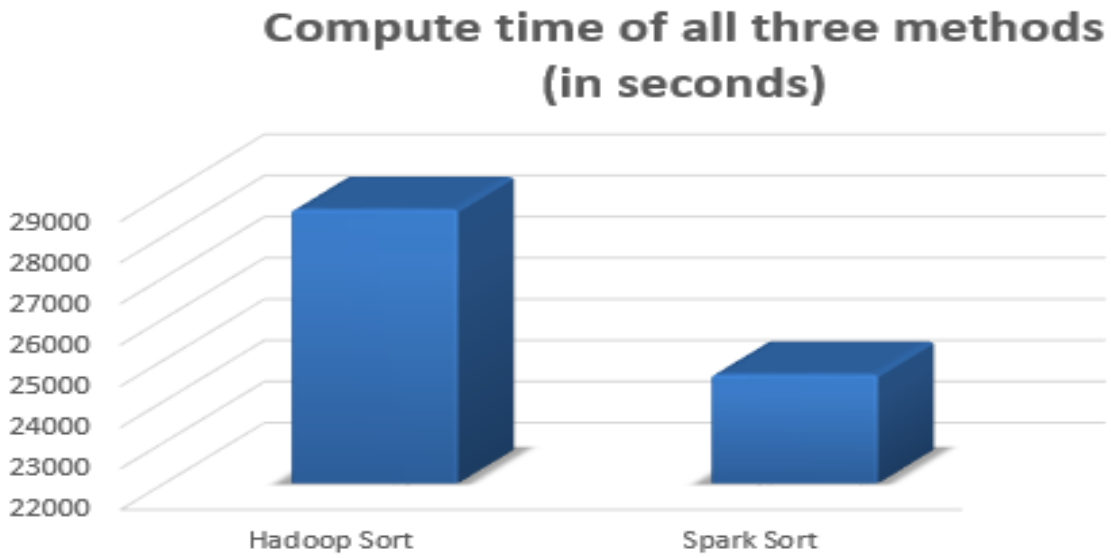


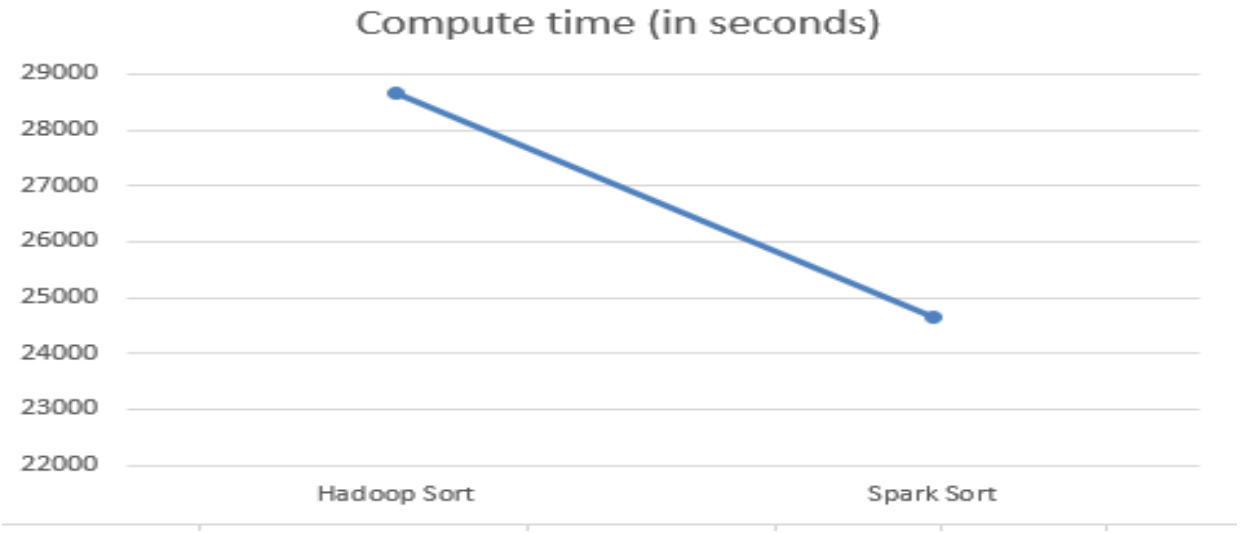
The throughput of Spark Sort is the best as it performs the fastest sorting amongst all.
The Shared memory method has the second best throughput.

For 8 nodes in one cluster for instance type (i3.large)

Comparison of Hadoop and Spark Sorting:

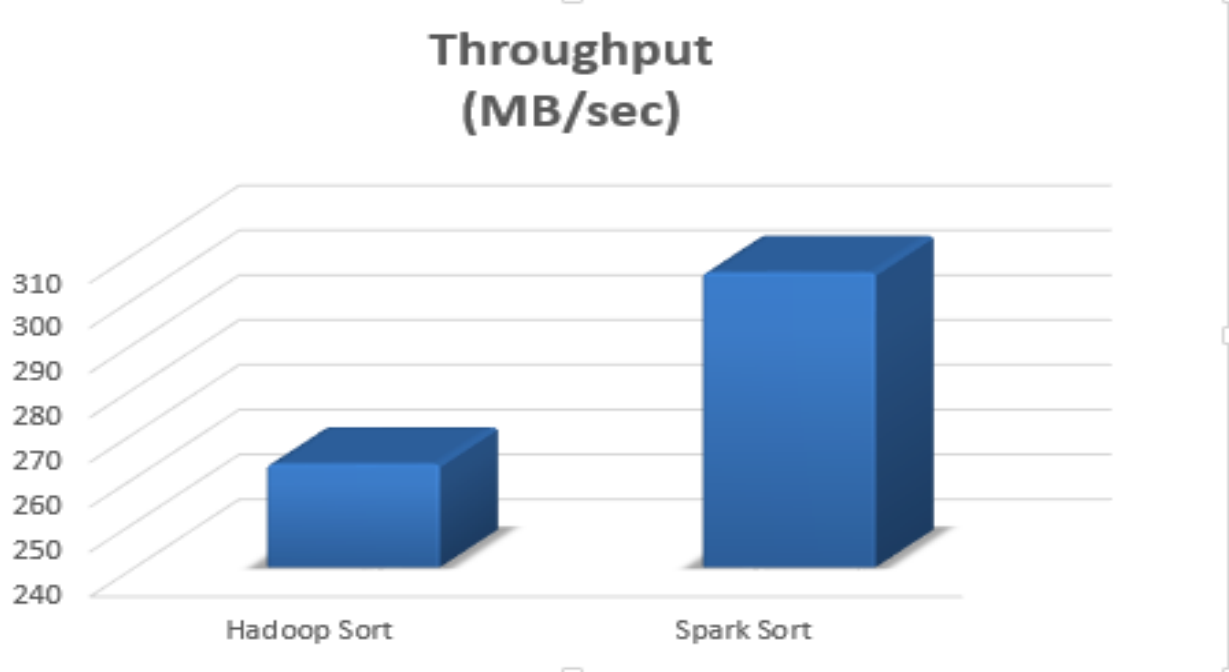
Compute time Comparison:

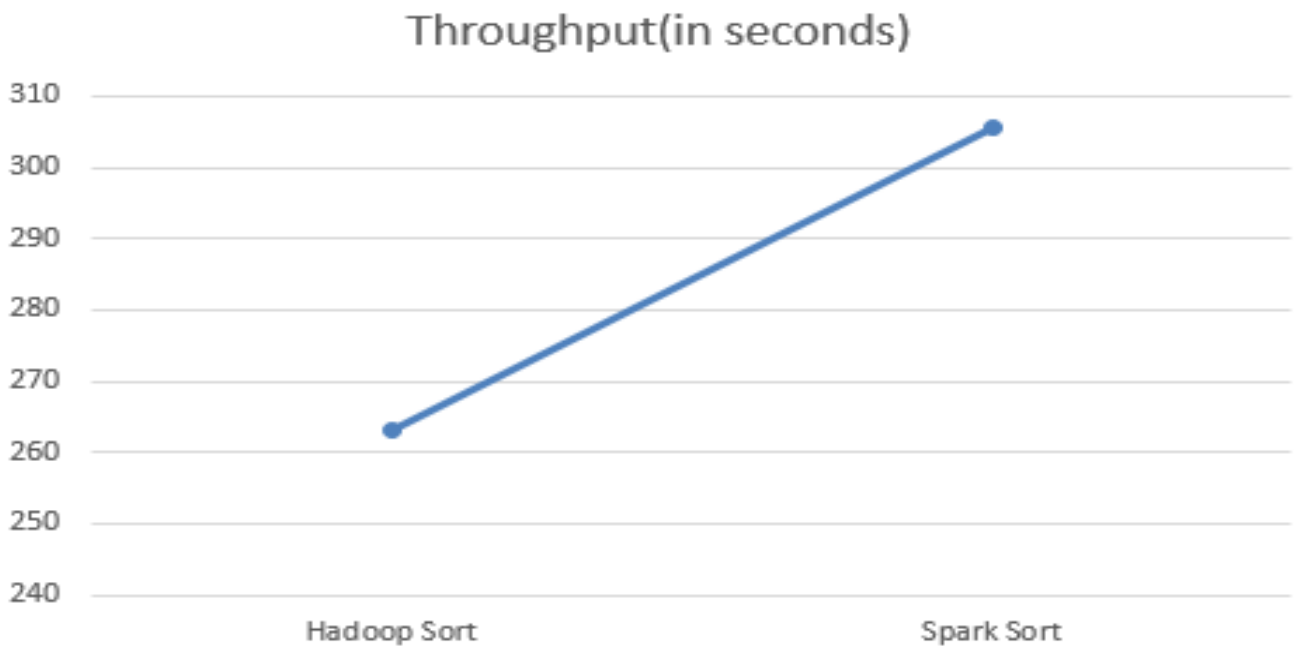




The compute time taken by Spark is considerably less than that taken by Hadoop.

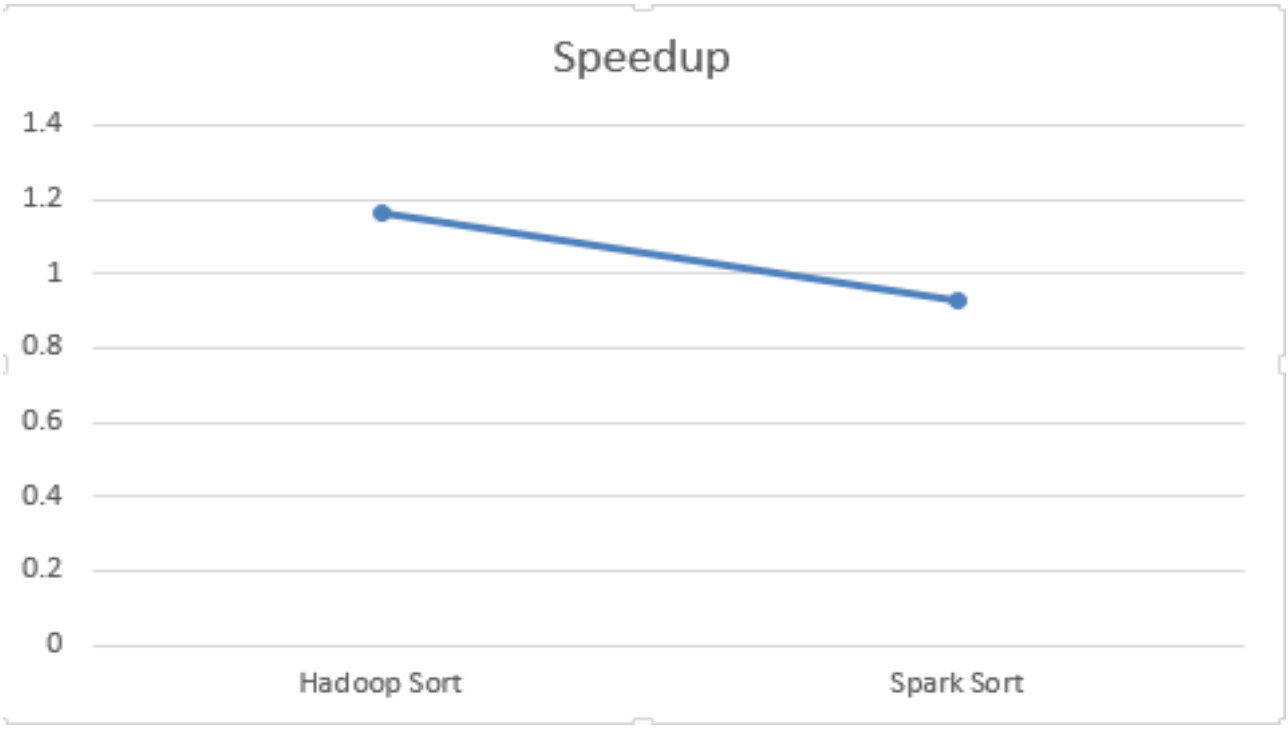
Throughput comparison:



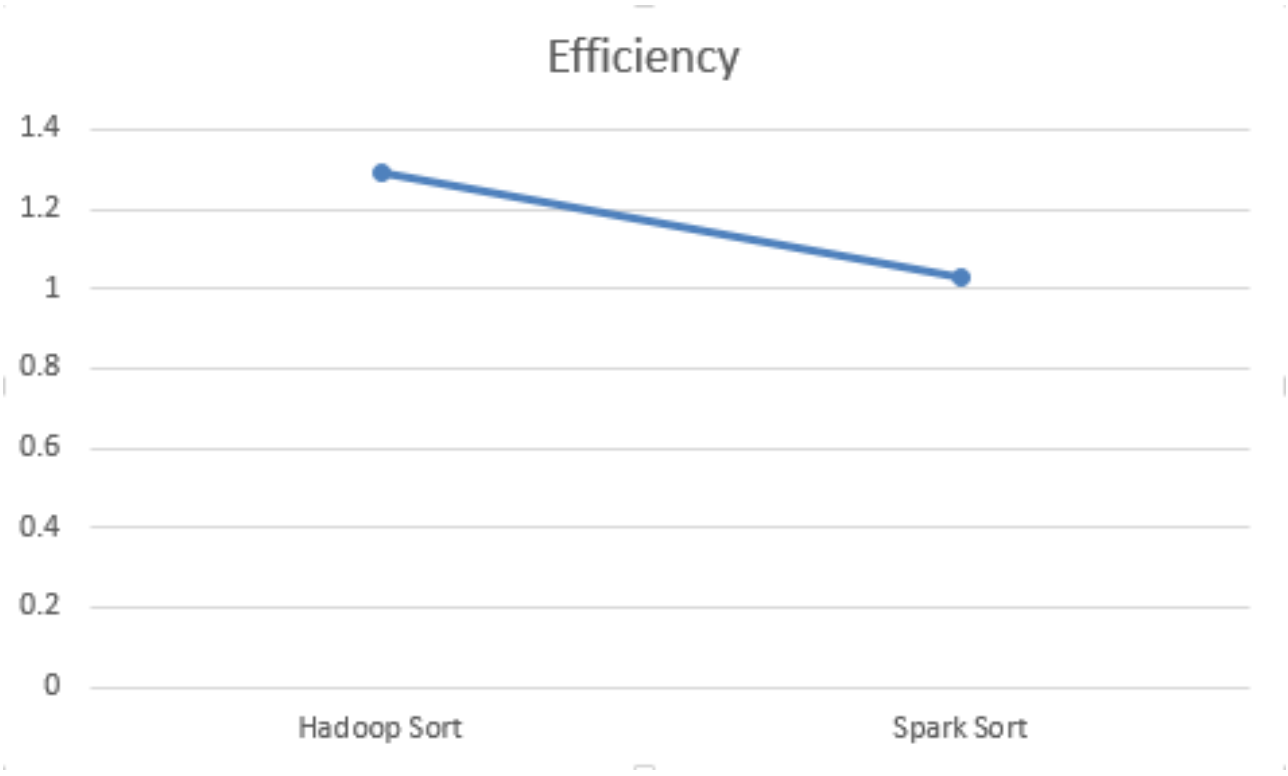


The Throughput of Spark is greater than Hadoop even in this type of setup.

Speedup for Hadoop and Spark:



Efficiency for Hadoop and Spark:



What conclusions can you draw?
The only conclusion that we can come to is that spark is the best sorting technique used in the whole assignment. And terasorting can be performed with all these sorting algorithms.

Which seems to be best at 1 node scale?
Performing sorting operations at 1 node is technically preferable with shared memory terasort, because with this method we are saved from setting up a cluster of nodes. Perform sorting of large datasets is quite difficult and time taking in a 1 node setup but it is the best option for relatively small datasets.

How about 8 nodes?
At 8 nodes we have a master and slave kind of distribution and Spark performs better than all other in this setup as it uses RDD (Resilient Distributed Datasets) and has better and updated architecture for data processing when compared to Hadoop. Spark can be as much as 10 times faster than MapReduce for batch processing and up to 100 times faster for in-memory analytics.

Can you predict which would be best at 100 node scale?
Spark is clearly the one to be most efficient to work with at 100 node scale or more. The reason for this is when compared with Hadoop MapReduce it operates in steps, the workflow for MapReduce is: "read data from cluster, perform an operation, write results to the cluster, read updated data from the cluster, perform next operation, write next result to cluster" and so on…… Spark on the other hand completes full data analytics operations in-memory and in near real-time: "Read data from the cluster, perform all of the requisite analytic operations, write results to the cluster, done".

How about 1000 node scales?
As I have stated earlier Spark will be the better option for this 1000 node setup because it is more efficient single step algorithm and its results gets better for bigger datasets with a large distribution of nodes. From our calculations also we can see that the performance of Spark keeps on improving as the number of nodes keeps on increasing.

Compare your results with those from the Sort Benchmark [9], specifically the winners in 2013 and 2014 who used Hadoop and Spark.
In 2013, according to Daytona GraySort, Hadoop was the winner with the sorting speed of 1.42 TB/min as it calculated 102.5 TB in 4,328 seconds with 2100 nodes of distributed systems.
In 2014, according to Daytona GraySort, Apache Spark was the winner with the sorting speed of 4.27 TB/min and it calculated 100 TB in 1,378 seconds with only 207 Amazon EC2 nodes.

Also, what can you learn from the CloudSort benchmark?
CloudSort benchmark is something that makes use of resources available at public cloud to perform sorting operations on the data. CloudSort proposes using the cloud to define a benchmark that measures the efficiency of external sort from a total-cost of ownership perspective. The CloudSort Benchmark is summarized as follows:
1. Sort a fixed number (currently 1012 , ~100TB) of randomly permuted 100-byte records with 10-byte keys
2. The sort must start with the input on a non-ephemeral, persistent store and finish with output on a nonephemeral, persistent store.
3. All operations must be performed on a commercially available public cloud.
4. The winner is the system with the minimum cost prorated for the duration of the sort.

In all CloudSort benchmark is one of the best public cloud benchmark system we have and it takes in consideration all the factors like cost and speed and efficiency for the calculation of benchmark.

Conclusion:

We have learned from this assignment that Spark performs better than Hadoop and Shared Memory. Spark performs better in the distributed environment and huge datasets because of the special features of the algorithm that it performs all the operations collectively and not in steps.

Ideally the shared memory should perform better on the single node irrespective of the size of the dataset. The shared memory proves to be true in the results from our programs.

We also learned the application of AWS and how to create the master and slave node in cluster for performing calculation of huge datasets.

Implementing MPI was tough and was taking us a lot of time to give output so couldn’t include it in the report.

Though Spark was the fastest to sort the data we can see that Hadoop can also perform well for bigger datasets in cluster computing.

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