MIDS W261: Machine Learning at Scale

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Week 2: Homework
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HW2.0.

What is a race condition in the context of parallel computation? Give an example. What is MapReduce? How does it differ from Hadoop? Which programming paradigm is Hadoop based on? Explain and give a simple example in code and show the code running.

- Race condition could manifest itself as a bug in a parallel program without synchronization. The final value of the operation depends on operation order. For instance, if both A and B were to perform an operation X = X + 1, on the same variable. Depending on which gets done first, the result could be X + 1 or X + 2.
- MapReduce is a parallel programming paradigm that enables distributed processing of data sets on commodity nodes. Hadoop is a set of open-source projects that facilitate parallel computing, including MapReduce, HDFS, Avro, Hive, and other utilities.
- Hadoop utilizes MapReduce for processing, which resembles functional programming closely. Functional programming treats computations as functions, and avoids saving states whenever possible. MapReduce closely approximates the map and reduce functions in that regime. Examine sample code below:

```python
# Mapper
input = [1,2,3,4,5]
# Compute x^2 using map
print "Sample mapper that computes x-square:"
print map(lambda x: x**2, input)

# Reducer
print "Sample reducer sums all elements:"
print reduce(lambda x,y: x+y, input)

# Note: both mapper and reducer take another function, and use that function to transform the input
```

```
Sample mapper that computes x-square:
[1, 4, 9, 16, 25]
Sample reducer sums all elements:
15
```

HW2.1. Sort in Hadoop MapReduce

Given as input: Records of the form `<integer, "NA">`, where integer is any integer, and "NA" is just the empty string. Output: sorted key value pairs of the form `<integer, "NA">` in decreasing order; what happens if you have multiple reducers? Do you need additional steps? Explain.

Write code to generate N random records of the form `<integer, "NA">`. Let N = 10,000. Write the python Hadoop streaming map-reduce job to perform this sort. Display the top 10 biggest numbers. Display the 10 smallest numbers

```
## Start HDFS and Yarn
!start-yarn.sh
!start-dfs.sh
```

```
starting yarn daemons
starting resourcemanager, logging to /Users/InfernoIX/hadoop-2.7.1/logs/yarn-InfernoIX-resourcemanager-Ko
localhost: starting nodemanager, logging to /Users/InfernoIX/hadoop-2.7.1/logs/yarn-InfernoIX-nodemanager
16/01/23 15:26:17 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
Starting namenodes on [localhost]
localhost: starting namenode, logging to /Users/InfernoIX/hadoop-2.7.1/logs/hadoop-InfernoIX-namenode-Kon
localhost: starting datanode, logging to /Users/InfernoIX/hadoop-2.7.1/logs/hadoop-InfernoIX-datanode-Kon
Starting secondary namenodes [0.0.0.0]
0.0.0.0: starting secondarynamenode, logging to /Users/InfernoIX/hadoop-2.7.1/logs/hadoop-InfernoIX-secon
16/01/23 15:26:37 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

```
# Import packages
from __future__ import division
import sys
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
%matplotlib inline
```

```
# Create input file
def hw_2_1():
    np.random.seed(0)
    # Pick 10,000 numbers from 100,000 and save to txt
    N = 10000
    # Save
    np.savetxt("hw_2_1.txt", np.random.randint(0, 100000, N), fmt='%i,')

hw_2_1()
```

```
!wc -l hw_2_1.txt
```

```
   10000 hw_2_1.txt
```

```
!head hw_2_1.txt
```

```
68268,
43567,
42613,
45891,
21243,
95939,
97639,
41993,
86293,
55026,
```

```
# Put on HDFS
!hdfs dfs -put hw_2_1.txt /user/konniam/week_02
```

```
16/01/23 01:10:36 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

```
%%writefile ~/mapper.py
#!/usr/bin/env python
# MapReduce Task to Sort Numbers
# The mapper will split the record of the form <integer, ""> into <integer \t>.
# This output will get sorted in reverse numerical order.
# The reducer doesn't need to do anything, so it could be an IdentityReducer
import sys
for line in sys.stdin:
    # Extract the number
    num = line.strip().split(',')[0]
    # Output the number
    print num
```

```
Overwriting /Users/InfernoIX/mapper.py
```

```
!chmod a+x ~/mapper.py
```

```
# Run MapReduce job
# The keycomparator options make the sorting come in descending order
# Use 1 reducer
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.output.key.comparator.class=org.apache.hadoop.mapreduce.lib.partition.KeyFieldBasedComp
-D mapreduce.partition.keycomparator.options=-k1,1nr \
-D mapreduce.job.reduces=1 \
-mapper ~/mapper.py \
-reducer org.apache.hadoop.mapred.lib.IdentityReducer \
-input /user/konniam/week_02/hw_2_1.txt \
-output /user/konniam/week_02/hw_2_1_output \
```

```
16/01/25 23:28:49 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
packageJobJar: [/var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/hadoop-unjar8474472715611845283/] [] /va
16/01/25 23:28:51 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 23:28:51 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 23:28:52 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/25 23:28:53 INFO mapreduce.JobSubmitter: number of splits:2
16/01/25 23:28:53 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453765434085_0010
16/01/25 23:28:53 INFO impl.YarnClientImpl: Submitted application application_1453765434085_0010
16/01/25 23:28:53 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/25 23:28:53 INFO mapreduce.Job: Running job: job_1453765434085_0010
16/01/25 23:29:04 INFO mapreduce.Job: Job job_1453765434085_0010 running in uber mode : false
16/01/25 23:29:04 INFO mapreduce.Job:  map 0% reduce 0%
16/01/25 23:29:17 INFO mapreduce.Job:  map 100% reduce 0%
16/01/25 23:29:24 INFO mapreduce.Job:  map 100% reduce 100%
16/01/25 23:29:24 INFO mapreduce.Job: Job job_1453765434085_0010 completed successfully
16/01/25 23:29:24 INFO mapreduce.Job: Counters: 49
    File System Counters
        FILE: Number of bytes read=88889
        FILE: Number of bytes written=529572
        FILE: Number of read operations=0
        FILE: Number of large read operations=0
        FILE: Number of write operations=0
        HDFS: Number of bytes read=62420
        HDFS: Number of bytes written=68883
        HDFS: Number of read operations=9
        HDFS: Number of large read operations=0
        HDFS: Number of write operations=2
    Job Counters
        Launched map tasks=2
        Launched reduce tasks=1
        Data-local map tasks=2
        Total time spent by all maps in occupied slots (ms)=22615
        Total time spent by all reduces in occupied slots (ms)=4512
        Total time spent by all map tasks (ms)=22615
        Total time spent by all reduce tasks (ms)=4512
        Total vcore-seconds taken by all map tasks=22615
        Total vcore-seconds taken by all reduce tasks=4512
        Total megabyte-seconds taken by all map tasks=23157760
        Total megabyte-seconds taken by all reduce tasks=4620288
    Map-Reduce Framework
        Map input records=10000
        Map output records=10000
        Map output bytes=68883
        Map output materialized bytes=88895
        Input split bytes=210
        Combine input records=0
        Combine output records=0
        Reduce input groups=9491
        Reduce shuffle bytes=88895
        Reduce input records=10000
        Reduce output records=10000
        Spilled Records=20000
        Shuffled Maps =2
        Failed Shuffles=0
        Merged Map outputs=2
        GC time elapsed (ms)=561
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=490209280
    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=62210
    File Output Format Counters
        Bytes Written=68883
16/01/25 23:29:24 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_1_output
```

```
# Display 10 biggest numbers
!hdfs dfs -cat /user/konniam/week_02/hw_2_1_output/* | head
```

```
16/01/25 23:29:33 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
99980
99975
99965
99963
99943
99938
99920
99914
99913
99892
cat: Unable to write to output stream.
```

```
# Display 10 smallest numbers
!hdfs dfs -cat /user/konniam/week_02/hw_2_1_output/* | tail
```

```
16/01/25 23:29:38 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
102
100
95
93
75
43
30
21
13
10
```

2.1 Response Here we used one reducer. If we were to use multiple reducers, each reducer will output its own file with sorted numbers. However, unless we sort all the numbers before we partition them for the reducers. We only get a few files with their own sorted list. We would have to sort all the files one more time.

HW2.2. WORDCOUNT

Using the Enron data from HW1 and Hadoop MapReduce streaming, write the mapper/reducer job that will determine the word count (number of occurrences) of each white-space delimitted token (assume spaces, fullstops, comma as delimiters). Examine the word "assistance" and report its word count results.

CROSSCHECK: >grep assistance enronemail_1h.txt|cut -d$‘’ -f4| grep assistance|wc -l
8
NOTE "assistance" occurs on 8 lines but how many times does the token occur? 10 times! This is the number we are looking for!

(Optional) Remove ^A and ^M characters using vi from the training data first.

```
%%writefile ~/mapper.py
#!/usr/bin/env python
## mapper.py
## Author: Konniam Chan
## Description: mapper code for HW2.2
import sys
import re
import string
from collections import Counter

# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')
# Counter dictionary
wordcounts = Counter()

# Process each document
for line in sys.stdin:
    # Lower case
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)
    # Sum words that go through each mapper
    wordcounts += Counter(words)

# Output
for word, count in wordcounts.items():
    print '%s\t%s' % (word, count)
```

```
Overwriting /Users/InfernoIX/mapper.py
```

```
%%writefile ~/reducer.py
#!/usr/bin/env python
## reducer.py
## Author: Konniam Chan
## Description: reducer code for HW2.2
import sys
current_word = None
current_count = 0
word = None

for line in sys.stdin:
    # Obtain word and intermediate counts
    line = line.strip()
    word, count = line.split('\t', 1)
    count = int(count)
    # Rely on sorting to increment word counts
    if current_word == word:
        current_count += count
    else:
        if current_word:
            print '%s\t%s' % (current_word, current_count)
        current_count = count
        current_word = word

# Output last word
if current_word == word:
    print '%s\t%s' % (current_word, current_count)
```

```
Overwriting /Users/InfernoIX/reducer.py
```

```
!chmod a+x ~/reducer.py
```

```
# Put enron emails onto HDFS
!hdfs dfs -put enronemail_1h.txt /user/konniam/week_02
```

```
16/01/24 11:57:21 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
```

```
# Run MapReduce job
# Specify 1 reducer in this case
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=1 \
-mapper ~/mapper.py \
-reducer ~/reducer.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_2_output \
```

```
16/01/24 11:58:04 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
packageJobJar: [/var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/hadoop-unjar2874213692464979909/] [] /va
16/01/24 11:58:06 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 11:58:06 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 11:58:07 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/24 11:58:07 INFO mapreduce.JobSubmitter: number of splits:2
16/01/24 11:58:07 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453657675452_0002
16/01/24 11:58:07 INFO impl.YarnClientImpl: Submitted application application_1453657675452_0002
16/01/24 11:58:07 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/24 11:58:07 INFO mapreduce.Job: Running job: job_1453657675452_0002
16/01/24 11:58:16 INFO mapreduce.Job: Job job_1453657675452_0002 running in uber mode : false
16/01/24 11:58:16 INFO mapreduce.Job:  map 0% reduce 0%
16/01/24 11:58:25 INFO mapreduce.Job:  map 100% reduce 0%
16/01/24 11:58:33 INFO mapreduce.Job:  map 100% reduce 100%
16/01/24 11:58:33 INFO mapreduce.Job: Job job_1453657675452_0002 completed successfully
16/01/24 11:58:33 INFO mapreduce.Job: Counters: 49
    File System Counters
        FILE: Number of bytes read=94462
        FILE: Number of bytes written=541093
        FILE: Number of read operations=0
        FILE: Number of large read operations=0
        FILE: Number of write operations=0
        HDFS: Number of bytes read=217192
        HDFS: Number of bytes written=64704
        HDFS: Number of read operations=9
        HDFS: Number of large read operations=0
        HDFS: Number of write operations=2
    Job Counters
        Launched map tasks=2
        Launched reduce tasks=1
        Data-local map tasks=2
        Total time spent by all maps in occupied slots (ms)=13746
        Total time spent by all reduces in occupied slots (ms)=4853
        Total time spent by all map tasks (ms)=13746
        Total time spent by all reduce tasks (ms)=4853
        Total vcore-seconds taken by all map tasks=13746
        Total vcore-seconds taken by all reduce tasks=4853
        Total megabyte-seconds taken by all map tasks=14075904
        Total megabyte-seconds taken by all reduce tasks=4969472
    Map-Reduce Framework
        Map input records=100
        Map output records=7926
        Map output bytes=78604
        Map output materialized bytes=94468
        Input split bytes=224
        Combine input records=0
        Combine output records=0
        Reduce input groups=6374
        Reduce shuffle bytes=94468
        Reduce input records=7926
        Reduce output records=6374
        Spilled Records=15852
        Shuffled Maps =2
        Failed Shuffles=0
        Merged Map outputs=2
        GC time elapsed (ms)=346
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=492830720
    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=216968
    File Output Format Counters
        Bytes Written=64704
16/01/24 11:58:33 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_2_output
```

```
# Check the word "assistance"
!hdfs dfs -cat /user/konniam/week_02/hw_2_2_output/* | grep assistance
```

```
16/01/24 12:01:46 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
assistance  10
```

HW2.2.1

Using Hadoop MapReduce and your wordcount job (from HW2.2) determine the top-10 occurring tokens (most frequent tokens)

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_2_output/* | sort -k2,2nr | head
```

```
16/01/24 12:00:31 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
the 1240
to  914
and 659
of  556
a   527
in  415
you 407
your    389
for 369
@   361
sort: write failed: standard output: Broken pipe
sort: write error
```

HW2.3. Multinomial NAIVE BAYES with NO Smoothing

Using the Enron data from HW1 and Hadoop MapReduce, write a mapper/reducer job(s) that will both learn Naive Bayes classifier and classify the Enron email messages using the learnt Naive Bayes classifier. Use all white-space delimitted tokens as independent input variables (assume spaces, fullstops, commas as delimiters). Note: for multinomial Naive Bayes, the Pr(X="assistance"|Y=SPAM) is calculated as follows:

the number of times "assistance" occurs in SPAM labeled documents / the number of words in documents labeled SPAM

E.g., "assistance" occurs 5 times in all of the documents Labeled SPAM, and the length in terms of the number of words in all documents labeled as SPAM (when concatenated) is 1,000. Then Pr(X="assistance"|Y=SPAM) = 5/1000. Note this is a multinomial estimation of the class conditional for a Naive Bayes Classifier. No smoothing is needed in this HW. Multiplying lots of probabilities, which are between 0 and 1, can result in floating-point underflow. Since log(xy) = log(x) + log(y), it is better to perform all computations by summing logs of probabilities rather than multiplying probabilities. Please pay attention to probabilites that are zero! They will need special attention. Count up how many times you need to process a zero probabilty for each class and report.

Report the performance of your learnt classifier in terms of misclassifcation error rate of your multinomial Naive Bayes Classifier. Plot a histogram of the log posterior probabilities (i.e., log(Pr(Class|Doc))) for each class over the training set. Summarize what you see.

Error Rate = misclassification rate with respect to a provided set (say training set in this case). It is more formally defined here:

Let DF represent the evalution set in the following: Err(Model, DF) = |{(X, c(X))   DF : c(X) != Model(x)}| / |DF|

Where || denotes set cardinality; c(X) denotes the class of the tuple X in DF; and Model(X) denotes the class inferred by the Model "Model"

2.3 Strategy Split this exercise into 2 sets of MR jobs.
Training Step
1 - Mapper: (Input docs) -> intermediate (word, spam/ham, count)
1 - Reducer: intermediate (word, spam/ham, count) -> final (word, spam/ham, count)
Classification Step
2 - Mapper: (Input docs) -> predicted labels
2 - Reducer: None
(pass in word counts from training step to do classification)

We will use this same strategy for all MapReduce NB jobs here in this HW.

2.3 Training

```
%%writefile ~/mapper.py
#!/usr/bin/env python
## mapper.py
## Author: Konniam Chan
## Description: mapper code for HW2.3
import sys
import re
import string
from collections import Counter
# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Dictionary to keep track of terms
wordcounts = {"spam": Counter(), "ham": Counter()}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Process each document
for line in sys.stdin:
    # Lower case
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)
    # Sum words that go through each mapper
    label = label_map[label]
    wordcounts[label] += Counter(words)
    # Increment number of documents
    wordcounts[label]["*numdocs"] += 1
# Output each word
```

```
for label in wordcounts:
    for word in wordcounts[label]:
        print '%s\t%s\t%s' % (word, label, wordcounts[label][word])
```

```
Overwriting /Users/InfernoIX/mapper.py
```

```
%%writefile ~/reducer.py
#!/usr/bin/env python
## reducer.py
## Author: Konniam Chan
## Description: reducer code for HW2.3
import sys
from collections import Counter

# Dictionary to keep track of terms
wordcounts = {"spam": Counter(), "ham": Counter()}
# Process each tuple in the form of (word, spam/ham, count) separated by \t
for line in sys.stdin:
    word, label, count = line.strip().split("\t")
    wordcounts[label][word] += int(count)

# Output each word
for label in wordcounts:
    for word in wordcounts[label]:
        print '%s\t%s\t%s' % (word, label, wordcounts[label][word])
```

```
Overwriting /Users/InfernoIX/reducer.py
```

```
# Run MapReduce job
# Specify 1 reducer
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=1 \
-mapper ~/mapper.py \
-reducer ~/reducer.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_3_output
```

```
16/01/24 12:07:02 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
packageJobJar: [/var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/hadoop-unjar8048476221407268102/] [] /va
16/01/24 12:07:03 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 12:07:04 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 12:07:05 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/24 12:07:05 INFO mapreduce.JobSubmitter: number of splits:2
16/01/24 12:07:05 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453657675452_0004
16/01/24 12:07:05 INFO impl.YarnClientImpl: Submitted application application_1453657675452_0004
16/01/24 12:07:05 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/24 12:07:05 INFO mapreduce.Job: Running job: job_1453657675452_0004
16/01/24 12:07:13 INFO mapreduce.Job: Job job_1453657675452_0004 running in uber mode : false
16/01/24 12:07:13 INFO mapreduce.Job:  map 0% reduce 0%
16/01/24 12:07:23 INFO mapreduce.Job:  map 100% reduce 0%
16/01/24 12:07:30 INFO mapreduce.Job:  map 100% reduce 100%
16/01/24 12:07:31 INFO mapreduce.Job: Job job_1453657675452_0004 completed successfully
16/01/24 12:07:31 INFO mapreduce.Job: Counters: 49
```

```
File System Counters
    FILE: Number of bytes read=147362
    FILE: Number of bytes written=646893
    FILE: Number of read operations=0
    FILE: Number of large read operations=0
    FILE: Number of write operations=0
    HDFS: Number of bytes read=217192
    HDFS: Number of bytes written=107220
    HDFS: Number of read operations=9
    HDFS: Number of large read operations=0
    HDFS: Number of write operations=2
Job Counters
    Launched map tasks=2
    Launched reduce tasks=1
    Data-local map tasks=2
    Total time spent by all maps in occupied slots (ms)=14192
    Total time spent by all reduces in occupied slots (ms)=4674
    Total time spent by all map tasks (ms)=14192
    Total time spent by all reduce tasks (ms)=4674
    Total vcore-seconds taken by all map tasks=14192
    Total vcore-seconds taken by all reduce tasks=4674
    Total megabyte-seconds taken by all map tasks=14532608
    Total megabyte-seconds taken by all reduce tasks=4786176
Map-Reduce Framework
    Map input records=100
    Map output records=9056
    Map output bytes=129244
    Map output materialized bytes=147368
    Input split bytes=224
    Combine input records=0
    Combine output records=0
    Reduce input groups=6375
    Reduce shuffle bytes=147368
    Reduce input records=9056
    Reduce output records=7390
    Spilled Records=18112
    Shuffled Maps =2
    Failed Shuffles=0
    Merged Map outputs=2
    GC time elapsed (ms)=271
    CPU time spent (ms)=0
    Physical memory (bytes) snapshot=0
    Virtual memory (bytes) snapshot=0
    Total committed heap usage (bytes)=502792192
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=216968
File Output Format Counters
```

```
        Bytes Written=107220
16/01/24 12:07:31 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_3_output
```

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_3_output/part* | sort -k1,1 | head
```

```
16/01/24 15:43:47 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
!!  spam    1
""  ham 83
""  spam    174
""'bcli ham 1
""'benewm   ham 1
""'bjeffrie ham 1
""'blong    ham 1
""'bredd    ham 1
""'celias   ham 1
""'cenochs  ham 1
sort: write failed: standard output: Broken pipe
sort: write error
```

2.3 Classification The above MR job trained the model by obtaining the counts of all terms in either spam or ham.
We can now pass the result file from above when we want to classify our training data.

```
%%writefile ~/mapper_classify.py
#!/usr/bin/env python
## mapper_classify.py
## Author: Konniam Chan
## Description: classification mapper code for HW2.3
from __future__ import division
import sys
import re
import string
import math

# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Load trained Naive Bayes model in memory
wordcounts = {"spam": {}, "ham": {}}
with open("wordcounts_2_3.txt", "r") as f:
    for line in f:
        word, label, count = line.strip().split("\t")
        wordcounts[label][word] = int(count)
# Calculate total number of terms
terms_spam = sum(wordcounts['spam'].values())
terms_ham = sum(wordcounts['ham'].values())
# Calculate priors
prior_spam = wordcounts['spam']['*numdocs'] / (wordcounts['spam']['*numdocs'] + wordcounts['ham']['*num
prior_ham = 1 - prior_spam
```

```
# Process each document
for line in sys.stdin:
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)

    # Initialize probabilities with priors
    log_probs = {"spam": math.log(prior_spam), "ham": math.log(prior_ham)}
    # Keep track of number of zero probabilities for each doc
    zero_spam, zero_ham = 0, 0
    # Iterate through each word and add probabilities
    for word in words:
        # If word frequency is zero, record it, then skip the term
        if word not in wordcounts['spam'] or word not in wordcounts['ham']:
            if word not in wordcounts['spam']:
                zero_spam += 1
            else:
                zero_ham += 1
            # Skip this term in calculation of probabilities
            continue
        else:
            # Usual definition of NB probabilities
            log_probs["spam"] += math.log(wordcounts['spam'][word] / terms_spam)
            log_probs["ham"] += math.log(wordcounts['ham'][word] / terms_ham)

    # Classify
    predicted_label = "1" if log_probs["spam"] > log_probs["ham"] else "0"
    # Normalize probabilities for output, prevent overflow
    if log_probs["ham"] - log_probs["spam"] > 700:
            probs_spam = 0
    else:
        probs_spam = 1 / (1 + math.exp(log_probs["ham"] - log_probs["spam"]))
    probs_ham = 1 - probs_spam

    # Output (DocID, label, predicted label, p_spam, p_ham, zero_spam, zero_ham)
    print '\t'.join([doc_id, label, predicted_label,
                     str(probs_spam), str(probs_ham),
                     str(zero_spam), str(zero_ham)])
```

```
Overwriting /Users/InfernoIX/mapper_classify.py
```

```
!chmod a+x ~/mapper_classify.py
```

```
# Transfer results from 1st MR job to a local directory
!hdfs dfs -get "/user/konniam/week_02/hw_2_3_output/part-00000" ~/wordcounts_2_3.txt
```

```
16/01/24 13:53:07 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
16/01/24 13:53:08 WARN hdfs.DFSClient: DFSInputStream has been closed already
```

```
# Run MapReduce job
# Map-only job. Pass in text file with wordcounts
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=0 \
-mapper ~/mapper_classify.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_3_output_classify \
-file ~/wordcounts_2_3.txt
```

```
16/01/24 15:04:59 WARN streaming.StreamJob: -file option is deprecated, please use generic option -files ins
16/01/24 15:04:59 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
packageJobJar: [/Users/InfernoIX/wordcounts_2_3.txt, /var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/ha
16/01/24 15:05:01 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 15:05:01 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 15:05:02 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/24 15:05:03 INFO mapreduce.JobSubmitter: number of splits:2
16/01/24 15:05:03 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453657675452_0008
16/01/24 15:05:03 INFO impl.YarnClientImpl: Submitted application application_1453657675452_0008
16/01/24 15:05:03 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/24 15:05:03 INFO mapreduce.Job: Running job: job_1453657675452_0008
16/01/24 15:05:14 INFO mapreduce.Job: Job job_1453657675452_0008 running in uber mode : false
16/01/24 15:05:14 INFO mapreduce.Job:  map 0% reduce 0%
16/01/24 15:05:24 INFO mapreduce.Job:  map 100% reduce 0%
16/01/24 15:05:25 INFO mapreduce.Job: Job job_1453657675452_0008 completed successfully
16/01/24 15:05:25 INFO mapreduce.Job: Counters: 30
	File System Counters
		FILE: Number of bytes read=0
		FILE: Number of bytes written=236380
		FILE: Number of read operations=0
		FILE: Number of large read operations=0
		FILE: Number of write operations=0
		HDFS: Number of bytes read=217192
		HDFS: Number of bytes written=5600
		HDFS: Number of read operations=10
		HDFS: Number of large read operations=0
		HDFS: Number of write operations=4
	Job Counters
		Launched map tasks=2
		Data-local map tasks=2
		Total time spent by all maps in occupied slots (ms)=17437
		Total time spent by all reduces in occupied slots (ms)=0
		Total time spent by all map tasks (ms)=17437
		Total vcore-seconds taken by all map tasks=17437
		Total megabyte-seconds taken by all map tasks=17855488
	Map-Reduce Framework
		Map input records=100
		Map output records=100
```

```
        Input split bytes=224
        Spilled Records=0
        Failed Shuffles=0
        Merged Map outputs=0
        GC time elapsed (ms)=258
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=186646528
    File Input Format Counters
        Bytes Read=216968
    File Output Format Counters
        Bytes Written=5600
16/01/24 15:05:25 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_3_output_classif
```

```
# Examine output (format: DocID, label, predicted_label, zero_spam, zero_ham)
!hdfs dfs -cat /user/konniam/week_02/hw_2_3_output_classify/part* | head
```

```
16/01/24 15:14:52 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
0011.2003-12-18.gp  1   1   0.999999989025  1.09750638577e-08   0   37
0011.2004-08-01.bg  1   1   0.999999956896  4.3104383729e-08    0   37
0012.1999-12-14.farmer  0   0   1.51562851903e-45   1.0 142 0
0012.1999-12-14.kaminski    0   0   3.07583767617e-35   1.0 62  0
0012.2000-01-17.beck    0   0   4.96321540941e-110  1.0 156 0
0012.2000-06-08.lokay   0   1   0.999999997354  2.64601918154e-09   31  0
0012.2001-02-09.kitchen 0   0   7.99826839655e-06   0.999992001732  20  0
0012.2003-12-19.gp  1   1   0.996915425172  0.00308457482785    0   9
0013.1999-12-14.farmer  0   0   3.9936291718e-25    1.0 69  0
0013.1999-12-14.kaminski    0   0   3.51968974018e-38   1.0 67  0
cat: Unable to write to output stream.
```

2.3 Error Assessment

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_3_output_classify/part* > hw_2_3_results.txt
```

```
16/01/24 15:12:48 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

```
def hw_2_3_error():
    # Parse results
    columns = ['docid', 'label', 'preds', 'probs_spam', 'probs_ham', 'zero_spam', 'zero_ham']
    df = pd.read_table("hw_2_3_results.txt", header=None, names=columns)
    # Print total number of zero probabilities for each class
    print "Number of words that hit zero probability for class spam: {}.".format(
        sum(df['zero_spam']))
    print "Number of words that hit zero probability for class ham: {}.".format(
        sum(df['zero_ham']))
    # Calculate error rate and output
    print "The training error is {}.".format(np.mean(df['label'] != df['preds']))
    # Plot histograms
    plt.figure(figsize=(12,12))
    plt.subplot(211)
    sns.distplot(df['probs_spam'], bins = 20, kde=None)
    plt.subplot(212)
    sns.distplot(df['probs_ham'], bins = 20, kde=None)

hw_2_3_error()
```

```
Number of words that hit zero probability for class spam: 4932.
Number of words that hit zero probability for class ham: 6447.
The training error is 0.11.
```

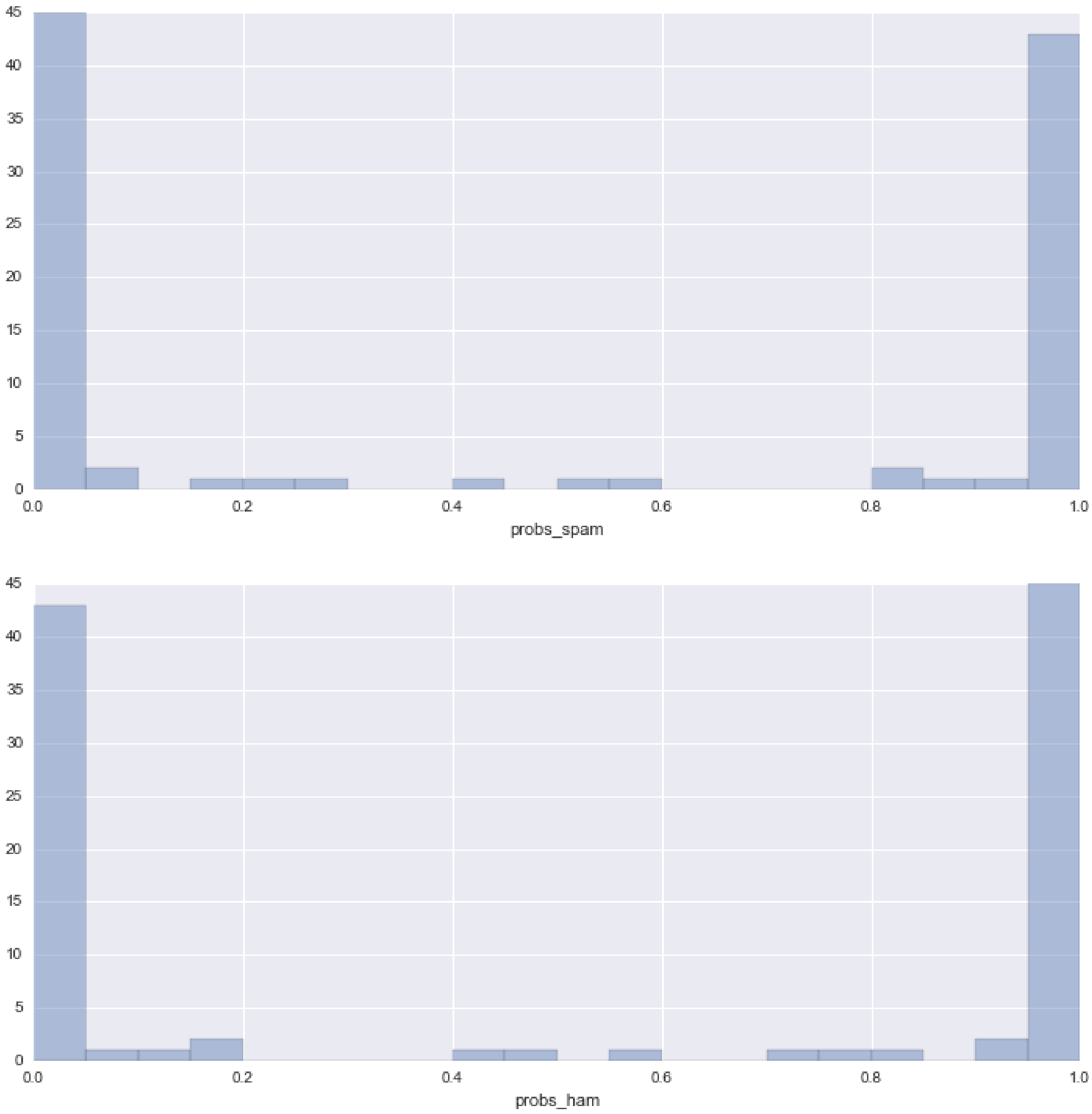


Figure 1: png

2.3 Response The error (without smoothing) is 11%, which is pretty bad considering we have over 7000 parameters for 100 data points. 4932 and 6447 terms hit zero probabilities for either spam or ham, and are skipped in the NB calculation both both classes.

The plots of the probabilities show a very bimodal distribution, with significant density near 0 or 1, showing that NB is usually very confident in its predictions.

HW2.4

Repeat HW2.3 with the following modification: use Laplace plus-one smoothing. Compare the misclassifcation error rates for 2.3 versus 2.4 and explain the differences.

For a quick reference on the construction of the Multinomial NAIVE BAYES classifier that you will code, please consult the "Document Classification" section of the following wikipedia page:

https://en.wikipedia.org/wiki/Naive_Bayes_classifier#Document_classification

OR the original paper by the curators of the Enron email data:

http://www.aueb.gr/users/ion/docs/ceas2006_paper.pdf

2.4 Strategy The classifier with Laplace smoothing can use the wordcounts created in the 1st MR job from 2.3. All we have to do is to modify how we calculate how probabilities.

2.4 Classification

```
%%writefile ~/mapper_classify.py
#!/usr/bin/env python
## mapper_classify.py
## Author: Konniam Chan
## Description: classification (with Laplace smoothing) mapper code for HW2.4
from __future__ import division
import sys
import re
import string
import math
from collections import defaultdict

# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Load wordcounts from 2.3 in memory
wordcounts = {"spam": defaultdict(int), "ham": defaultdict(int)}
with open("wordcounts_2_3.txt", "r") as f:
    for line in f:
        word, label, count = line.strip().split("\t")
        wordcounts[label][word] = int(count)
# Calculate total number of terms
terms_spam = sum(wordcounts['spam'].values())
terms_ham = sum(wordcounts['ham'].values())
# Calculate priors and size of vocab
```

```
prior_spam = wordcounts['spam']['*numdocs'] / (wordcounts['spam']['*numdocs'] + wordcounts['ham']['*numd
prior_ham = 1 - prior_spam
vocab_size = len(set(wordcounts['spam']).union(set(wordcounts['ham'])))

# Process each document
for line in sys.stdin:
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)

    # Initialize probabilities with priors
    log_probs = {"spam": math.log(prior_spam), "ham": math.log(prior_ham)}
    # Iterate through each word and add probabilities
    for word in words:
        # Laplace smoothing
        log_probs["spam"] += math.log((wordcounts['spam'][word] + 1) /
                                      (terms_spam + vocab_size))
        log_probs["ham"] += math.log((wordcounts['ham'][word] + 1) /
                                     (terms_ham + vocab_size))

    # Classify
    predicted_label = "1" if log_probs["spam"] > log_probs["ham"] else "0"
    # Normalize probabilities for output, prevent overflow
    if log_probs["ham"] - log_probs["spam"] > 700:
            probs_spam = 0
    else:
        probs_spam = 1 / (1 + math.exp(log_probs["ham"] - log_probs["spam"]))
    probs_ham = 1 - probs_spam

    # Output (DocID, label, predicted label, p_spam, p_ham)
    print '\t'.join([doc_id, label, predicted_label,
                     str(probs_spam), str(probs_ham)])
```

```
Overwriting /Users/InfernoIX/mapper_classify.py
```

```
# Run MapReduce job
# Map-only job. Pass in text file with wordcounts
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=0 \
-mapper ~/mapper_classify.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_4_output_classify \
-file ~/wordcounts_2_3.txt
```

```
16/01/24 16:42:15 WARN streaming.StreamJob: -file option is deprecated, please use generic option -files ins
16/01/24 16:42:15 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
packageJobJar: [/Users/InfernoIX/wordcounts_2_3.txt, /var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/ha
16/01/24 16:42:17 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 16:42:17 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 16:42:18 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/24 16:42:18 INFO mapreduce.JobSubmitter: number of splits:2
16/01/24 16:42:18 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453657675452_0010
16/01/24 16:42:19 INFO impl.YarnClientImpl: Submitted application application_1453657675452_0010
16/01/24 16:42:19 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/24 16:42:19 INFO mapreduce.Job: Running job: job_1453657675452_0010
16/01/24 16:42:27 INFO mapreduce.Job: Job job_1453657675452_0010 running in uber mode : false
16/01/24 16:42:27 INFO mapreduce.Job:  map 0% reduce 0%
16/01/24 16:42:37 INFO mapreduce.Job:  map 100% reduce 0%
16/01/24 16:42:38 INFO mapreduce.Job: Job job_1453657675452_0010 completed successfully
16/01/24 16:42:38 INFO mapreduce.Job: Counters: 30
	File System Counters
		FILE: Number of bytes read=0
		FILE: Number of bytes written=236380
		FILE: Number of read operations=0
		FILE: Number of large read operations=0
		FILE: Number of write operations=0
		HDFS: Number of bytes read=217192
		HDFS: Number of bytes written=4474
		HDFS: Number of read operations=10
		HDFS: Number of large read operations=0
		HDFS: Number of write operations=4
	Job Counters
		Launched map tasks=2
		Data-local map tasks=2
		Total time spent by all maps in occupied slots (ms)=16122
		Total time spent by all reduces in occupied slots (ms)=0
		Total time spent by all map tasks (ms)=16122
		Total vcore-seconds taken by all map tasks=16122
		Total megabyte-seconds taken by all map tasks=16508928
	Map-Reduce Framework
		Map input records=100
		Map output records=100
		Input split bytes=224
		Spilled Records=0
		Failed Shuffles=0
		Merged Map outputs=0
		GC time elapsed (ms)=324
		CPU time spent (ms)=0
		Physical memory (bytes) snapshot=0
		Virtual memory (bytes) snapshot=0
		Total committed heap usage (bytes)=187170816
	File Input Format Counters
		Bytes Read=216968
	File Output Format Counters
		Bytes Written=4474
16/01/24 16:42:38 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_4_output_classify
```

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_4_output_classify/part* | head
```

```
16/01/24 16:42:44 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
0011.2003-12-18.gp  1   1   1.0 0.0
0011.2004-08-01.bg  1   1   1.0 0.0
0012.1999-12-14.farmer  0   0   3.04906108027e-156  1.0
0012.1999-12-14.kaminski    0   0   2.5675875679e-107   1.0
0012.2000-01-17.beck    0   0   8.15760689166e-266  1.0
0012.2000-06-08.lokay   0   0   4.71892179913e-09   0.999999995281
0012.2001-02-09.kitchen 0   0   2.59286926427e-14   1.0
0012.2003-12-19.gp  1   1   0.99999901192   9.88080343989e-07
0013.1999-12-14.farmer  0   0   1.94778405505e-69   1.0
0013.1999-12-14.kaminski    0   0   3.59263723869e-120  1.0
cat: Unable to write to output stream.
```

```
# Copy file back to local directory
!hdfs dfs -cat /user/konniam/week_02/hw_2_4_output_classify/part* > hw_2_4_results.txt
```

```
16/01/24 16:42:53 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

2.4 Error Assessment

```
def hw_2_4_error():
    # Parse results
    columns = ['docid', 'label', 'preds', 'probs_spam', 'probs_ham']
    df = pd.read_table("hw_2_4_results.txt", header=None, names=columns)
    # Calculate error rate and output
    print "The training error is {}.".format(np.mean(df['label'] != df['preds']))
    # Plot histograms
    plt.figure(figsize=(12,12))
    plt.subplot(211)
    sns.distplot(df['probs_spam'], bins = 20, kde=None)
    plt.subplot(212)
    sns.distplot(df['probs_ham'], bins = 20, kde=None)

hw_2_4_error()
```

```
The training error is 0.0.
```

2.4 Response With Laplace smoothing, the model produced a training error of 0%, a drop from the previous erorr of 11%. In the case without smoothing, we skipped over many terms that don't have conditional probabilities in one class. However, such terms are valuable precisely because of this. For instance, "lottery" might have appeared 20 times in spam but not ham. Thus, "lottery" is a great predictor of the class. Laplace smoothing allows such terms to be included and we expected the in-sample error rate to improve.

Nonetheless, we should not get too excited about 0% error because we have over 7000 parameters and only 100 examples. There likely is a substantial amount of overfitting and we don't expect the out-of-sample performance to be great.

HW2.5.

Repeat HW2.4. This time when modeling and classification ignore tokens with a frequency of less than three (3) in the training set. How does it affect the misclassifcation error of learnt naive multinomial Bayesian Classifier on the training dataset:

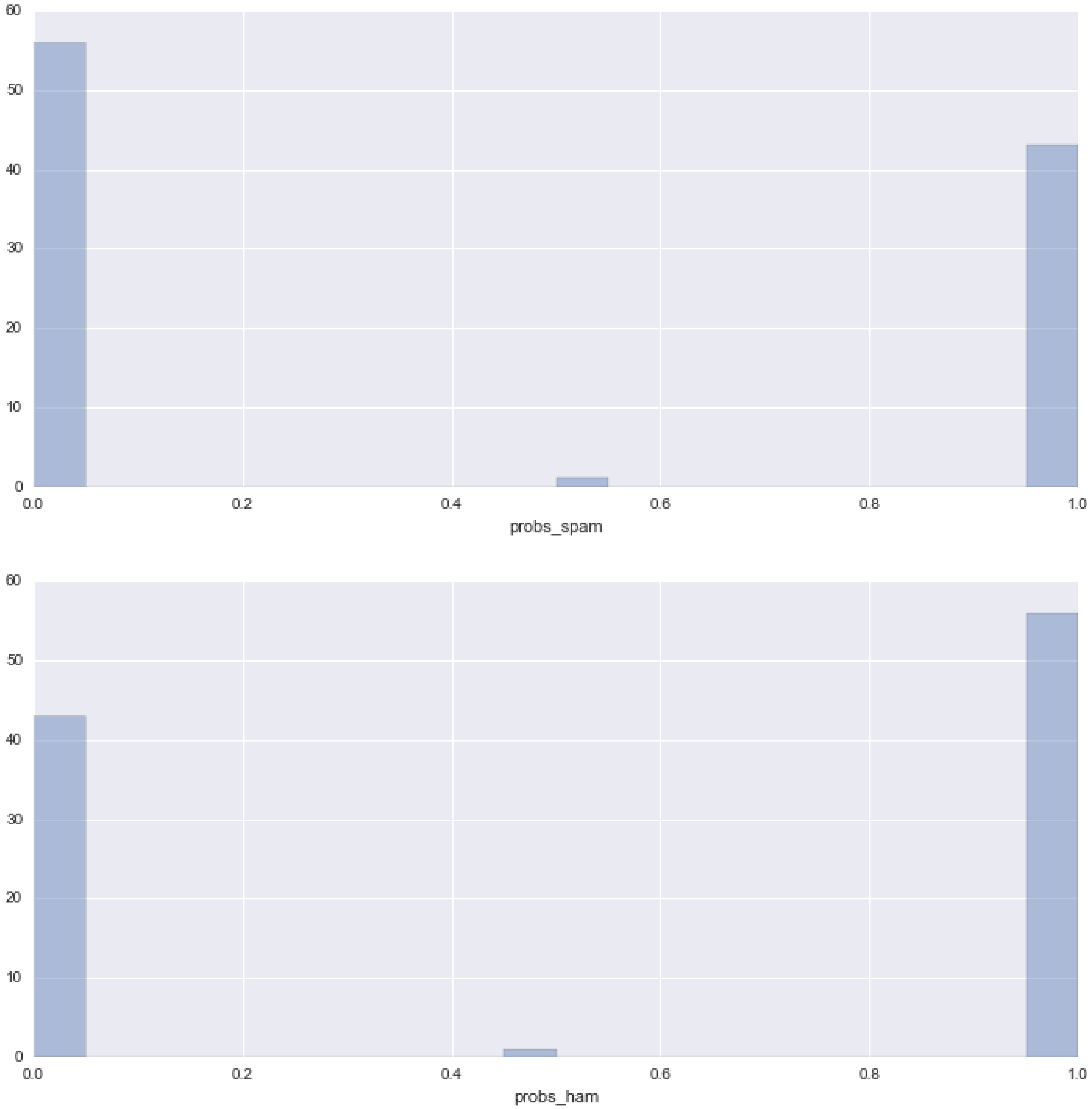

60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_spam
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_ham

Figure 2: png

2.5 Strategy Like HW2.4, we can use the wordcount data from the 1st MR job from 2.3. We first change the vocab dictionary in our classifier mapper. Then we'll have to skip these terms in the prediction step.

```
%%writefile ~/mapper_classify.py
#!/usr/bin/env python
## mapper_classify.py
## Author: Konniam Chan
## Description: classification (with Laplace smoothing, ignore infrequent terms)
## mapper code for HW2.5
from __future__ import division
import sys
import re
import string
import math
from collections import defaultdict

# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Load wordcounts from 2.3 in memory
wordcounts = {"spam": defaultdict(int), "ham": defaultdict(int)}
with open("wordcounts_2_3.txt", "r") as f:
    for line in f:
        word, label, count = line.strip().split("\t")
        wordcounts[label][word] = int(count)
# Drop terms with total frequencies less than 3
vocab_set = set(wordcounts['spam']).union(set(wordcounts['ham']))
for word in vocab_set:
    if (wordcounts['spam'][word] + wordcounts['ham'][word]) < 3:
        del wordcounts['spam'][word]
        del wordcounts['ham'][word]
# Update vocabulary after deletion
vocab_set = set(wordcounts['spam']).union(set(wordcounts['ham']))
vocab_size = len(vocab_set)

# Calculate total number of terms
terms_spam = sum(wordcounts['spam'].values())
terms_ham = sum(wordcounts['ham'].values())
# Calculate priors and size of vocab
prior_spam = wordcounts['spam']['*numdocs'] / (wordcounts['spam']['*numdocs'] + wordcounts['ham']['*num
prior_ham = 1 - prior_spam


# Process each document
for line in sys.stdin:
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)

    # Initialize probabilities with priors
    log_probs = {"spam": math.log(prior_spam), "ham": math.log(prior_ham)}
    # Iterate through each word and add probabilities
    for word in words:
        # Skip words that aren't in the vocab (frequencies < 3)
        if word not in wordcounts['spam'] and word not in wordcounts['ham']:
            continue
        # Laplace smoothing
        log_probs["spam"] += math.log((wordcounts['spam'][word] + 1) /
                                      (terms_spam + vocab_size))
        log_probs["ham"] += math.log((wordcounts['ham'][word] + 1) /
                                     (terms_ham + vocab_size))

    # Classify
    predicted_label = "1" if log_probs["spam"] > log_probs["ham"] else "0"
    # Normalize probabilities for output, prevent overflow
    if log_probs["ham"] - log_probs["spam"] > 700:
            probs_spam = 0
    else:
        probs_spam = 1 / (1 + math.exp(log_probs["ham"] - log_probs["spam"]))
    probs_ham = 1 - probs_spam

    # Output (DocID, label, predicted label, p_spam, p_ham)
    print '\t'.join([doc_id, label, predicted_label,
                     str(probs_spam), str(probs_ham)])
```

```
Overwriting /Users/InfernoIX/mapper_classify.py
```

```
# Run MapReduce job
# Map-only job. Pass in text file with wordcounts
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=0 \
-mapper ~/mapper_classify.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_5_output_classify \
-file ~/wordcounts_2_3.txt
```

```
16/01/24 17:55:22 WARN streaming.StreamJob: -file option is deprecated, please use generic option -files ins
16/01/24 17:55:23 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
packageJobJar: [/Users/InfernoIX/wordcounts_2_3.txt, /var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/ha
16/01/24 17:55:24 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 17:55:25 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/24 17:55:26 INFO mapred.FileInputFormat: Total input paths to process : 1
```

```
16/01/24 17:55:26 INFO mapreduce.JobSubmitter: number of splits:2
16/01/24 17:55:26 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453657675452_0012
16/01/24 17:55:27 INFO impl.YarnClientImpl: Submitted application application_1453657675452_0012
16/01/24 17:55:27 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/24 17:55:27 INFO mapreduce.Job: Running job: job_1453657675452_0012
16/01/24 17:55:36 INFO mapreduce.Job: Job job_1453657675452_0012 running in uber mode : false
16/01/24 17:55:36 INFO mapreduce.Job:  map 0% reduce 0%
16/01/24 17:55:46 INFO mapreduce.Job:  map 100% reduce 0%
16/01/24 17:55:47 INFO mapreduce.Job: Job job_1453657675452_0012 completed successfully
16/01/24 17:55:47 INFO mapreduce.Job: Counters: 30
    File System Counters
        FILE: Number of bytes read=0
        FILE: Number of bytes written=236380
        FILE: Number of read operations=0
        FILE: Number of large read operations=0
        FILE: Number of write operations=0
        HDFS: Number of bytes read=217192
        HDFS: Number of bytes written=4739
        HDFS: Number of read operations=10
        HDFS: Number of large read operations=0
        HDFS: Number of write operations=4
    Job Counters
        Launched map tasks=2
        Data-local map tasks=2
        Total time spent by all maps in occupied slots (ms)=15923
        Total time spent by all reduces in occupied slots (ms)=0
        Total time spent by all map tasks (ms)=15923
        Total vcore-seconds taken by all map tasks=15923
        Total megabyte-seconds taken by all map tasks=16305152
    Map-Reduce Framework
        Map input records=100
        Map output records=100
        Input split bytes=224
        Spilled Records=0
        Failed Shuffles=0
        Merged Map outputs=0
        GC time elapsed (ms)=321
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=187695104
    File Input Format Counters
        Bytes Read=216968
    File Output Format Counters
        Bytes Written=4739
16/01/24 17:55:47 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_5_output_classif
```

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_5_output_classify/part* | head
```

```
16/01/24 17:56:09 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
0011.2003-12-18.gp  1   1   1.0 0.0
0011.2004-08-01.bg  1   1   1.0 5.10702591328e-15
0012.1999-12-14.farmer  0   0   6.56589297435e-128  1.0
0012.1999-12-14.kaminski    0   0   1.43801209308e-101  1.0
```

```
0012.2000-01-17.beck    0   0   6.30592690511e-270  1.0
0012.2000-06-08.lokay   0   1   0.827662523121  0.172337476879
0012.2001-02-09.kitchen 0   0   1.40530534624e-08   0.999999985947
0012.2003-12-19.gp  1   1   0.999972184144  2.78158562613e-05
0013.1999-12-14.farmer  0   0   4.39797857303e-54   1.0
0013.1999-12-14.kaminski    0   0   9.27075827653e-116  1.0
cat: Unable to write to output stream.
```

```
# Copy file back to local directory
!hdfs dfs -cat /user/konniam/week_02/hw_2_5_output_classify/part* > hw_2_5_results.txt
```

```
16/01/24 17:56:17 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

2.5 Error Assessment

```
def hw_2_5_error():
    # Parse results
    columns = ['docid', 'label', 'preds', 'probs_spam', 'probs_ham']
    df = pd.read_table("hw_2_5_results.txt", header=None, names=columns)
    # Calculate error rate and output
    print "The training error is {}.".format(np.mean(df['label'] != df['preds']))
    # Plot histograms
    plt.figure(figsize=(12,12))
    plt.subplot(211)
    sns.distplot(df['probs_spam'], bins = 20, kde=None)
    plt.subplot(212)
    sns.distplot(df['probs_ham'], bins = 20, kde=None)

hw_2_5_error()
```

```
The training error is 0.04.
```

Our training error went to 4% (up from 0% in HW2.4). By limiting our vocabulary to words with frequencies >= 3 (in each class), we effectively performed feature selection and lowered our model complexity due to the fewer number of parameters. As we see on the learning curve below (taken from Elements of Statistical Learning), the in-sample-error always drops as model complexity increases. In HW2.5, we traversed backwards on the learning curve from HW2.4. We expect our error to increase, matching our results. Nonetheless, we should keep in mind that we still have over 1500 features, which are still way too many for 100 examples. Our generalization likely won't be great because of the amount of overfitting.

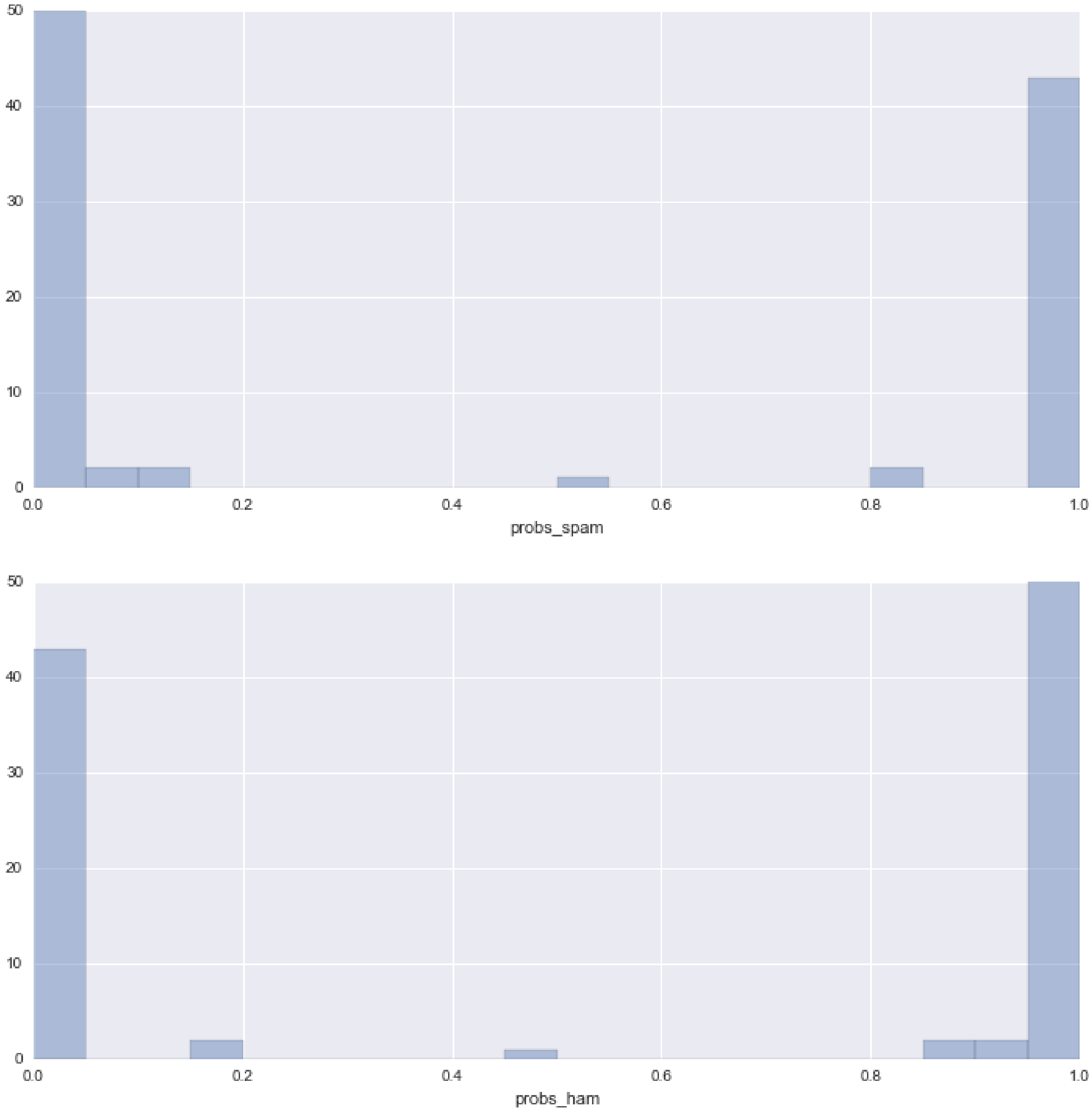
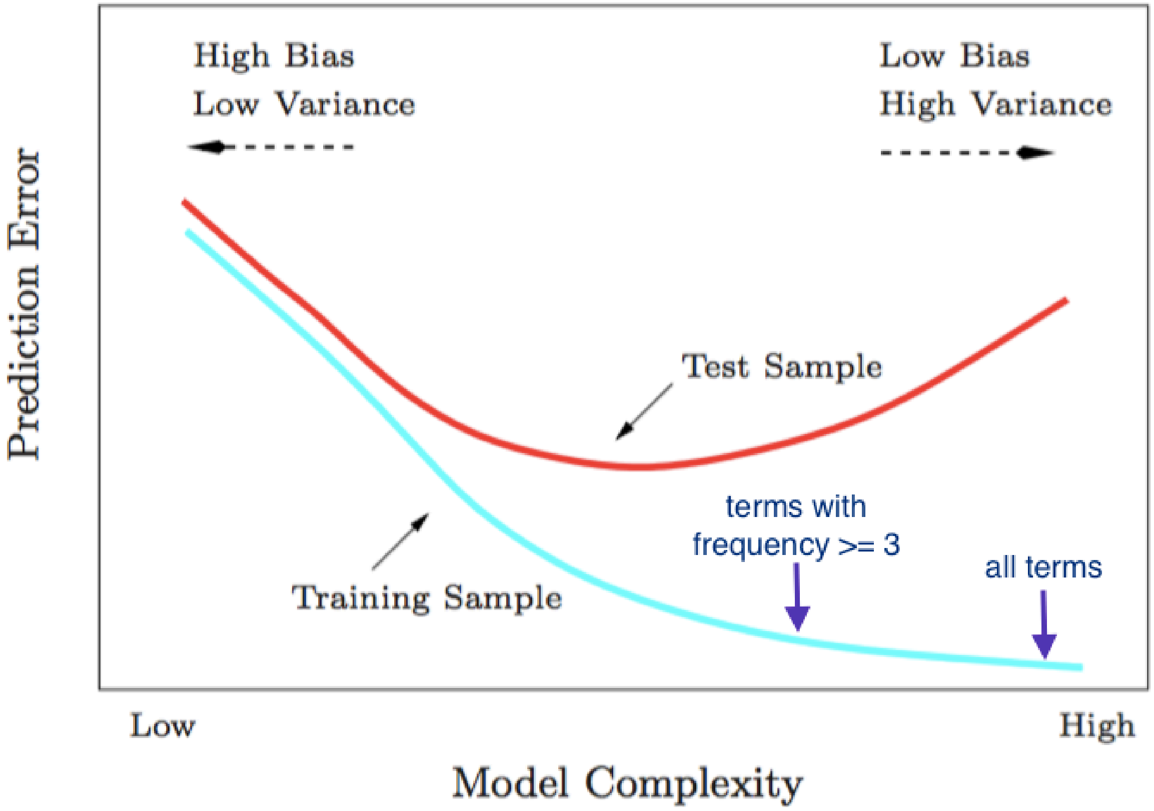

50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_spam
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_ham

Figure 3: png



HW2.6 Benchmark your code with the Python SciKit-Learn implementation of the multinomial Naive Bayes algorithm

It always a good idea to benchmark your solutions against publicly available libraries such as SciKit-Learn, The Machine Learning toolkit available in Python. In this exercise, we benchmark ourselves against the SciKit-Learn implementation of multinomial Naive Bayes. For more information on this implementation see: http://scikit-learn.org/stable/modules/naive_bayes.html more

In this exercise, please complete the following:

- Run the Multinomial Naive Bayes algorithm (using default settings) from SciKit-Learn over the same training data used in HW2.5 and report the misclassification error (please note some data preparation might be needed to get the Multinomial Naive Bayes algorithm from SkiKit-Learn to run over this dataset)
- Prepare a table to present your results, where rows correspond to approach used (SkiKit-Learn versus your Hadoop implementation) and the column presents the training misclassification error
- Explain/justify any differences in terms of training error rates over the dataset in HW2.5 between your Multinomial Naive Bayes implementation (in Map Reduce) versus the Multinomial Naive Bayes implementation in SciKit-Learn

```
# Import sklearn packages
from sklearn.naive_bayes import MultinomialNB
from sklearn.naive_bayes import BernoulliNB
from sklearn.feature_extraction.text import CountVectorizer
```

```python
def sklearn_NB(NB_model, vectorizer):
    '''
    Runs sklearn NB implentation on enron emails, using input choice of NB model and vectorizer
    '''
    # Load text file
    doc_ids, labels, content = [], [], []
    with open("enronemail_1h.txt", "r") as f:
        for line in f:
            # Some lines have missing subjects
            if len(line.split("\t")) == 4:
                doc_id, label, subject, body = line.split("\t")
            else:
                subject = "na"
                doc_id, label, body = line.split("\t")
            # Put into array format
            doc_ids.append(doc_id)
            labels.append(int(label))
            content.append(subject + " " + body)
    # Vectorize train_data
    content_vector = vectorizer.fit_transform(content)
    print "Vocab size: {}.".format(content_vector.shape[1])
    # Classify with sklearn NB model
    NB_model.fit(content_vector, labels)
    preds = NB_model.predict(content_vector)
    print "The classification error is: {}.".format(np.mean(np.array(labels) != preds))

# MultinomialNB, using terms of frequencies >= 3
sklearn_NB(MultinomialNB(), CountVectorizer(min_df=3))
```

```
Vocab size: 1357.
The classification error is: 0.04.
```

Model	Training Error
Multinomial NB, MapReduce implementation (HW2.5)	0.04
Multinomial NB, Scikit-Learn Implementation (HW2.6)	0.04

2.6 Response The MapReduce implementation performed the same as the sklearn implementation. The two models use different features. In the MapReduce implementation, we dropped terms with less than 3 occurrences, but kept all punctuations and numbers (besides the period and comma in position as delimiters). The sklearn implementation performed a more restrictive tokenization by removing all punctuation and any length-1 alphanumeric characters. The vocab size is 1357, compared to around 1800 for our MR model.

From the above learning curve, we would expect the training error for the sklearn implementation to be a little higher. However, it is likely that the extra features that were removed are not predictive of the class and didn't affect training performance.

HW 2.6.1 OPTIONAL (note this exercise is a stretch HW and optional)

- Run the Bernoulli Naive Bayes algorithm from SciKit-Learn (using default settings) over the same training data used in HW2.6 and report the misclassification error

- Discuss the performance differences in terms of misclassification error rates over the dataset in HW2.5 between the Multinomial Naive Bayes implementation in SciKit-Learn with the Bernoulli Naive Bayes implementation in SciKit-Learn. Why such big differences. Explain.

Which approach to Naive Bayes would you recommend for SPAM detection? Justify your selection.

```
# Run 2.6 with Bernoulli NB
# BernoulliNB, using terms of frequencies >= 3 and binary features
sklearn_NB(BernoulliNB(), CountVectorizer(min_df=3, binary=True))
```

```
Vocab size: 1357.
The classification error is: 0.12.
```

Model	Training Error
Multinomial NB, MapReduce implementation (HW2.5)	0.04
Multinomial NB, Scikit-Learn Implementation (HW2.6)	0.04
Bernoulli NB, Scikit-Learn Implementation (HW2.6.1)	0.12

2.6.1 Response The Bernoulli NB model performed the worst, with a 12% error versus 4% for the multinomial models. Multinomial NB represents features as term occurrences, models probability with a multinomial distribution of terms, and only considers terms in the document. Bernoulli NB represents features as a binary vector (of whether a particular term appears in a document), models probability with a Bernoulli distribution, and considers both appearance and non-apperaance of terms in the document. Because Bernoulli NB does not use information about repeated occurrence of a word in a doc, it leaves a lot of information on the table during classification. Multinomial NB uses more information and represents the document in a more nuanced way.

For spam classification in emails, Multinomial NB works better, because multiple occurrences are likely to be important in predicting the class. There is a big difference between “assistance” appearing once and “assistance” appearing 5 times. Multinomial NB will take the 5 occurrences into account and assigns heavy probability to the spam class. On the other hand, Bernoulli NB only note the appearnce of “assistance”.

HW2.7 OPTIONAL (note this exercise is a stretch HW and optional)

The Enron SPAM data in the following folder enron1-Training-Data-RAW is in raw text form (with subfolders for SPAM and HAM that contain raw email messages in the following form:

— Line 1 contains the subject — The remaining lines contain the body of the email message.

In Python write a script to produce a TSV file called train-Enron-1.txt that has a similar format as the enronemail_1h.txt that you have been using so far. Please pay attend to funky characters and tabs. Check your resulting formated email data in Excel and in Python (e.g., count up the number of fields in each row; the number of SPAM mails and the number of HAM emails). Does each row correspond to an email record with four values? Note: use “NA” to denote empty field values.

```
%%writefile enron_merge.py
#!/usr/bin/env python
from __future__ import unicode_literals
import os
import string
import codecs
```

```
# Home directory
home_path = os.getcwd()
os.chdir(os.path.join(home_path, "enron1-training-data-raw"))
# Label mapping
label_map = {"spam":"1", "ham":"0"}
# Output
out_path = os.path.join(home_path, "train-Enron-1.txt")

# Iterate over directory
with open(out_path, "w") as out_file:
    for root, dirs, filenames in os.walk(os.getcwd()):
        # Skip irrelevant folders
        if not(root.endswith("spam") or root.endswith("ham")):
            continue
        # Spam and ham folders
        for filename in filenames:
            # Skip Mac internal files
            if filename.startswith("."):
                continue
            # Process each file
            doc_id, label, ext = os.path.basename(filename).rsplit(".", 2)
            label = label_map[label]
            # Ignore characters with non-standard coding
            with codecs.open(os.path.join(root, filename), "r", encoding='utf-8', errors='replace') as 
                # Only take printable characters
                subject = email.readline()
                subject = filter(lambda x: x in string.printable, subject)
                subject = subject.strip().split("Subject: ")
                if len(subject)!=2 or not subject[1]:
                    subject = "NA"
                else:
                    subject = subject[1]
                # Strip newlines to convert to string
                body = email.read()
                body = filter(lambda x: x in string.printable, body)
                body = body.strip().replace('\r\n', '')
                if not body:
                    body = "NA"
            # Write to output file
            out_file.write(('\t'.join([doc_id, label, subject, body]) + '\n').encode('ascii', 'replace'
```

```
Overwriting enron_merge.py
```

```
!./enron_merge.py
```

```
!chmod a+x enron_merge.py
```

```
!wc -l train-Enron-1.txt
```

```
    5172 train-Enron-1.txt
```

```
!head train-Enron-1.txt
```

```
0001.1999-12-10.farmer  0   christmas tree farm pictures    NA
0002.1999-12-13.farmer  0  vastar resources , inc .   gary , production from the high island larger block a -
0003.1999-12-14.farmer  0  calpine daily gas nomination   - calpine daily gas nomination 1 . doc
0004.1999-12-14.farmer  0  re : issue  fyi - see note below - already done .stella- - - - - - - - - - - - - - - -
0005.1999-12-14.farmer  0  meter 7268 nov allocation  fyi .- - - - - - - - - - - - - - - - - - - - - - forwarded
0007.1999-12-14.farmer  0  mcmullen gas for 11 / 99   jackie ,since the inlet to 3 river plant is shut in on 1
0009.1999-12-14.farmer  0  meter 1517 - jan 1999  george ,i need the following done :jan 13zero out 012 - 270
0010.1999-12-14.farmer  0  duns number changes fyi- - - - - - - - - - - - - - - - - - - - - - forwarded by gary l
0011.1999-12-14.farmer  0  king ranch  there are two fields of gas that i am having difficulty with in the uni
0012.1999-12-14.farmer  0  re : entex transistion  thanks so much for the memo . i would like to reiterate my
```

HW2.8 OPTIONAL

Using Hadoop Map-Reduce write job(s) to perform the following: - Train a multinomial Naive Bayes Classifier with Laplace plus one smoothing using the data extracted in HW2.7 (i.e., train-Enron-1.txt). Use all white-space delimitted tokens as independent input variables (assume spaces, fullstops, commas as delimiters). Drop tokens with a frequency of less than three (3). - Test the learnt classifier using enronemail_1h.txt and report the misclassification error rate. Remember to use all white-space delimitted tokens as independent input variables (assume spaces, fullstops, commas as delimiters). How do we treat tokens in the test set that do not appear in the training set?

```
!hdfs dfs -put train-Enron-1.txt /user/konniam/week_02
```

```
16/01/25 20:40:12 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

2.8 Strategy Using the entire corpus producted in 2.7, we use a similar 2-step training/classifcation strategy to learn a NB model.

2.8 Training

```
%%writefile ~/mapper.py
#!/usr/bin/env python
## mapper.py
## Author: Konniam Chan
## Description: mapper code for HW2.8
from __future__ import unicode_literals
import sys
import re
from collections import Counter

# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Dictionary to keep track of terms
wordcounts = {"spam": Counter(), "ham": Counter()}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Process each document
for line in sys.stdin:
    # Lower case
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "NA"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)
    # Sum words that go through each mapper
    label = label_map[label]
    wordcounts[label] += Counter(words)
    # Increment number of documents
    wordcounts[label]["*numdocs"] += 1
# Delete any stray spaces
del wordcounts['spam']['']
del wordcounts['ham']['']
# Output each word
for label in wordcounts:
    for word in wordcounts[label]:
        print '%s\t%s\t%s'.encode('ascii', 'replace') % (word, label, wordcounts[label][word])
```

```
Overwriting /Users/InfernoIX/mapper.py
```

```
%%writefile ~/reducer.py
#!/usr/bin/env python
## reducer.py
## Author: Konniam Chan
## Description: reducer code for HW2.8
import sys
from collections import Counter

# Dictionary to keep track of terms
wordcounts = {"spam": Counter(), "ham": Counter()}
# Process each tuple in the form of (word, spam/ham, count) separated by \t
for line in sys.stdin:
    word, label, count = line.strip().split("\t")
    wordcounts[label][word] += int(count)

# Output each word
for label in wordcounts:
    for word in wordcounts[label]:
        print '%s\t%s\t%s' % (word, label, wordcounts[label][word])
```

```
Overwriting /Users/InfernoIX/reducer.py
```

```
# Run MapReduce job
# Specify 1 reducer
```

```
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=1 \
-mapper ~/mapper.py \
-reducer ~/reducer.py \
-input /user/konniam/week_02/train-Enron-1.txt \
-output /user/konniam/week_02/hw_2_8_output
```

```
16/01/25 20:40:57 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
packageJobJar: [/var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/hadoop-unjar8638680243381962498/] [] /va
16/01/25 20:40:59 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 20:40:59 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 20:41:00 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/25 20:41:00 INFO mapreduce.JobSubmitter: number of splits:2
16/01/25 20:41:01 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453765434085_0006
16/01/25 20:41:01 INFO impl.YarnClientImpl: Submitted application application_1453765434085_0006
16/01/25 20:41:01 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/25 20:41:01 INFO mapreduce.Job: Running job: job_1453765434085_0006
16/01/25 20:41:10 INFO mapreduce.Job: Job job_1453765434085_0006 running in uber mode : false
16/01/25 20:41:11 INFO mapreduce.Job:  map 0% reduce 0%
16/01/25 20:41:26 INFO mapreduce.Job:  map 16% reduce 0%
16/01/25 20:41:29 INFO mapreduce.Job:  map 21% reduce 0%
16/01/25 20:41:32 INFO mapreduce.Job:  map 26% reduce 0%
16/01/25 20:41:35 INFO mapreduce.Job:  map 29% reduce 0%
16/01/25 20:41:38 INFO mapreduce.Job:  map 33% reduce 0%
16/01/25 20:41:41 INFO mapreduce.Job:  map 34% reduce 0%
16/01/25 20:41:44 INFO mapreduce.Job:  map 36% reduce 0%
16/01/25 20:41:47 INFO mapreduce.Job:  map 37% reduce 0%
16/01/25 20:41:53 INFO mapreduce.Job:  map 41% reduce 0%
16/01/25 20:41:56 INFO mapreduce.Job:  map 42% reduce 0%
16/01/25 20:42:02 INFO mapreduce.Job:  map 46% reduce 0%
16/01/25 20:42:08 INFO mapreduce.Job:  map 47% reduce 0%
16/01/25 20:42:14 INFO mapreduce.Job:  map 49% reduce 0%
16/01/25 20:42:17 INFO mapreduce.Job:  map 50% reduce 0%
16/01/25 20:42:27 INFO mapreduce.Job:  map 52% reduce 0%
16/01/25 20:42:30 INFO mapreduce.Job:  map 54% reduce 0%
16/01/25 20:42:33 INFO mapreduce.Job:  map 55% reduce 0%
16/01/25 20:42:38 INFO mapreduce.Job:  map 57% reduce 0%
16/01/25 20:42:44 INFO mapreduce.Job:  map 60% reduce 0%
16/01/25 20:42:53 INFO mapreduce.Job:  map 63% reduce 0%
16/01/25 20:43:02 INFO mapreduce.Job:  map 66% reduce 0%
16/01/25 20:43:14 INFO mapreduce.Job:  map 67% reduce 0%
16/01/25 20:43:16 INFO mapreduce.Job:  map 83% reduce 0%
16/01/25 20:43:25 INFO mapreduce.Job:  map 100% reduce 0%
16/01/25 20:43:28 INFO mapreduce.Job:  map 100% reduce 100%
16/01/25 20:43:29 INFO mapreduce.Job: Job job_1453765434085_0006 completed successfully
16/01/25 20:43:29 INFO mapreduce.Job: Counters: 49
    File System Counters
        FILE: Number of bytes read=1599080
        FILE: Number of bytes written=3550329
        FILE: Number of read operations=0
        FILE: Number of large read operations=0
        FILE: Number of write operations=0
        HDFS: Number of bytes read=5321872
        HDFS: Number of bytes written=1329445
        HDFS: Number of read operations=9
        HDFS: Number of large read operations=0
        HDFS: Number of write operations=2
    Job Counters
        Launched map tasks=2
        Launched reduce tasks=1
        Data-local map tasks=2
        Total time spent by all maps in occupied slots (ms)=255600
        Total time spent by all reduces in occupied slots (ms)=8751
        Total time spent by all map tasks (ms)=255600
        Total time spent by all reduce tasks (ms)=8751
        Total vcore-seconds taken by all map tasks=255600
        Total vcore-seconds taken by all reduce tasks=8751
        Total megabyte-seconds taken by all map tasks=261734400
        Total megabyte-seconds taken by all reduce tasks=8961024
    Map-Reduce Framework
        Map input records=5172
        Map output records=91474
        Map output bytes=1416125
        Map output materialized bytes=1599086
        Input split bytes=224
        Combine input records=0
        Combine output records=0
        Reduce input groups=76300
        Reduce shuffle bytes=1599086
        Reduce input records=91474
        Reduce output records=84938
        Spilled Records=182948
        Shuffled Maps =2
        Failed Shuffles=0
        Merged Map outputs=2
        GC time elapsed (ms)=373
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=477626368
    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=5321648
    File Output Format Counters
        Bytes Written=1329445
16/01/25 20:43:29 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_8_output
```

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_8_output/part* | sort -k1,1 | head
```

```
16/01/25 20:43:46 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
!   ham 683
!   spam    1288
```

```
!"  spam    1
!$  ham 1
!$  spam    2
!$68    spam    1
!%  spam    11
!'  spam    1
!(  ham 7
!(  spam    1
sort: write failed: standard output: Broken pipe
sort: write error
```

The above MR job trained the model by obtaining the counts of all terms in either spam or ham.
We can now pass the result file from above when we want to classify our training data.

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_8_output/part* | wc -l
```

```
16/01/25 21:48:04 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
   84938
```

```
# Save wordcounts to file on local drive
!hdfs dfs -cat /user/konniam/week_02/hw_2_8_output/part* > ~/wordcounts_2_8.txt
```

```
16/01/25 22:06:08 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

Run 2nd-stage MR job to classify the small email set, using the entire corpus:

2.8 Classification

```
%%writefile ~/mapper_classify.py
#!/usr/bin/env python
## mapper_classify.py
## Author: Konniam Chan
## Description: classification (with Laplace smoothing, ignore infrequent terms)
## mapper code for HW2.8
from __future__ import division
import sys
import re
import math
from collections import defaultdict

# Map from integer label to word label
label_map = {"1":"spam", "0":"ham"}
# Regex split objects with specified delimiters (space, period, comma)
regex_beg = re.compile(r'^[\s.,"]+')
regex_end = re.compile(r'[\s.,"]+$')
regex_split = re.compile(r'[\s.,]+')

# Load wordcounts from 2.8 in memory
wordcounts = {"spam": defaultdict(int), "ham": defaultdict(int)}
with open("wordcounts_2_8.txt", "r") as f:
    for line in f:
        word, label, count = line.strip().split("\t")
        wordcounts[label][word] = int(count)
# Drop terms with total frequencies less than 3
vocab_set = set(wordcounts['spam']).union(set(wordcounts['ham']))
for word in vocab_set:
    if (wordcounts['spam'][word] + wordcounts['ham'][word]) < 3:
        del wordcounts['spam'][word]
        del wordcounts['ham'][word]
# Update vocabulary after deletion
vocab_set = set(wordcounts['spam']).union(set(wordcounts['ham']))
vocab_size = len(vocab_set)

# Calculate total number of terms
terms_spam = sum(wordcounts['spam'].values())
terms_ham = sum(wordcounts['ham'].values())
# Calculate priors and size of vocab
prior_spam = wordcounts['spam']['*numdocs'] / (wordcounts['spam']['*numdocs'] + wordcounts['ham']['*num
prior_ham = 1 - prior_spam


# Process each document
for line in sys.stdin:
    line = line.strip().lower()
    # Some lines have missing subjects
    if len(line.split("\t")) == 4:
        doc_id, label, subject, body = line.split("\t")
    else:
        subject = "na"
        doc_id, label, body = line.split("\t")
    # Remove delimiters at beginning and end of subjects and body
    subject = regex_beg.sub('', subject)
    subject = regex_end.sub('', subject)
    body = regex_beg.sub('', body)
    body = regex_end.sub('', body)
    # Split into words
    words = regex_split.split(subject + " " + body)

    # Initialize probabilities with priors
    log_probs = {"spam": math.log(prior_spam), "ham": math.log(prior_ham)}
    # Iterate through each word and add probabilities
    for word in words:
        # Skip words that aren't in the vocab
        if word not in wordcounts['spam'] and word not in wordcounts['ham']:
            continue
        # Laplace smoothing
        log_probs["spam"] += math.log((wordcounts['spam'][word] + 1) /
                                      (terms_spam + vocab_size))
        log_probs["ham"] += math.log((wordcounts['ham'][word] + 1) /
                                     (terms_ham + vocab_size))

    # Classify
    predicted_label = "1" if log_probs["spam"] > log_probs["ham"] else "0"
    # Normalize probabilities for output, prevent overflow
    if log_probs["ham"] - log_probs["spam"] > 700:
            probs_spam = 0
    else:
        probs_spam = 1 / (1 + math.exp(log_probs["ham"] - log_probs["spam"]))
    probs_ham = 1 - probs_spam

    # Output (DocID, label, predicted label, p_spam, p_ham)
    print '\t'.join([doc_id, label, predicted_label,
                     str(probs_spam), str(probs_ham)])
```

```
Overwriting /Users/InfernoIX/mapper_classify.py
```

```
# Run MapReduce job
# Map-only job. Pass in text file with wordcounts
!hadoop jar hadoop-streaming-2.7.1.jar \
-D mapreduce.job.reduces=0 \
-mapper ~/mapper_classify.py \
-input /user/konniam/week_02/enronemail_1h.txt \
-output /user/konniam/week_02/hw_2_8_output_classify \
-file ~/wordcounts_2_8.txt
```

```
16/01/25 22:09:35 WARN streaming.StreamJob: -file option is deprecated, please use generic option -files ins
16/01/25 22:09:35 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usin
packageJobJar: [/Users/InfernoIX/wordcounts_2_8.txt, /var/folders/l8/h51_59852qscq403fs6q0xlh0000gn/T/ha
16/01/25 22:09:37 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 22:09:37 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0:8032
16/01/25 22:09:38 INFO mapred.FileInputFormat: Total input paths to process : 1
16/01/25 22:09:38 INFO mapreduce.JobSubmitter: number of splits:2
16/01/25 22:09:38 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_1453765434085_0008
16/01/25 22:09:39 INFO impl.YarnClientImpl: Submitted application application_1453765434085_0008
16/01/25 22:09:39 INFO mapreduce.Job: The url to track the job: http://Konniams-MacBook-Air.local:8088/prox
16/01/25 22:09:39 INFO mapreduce.Job: Running job: job_1453765434085_0008
16/01/25 22:09:49 INFO mapreduce.Job: Job job_1453765434085_0008 running in uber mode : false
16/01/25 22:09:49 INFO mapreduce.Job:  map 0% reduce 0%
16/01/25 22:10:01 INFO mapreduce.Job:  map 100% reduce 0%
16/01/25 22:10:02 INFO mapreduce.Job: Job job_1453765434085_0008 completed successfully
16/01/25 22:10:03 INFO mapreduce.Job: Counters: 30
    File System Counters
        FILE: Number of bytes read=0
        FILE: Number of bytes written=236382
        FILE: Number of read operations=0
        FILE: Number of large read operations=0
        FILE: Number of write operations=0
        HDFS: Number of bytes read=217192
        HDFS: Number of bytes written=4632
        HDFS: Number of read operations=10
        HDFS: Number of large read operations=0
        HDFS: Number of write operations=4
    Job Counters
        Launched map tasks=2
        Data-local map tasks=2
        Total time spent by all maps in occupied slots (ms)=20404
        Total time spent by all reduces in occupied slots (ms)=0
        Total time spent by all map tasks (ms)=20404
        Total vcore-seconds taken by all map tasks=20404
        Total megabyte-seconds taken by all map tasks=20893696
    Map-Reduce Framework
        Map input records=100
        Map output records=100
        Input split bytes=224
        Spilled Records=0
        Failed Shuffles=0
        Merged Map outputs=0
        GC time elapsed (ms)=433
        CPU time spent (ms)=0
        Physical memory (bytes) snapshot=0
        Virtual memory (bytes) snapshot=0
        Total committed heap usage (bytes)=188219392
    File Input Format Counters
        Bytes Read=216968
    File Output Format Counters
        Bytes Written=4632
16/01/25 22:10:03 INFO streaming.StreamJob: Output directory: /user/konniam/week_02/hw_2_8_output_classif
```

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_8_output_classify/* | head
```

```
16/01/25 23:55:16 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
0011.2003-12-18.gp  1   1   1.0 0.0
0011.2004-08-01.bg  1   1   1.0 0.0
0012.1999-12-14.farmer  0   0   5.31855091372e-127  1.0
0012.1999-12-14.kaminski    0   0   1.31343541076e-29   1.0
0012.2000-01-17.beck    0   0   1.53420842707e-39   1.0
0012.2000-06-08.lokay   0   1   1.0 4.04121180964e-14
0012.2001-02-09.kitchen 0   0   6.46025337376e-10   0.999999999354
0012.2003-12-19.gp  1   1   0.999999983328  1.66724848372e-08
0013.1999-12-14.farmer  0   0   1.84396706319e-35   1.0
0013.1999-12-14.kaminski    0   0   4.83587857574e-19   1.0
cat: Unable to write to output stream.
```

HW2.8.1 OPTIONAL

- Run both the Multinomial Naive Bayes and the Bernoulli Naive Bayes algorithms from SciKit-Learn (using default settings) over the same training data used in HW2.8 and report the misclassification error on both the training set and the testing set
- Prepare a table to present your results, where rows correspond to approach used (SciKit-Learn Multinomial NB; SciKit-Learn Bernouili NB; Your Hadoop implementation) and the columns presents the training misclassification error, and the misclassification error on the test data set
- Discuss the performance differences in terms of misclassification error rates over the test and training datasets by the different implementations. Which approch (Bernouili versus Multinomial) would you recommend for SPAM detection? Justify your selection.

2.8.1 Error Assessment

```
!hdfs dfs -cat /user/konniam/week_02/hw_2_8_output_classify/part* > hw_2_8_results.txt
```

```
16/01/25 22:15:06 WARN util.NativeCodeLoader: Unable to load native-hadoop library for your platform... usi
```

```
def hw_2_8_error():
    # Parse results
    columns = ['docid', 'label', 'preds', 'probs_spam', 'probs_ham']
    df = pd.read_table("hw_2_8_results.txt", header=None, names=columns)
    # Calculate error rate and output
    print "The training error is {}.".format(np.mean(df['label'] != df['preds']))
    # Plot histograms
    plt.figure(figsize=(12,12))
    plt.subplot(211)
    sns.distplot(df['probs_spam'], bins = 20, kde=None)
    plt.subplot(212)
    sns.distplot(df['probs_ham'], bins = 20, kde=None)

hw_2_8_error()
```

```
The training error is 0.12.
```

```
def hw_2_8_1(NB_model, binary_features=False):
    '''
    Runs sklearn NB implentation on enron emails, using input choice of NB model
    '''
    # Load train and test data
    data = {"train": {"path":"train-Enron-1.txt", "doc_ids":[], "labels":[],
                      "content":[]},
            "test": {"path": "enronemail_1h.txt", "doc_ids":[], "labels":[],
                     "content":[]}}
    vectorizer = CountVectorizer(min_df=3, binary=binary_features)

    # Vectorize train
    with open(data["train"]["path"], "r") as f:
        for line in f:
            doc_id, label, subject, body = line.split("\t")
            data["train"]["doc_ids"].append(doc_id)
            data["train"]["labels"].append(int(label))
            data["train"]["content"].append(subject + " " + body)
    # Vectorize
    data["train"]["content_vector"] = vectorizer.fit_transform(data["train"]["content"])

    # Vectorize test data
    with open(data["test"]["path"], "r") as f:
        for line in f:
            # Some lines have missing subjects
            if len(line.split("\t")) == 4:
                doc_id, label, subject, body = line.split("\t")
            else:
                subject = "NA"
                doc_id, label, body = line.split("\t")
            # Put into array format
            data["test"]["doc_ids"].append(doc_id)
            data["test"]["labels"].append(int(label))
            data["test"]["content"].append(subject + " " + body)
    # Vectorize
    data["test"]["content_vector"] = vectorizer.transform(data["test"]["content"])
```

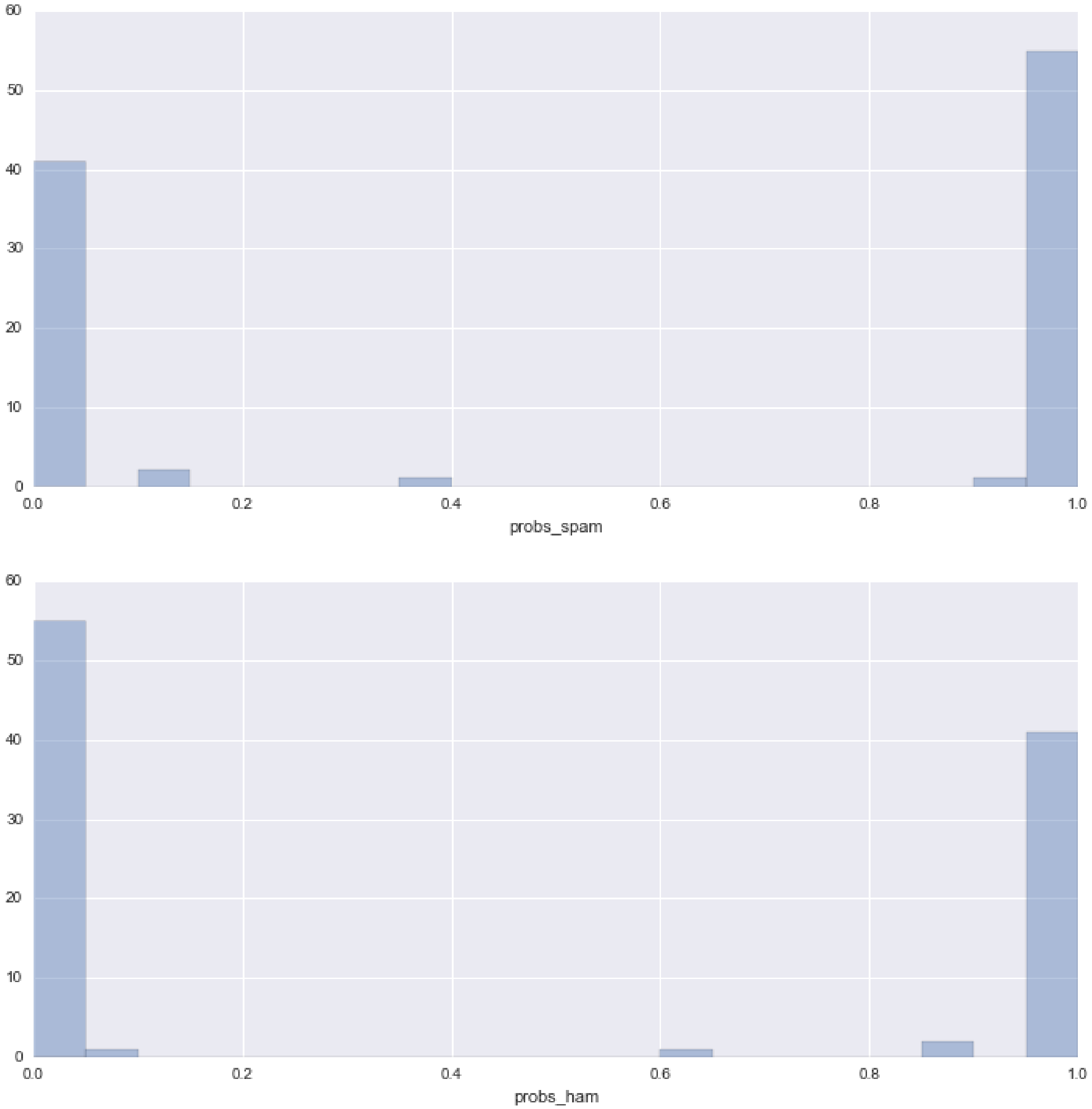

60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_spam
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
probs_ham

Figure 4: png

```
    # Classify with sklearn NB model
    NB_model.fit(data["train"]["content_vector"], data["train"]["labels"])
    preds = NB_model.predict(data["test"]["content_vector"])
    print "The classification error is: {}.".format(np.mean(np.array(data["test"]["labels"]) != preds))

# MultinomialNB, using terms of frequencies >= 3
hw_2_8_1(MultinomialNB(), False)
```

```
The classification error is: 0.07.
```

```
# Bernoulli NB
hw_2_8_1(BernoulliNB(), binary_features=True)
```

```
The classification error is: 0.08.
```

Model	Training Error
Multinomial NB, MapReduce implementation	0.12
Multinomial NB, Scikit-Learn Implementation	0.07
Bernoulli NB, Scikit-Learn Implementation	0.08

2.8.1 Response The sklearn implementatiaons performed better than the MR implementation. The main difference between the two is the feature selection process, as sklearn strips out all punctuations. It is likely that these stripped features are noisy and don't offer predictive power, making the sklearn models better overall.