# DATASCI W261, Machine Learning at Scale

**Assignement: week #2**

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## Due: 2016-09-13, 8AM PST

### *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.

- A race condition refers to the ssituation where the output is dependent on the sequence or timing of other uncontrollable events. For example, when a few paralle threads have interaction with some common resource, due to the lack of coordination and synchronization, the execution can cause invalid state of the resource, which can randomly affect the result of each thread.

For example, consider the following logic, where B is a global counter variable:

temp = B temp = temp + 1 B = temp It will increase the value of B by one. If it is run twice sequentially, B will be increased by two. However, if two threads are running it at the same time, there is a chance that B will only be increased by one, not two.

- MapReduce is a programming framework for processing large data sets with a parallel, distributed algorithm on a cluster. It has two phases:
  - Map(): performs filtering and sorting
  - Reduce(): performs a summary operation

- Hadoop is an open source project which provides an implementation of the MapReduce functionality. It has two components:
  - HDFS: Hadoop distributed file system (Storage)
  - MapReduce implementation (Calculation)

Therefore, MapReduce is a calculating component of Hadoop

- Hadoop is based on Functional Programing languages. key features of functional languages include (1) such language can accept other functions as arguments; (2) it is a declarative programming paradigm, which means programming is done with expressions.
  - Example is given below:

In [17]:
```
# function to count character in a word
def char_count(word):
    return len(word)

# apply the function on a sentence
sentence = 'Run  both the Multinomial Naive Bayes and the Bernoulli Naive Bayes alg
orithms'
print('Count alphabeta numbers in each word of sentence: ')
print({word:char_count(word) for word in sentence.split()})
```

```
Count alphabeta numbers in each word of sentence:
{'and': 3, 'both': 4, 'Run': 3, 'Multinomial': 11, 'Bernoulli': 9, 'Naive': 5, '
algorithms': 10, 'Bayes': 5, 'the': 3}
```

### HW2.1.1 Lower case and upper case sort.

In [18]:
```
!curl 'http://www.gutenberg.org/cache/epub/11/pg11.txt' -o alicesTExtFilename.txt
```

```
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100  163k  100  163k    0     0  25509      0  0:00:06  0:00:06 --:--:--  107k
```

In [19]:
```
%%writefile pWordCount_n.sh
#!/bin/bash
## pWordCount.sh
## Author: James G. Shanahan
## Usage: pWordCount.sh m wordlist testFile.txt
## Input:
##       m = number of processes (maps), e.g., 4
##       wordlist = a space-separated list of words in quotes, e.g., "the and of"
##       inputFile = a text input file
##
## Instructions: Read this script and its comments closely.
##               Do your best to understand the purpose of each command,
##               and focus on how arguments are supplied to mapper.py/reducer.py,
##               as this will determine how the python scripts take input.
##               When you are comfortable with the unix code below,
##               answer the questions on the LMS for HW1 about the starter code.



if [ $# -eq 0 ]
  then
    echo "No arguments supplied"
    echo "To run use"
    echo "     pWordCount.sh m wordlist inputFile"
    echo "Input:"
    echo "      number of processes (maps), e.g., 4"
    echo "      wordlist = a space-separated list of words in quotes, e.g., 'the an
d of'"
    echo "      inputFile = a text input file"
    exit
fi


## collect user input
m=$1 ## the number of parallel processes (maps) to run

wordlist=$2 ## if set to "*", then all words are used

## a text file
data="alicesTExtFilename.txt"

## 'wc' determines the number of lines in the data
## 'perl -pe' regex strips the piped wc output to a number
linesindata=`wc -l $data | perl -pe 's/^.*?(\d+).*?$/$1/'`

## determine the lines per chunk for the desired number of processes
linesinchunk=`echo "$linesindata/$m+1" | bc`

## split the original file into chunks by line
split -l $linesinchunk $data $data.chunk.

## assign python mappers (mapper.py) to the chunks of data
## and emit their output to temporary files
for datachunk in $data.chunk.*; do
    ## feed word list to the python mapper here and redirect STDOUT to a temporary
file on disk
    ####
    ####
    ./mapper_n.py $datachunk "$wordlist" > $datachunk.counts &
    ####
    ####
done

## wait for the mappers to finish their work
```

```
Overwriting pWordCount_n.sh
```

In [20]:
```
%%writefile mapper_n.py
#!/usr/bin/python
## mapper.py
## Given a file and list of words, read lines and count occurrences of words


import sys
import re

WORD_RE = re.compile(r"[\w']+")

filename = sys.argv[1]

## Words in the word list are space delimited
wordlist = sys.argv[2].split(' ')
counts = {}


with open (filename, "rU") as myfile:
    for text in myfile.readlines():
        for word in WORD_RE.findall(text):
            if word in wordlist:
                try:
                    counts[word] += 1
                except:
                    counts[word] = 1

for word in counts:
    sys.stdout.write('{0}\t{1}\n'.format(word, counts[word]))
```

```
Overwriting mapper_n.py
```

In [21]:
```
%%writefile reducer_n.py
#!/usr/bin/python2
import sys
counts_U = {}
counts_L = {}

for intermediate_file in sys.argv:
    with open(intermediate_file, 'rU') as infile:
        # intermediate files are word <tab> count per line
        for line in infile.readlines():
            word_count = line.split('\t')
            # starting with an uppercase
            word = word_count[0]
            if len(word_count) == 2 and (word[0] == word[0].upper()):
                try:
                    counts_U[word_count[0]] += int(word_count[1])
                except KeyError:
                    counts_U[word_count[0]] = int(word_count[1])

            elif len(word_count) == 2:
                try:
                    counts_L[word_count[0]] += int(word_count[1])
                except KeyError:
                    counts_L[word_count[0]] = int(word_count[1])

for word in counts_U:
    sys.stdout.write('{0}\t{1}\n'.format(word, counts_U[word]))

for word in counts_L:
    sys.stdout.write('{0}\t{1}\n'.format(word, counts_L[word]))
```

```
Overwriting reducer_n.py
```

**For example, I input "Alice", "the", "we", "The", "We", "How", "dog"**

**they are sorted as alphabetical order for Upper case begin (saved .outputU file),**

**and Lower case begin (saved .outputL)**

In [67]:
```
!chmod a+x mapper_n.py
!chmod a+x reducer_n.py
!chmod a+x pWordCount_n.sh
!./pWordCount_n.sh 4 "Alice the we The We How dog"
print("Upper Case")
!cat *.outputU

print("Lower Case")
!cat *.outputL
```

```
Upper Case
Alice   398
ALICE   5
How     27
HOW     1
The     119
THE     13
We      11
WE      1
Lower Case
dog     3
how     44
the     1686
we      31
```

### HW2.1.2 TOTAL SORT using multiple reducers [OPTITIONAL for this week; will be covered in next live session]

In [65]:
```
!pwd
```

```
/home/cloudera
```

### HW2.1.3 How many times does the word alice occur in the book?

Write a MapReduce job to determine this. Please pay attention to what you use for a key and value as output from your mapper.

In [76]:
```
%%writefile pWordCount_13.sh
#!/bin/bash
## pWordCount.sh
## Author: James G. Shanahan
## Usage: pWordCount.sh m wordlist testFile.txt
## Input:
##       m = number of processes (maps), e.g., 4
##       wordlist = a space-separated list of words in quotes, e.g., "the and of"
##       inputFile = a text input file
##
## Instructions: Read this script and its comments closely.
##               Do your best to understand the purpose of each command,
##               and focus on how arguments are supplied to mapper.py/reducer.py,
##               as this will determine how the python scripts take input.
##               When you are comfortable with the unix code below,
##               answer the questions on the LMS for HW1 about the starter code.



if [ $# -eq 0 ]
  then
    echo "No arguments supplied"
    echo "To run use"
    echo "     pWordCount.sh m wordlist inputFile"
    echo "Input:"
    echo "      number of processes (maps), e.g., 4"
    echo "      wordlist = a space-separated list of words in quotes, e.g., 'the an
d of'"
    echo "      inputFile = a text input file"
    exit
fi


## collect user input
m=$1 ## the number of parallel processes (maps) to run

wordlist=$2 ## if set to "*", then all words are used

## a text file
data="alicesTExtFilename.txt"

## 'wc' determines the number of lines in the data
## 'perl -pe' regex strips the piped wc output to a number
linesindata=`wc -l $data | perl -pe 's/^.*?(\d+).*?$/$1/'`

## determine the lines per chunk for the desired number of processes
linesinchunk=`echo "$linesindata/$m+1" | bc`

## split the original file into chunks by line
split -l $linesinchunk $data $data.chunk.

## assign python mappers (mapper.py) to the chunks of data
## and emit their output to temporary files
for datachunk in $data.chunk.*; do
    ## feed word list to the python mapper here and redirect STDOUT to a temporary
file on disk
    ####
    ####
    ./mapper13.py $datachunk "$wordlist" > $datachunk.counts &
    ####
    ####
done

## wait for the mappers to finish their work
```

```
Overwriting pWordCount_13.sh
```

In [69]:
```
%%writefile mapper13.py
#!/usr/bin/python

import sys
import re

WORD_RE = re.compile(r"[\w']+")

filename = sys.argv[1]

## Words in the word list are space delimited
wordlist = sys.argv[2].lower().split(' ')
counts = {}


words = re.findall('\w+', open(filename).read())
for word in words:
            if word.lower() in wordlist:
                try:
                    counts[word.lower()] += 1
                except:
                    counts[word.lower()] = 1

for word in counts:
    sys.stdout.write('{0}\t{1}\n'.format(word, counts[word]))
```

```
Overwriting mapper13.py
```

In [70]:
```
%%writefile reducer13.py
#!/usr/bin/python

import sys
counts = {}

for intermediate_file in sys.argv:
    with open(intermediate_file, 'rU') as infile:
        # intermediate files are word <tab> count per line
        for line in infile.readlines():
            word_count = line.split('\t')
            if len(word_count) == 2:
                try:
                    counts[word_count[0]] += int(word_count[1])
                except KeyError:
                    counts[word_count[0]] = int(word_count[1])
for word in counts:
    sys.stdout.write('{0}\t{1}\n'.format(word, counts[word]))
```

```
Overwriting reducer13.py
```

In [77]:
```
!chmod a+x mapper13.py
!chmod a+x reducer13.py
!chmod a+x pWordCount_13.sh
!./pWordCount_13.sh 4 "Alice"
!cat output13
```

```
alice   403
```

## HW2.2.1 WORDCOUNT

Using the Enron data from 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 in both SPAM and HAM classes.

In [27]:
```
%%writefile mapper21.py
#!/usr/bin/python

import re
import sys

WORD_RE = re.compile(r"[\w']+")

# extract words to count from first positional argument, making them all lower case
wordlist = []
if len(sys.argv) > 1:
    for word in sys.argv[1].strip().split():
        wordlist.append(word.lower())


for line in sys.stdin:
    try:
        # Get the id, label, subject and body, respectively
        email_id, label, subject, body = line.split('\t')
    except ValueError:
        # if there are only 3 fields in the input, field 3 is default as body
        email_id, label, body = line.split('\t')
        subject = ''

    # extract words from the combined subject and body text
    for word in WORD_RE.findall(subject + ' ' + body):
        if len(wordlist) > 0:
            if word.lower() in wordlist:
                print('{0}\t{1}'.format(word.lower(), 1))
        else:
            # otherwise count all words
            print('{0}\t{1}'.format(word.lower(), 1))
```

```
Overwriting mapper21.py
```

In [82]:
```
%%writefile reducer21.py
#!/usr/bin/python

from operator import itemgetter
import sys

tmp_word = None
tmp_count = 0
word = None

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper.py
    word, count = line.split('\t', 1)

    # convert count to int
    try:
        count = int(count)
    except ValueError:
        continue


    if tmp_word == word:
        tmp_count += count
    else:
        if tmp_word:
            # write result to STDOUT
            print '%s\t%s' % (tmp_word, tmp_count)
        # update current word
        tmp_count = count
        tmp_word = word

# do not forget to output the last word if required
if tmp_word == word:
    print '%s\t%s' % (tmp_word, tmp_count)
```

```
Overwriting reducer21.py
```

In [83]:
```
!chmod a+x mapper21.py
!chmod a+x reducer21.py
!cat enronemail_1h.txt | ./mapper21.py "assistance" | sort -k1,1 | ./reducer21.py
```

```
assistance      10
```

In [84]:
```
!hdfs dfs -mkdir -p /user/shihyu
!hdfs dfs -put enronemail_1h.txt /user/shihyu
```

```
put: `/user/shihyu/enronemail_1h.txt': File exists
```

In [86]:
```
!hdfs dfs -rm -r results21
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper "/home/cloudera/mapper21.py 'assistance'" \
-reducer /home/cloudera/reducer21.py \
-input /user/shihyu/enronemail_1h.txt \
-output results21
```

```
Deleted results21
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob6452960282347316161.jar tmpDir=null
16/09/09 21:27:53 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:27:53 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:27:54 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 21:27:54 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 21:27:54 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0016
16/09/09 21:27:54 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0016
16/09/09 21:27:54 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0016/
16/09/09 21:27:54 INFO mapreduce.Job: Running job: job_1473444507507_0016
16/09/09 21:28:01 INFO mapreduce.Job: Job job_1473444507507_0016 running in uber
 mode : false
16/09/09 21:28:01 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 21:28:09 INFO mapreduce.Job:  map 50% reduce 0%
16/09/09 21:28:10 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 21:28:15 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 21:28:15 INFO mapreduce.Job: Job job_1473444507507_0016 completed succe
ssfully
16/09/09 21:28:15 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=156
                FILE: Number of bytes written=355991
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=14
                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)=11199
                Total time spent by all reduces in occupied slots (ms)=3594
                Total time spent by all map tasks (ms)=11199
                Total time spent by all reduce tasks (ms)=3594
                Total vcore-seconds taken by all map tasks=11199
                Total vcore-seconds taken by all reduce tasks=3594
                Total megabyte-seconds taken by all map tasks=11467776
                Total megabyte-seconds taken by all reduce tasks=3680256
        Map-Reduce Framework
                Map input records=100
                Map output records=10
                Map output bytes=130
                Map output materialized bytes=162
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=1
                Reduce shuffle bytes=162
                Reduce input records=10
                Reduce output records=1
                Spilled Records=20
                Shuffled Maps =2
                Failed Shuffles=0
                Merged Map outputs=2
```

In [88]:
```
!hdfs dfs -cat /user/cloudera/results21/part-00000 ### Should be 10
```

```
assistance      10
```

## HW2.2.2

Using Hadoop MapReduce and your wordcount job (from HW2.2.1) determine the top-10 occurring tokens (most frequent tokens) using a single reducer for the SPAM class and for the HAM class.

In [89]:
```
%%writefile reducer22.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator

tmp_word = None
tmp_count = 0
word = None
wordcount = {}

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper.py
    word, count = line.split('\t', 1)

    # convert count (currently a string) to int
    try:
        count = int(count)
    except ValueError:
        continue

    if tmp_word == word:
        tmp_count += count
    else:
        if tmp_word:
            # save count
            wordcount[tmp_word] = tmp_count
        tmp_count = count
        tmp_word = word

if tmp_word == word:
    wordcount[tmp_word] = tmp_count

# sort count top get top n counts:
n = 10
sorted_count = sorted(wordcount.items(), key=operator.itemgetter(1))
print 'Top %d counts from %d words:' %(n, len(sorted_count))
for i in range(n):
    print '%s\t%d' %(sorted_count[-i-1])
```

```
Overwriting reducer22.py
```

## Top 10 tokens of SPAM messages

In [95]:
```
!chmod a+x mapper21.py
!chmod a+x reducer22.py
!hdfs dfs -put spam_enronemail_1h.txt /user/shihyu
!hdfs dfs -rm -r results22_spam
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper21.py \
-reducer /home/cloudera/reducer22.py \
-input /user/shihyu/spam_enronemail_1h.txt \
-output results22_spam
```

```
put: `/user/shihyu/spam_enronemail_1h.txt': File exists
Deleted results22_spam
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob9139697224943270396.jar tmpDir=null
16/09/09 21:45:50 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:45:51 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:45:51 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 21:45:51 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 21:45:51 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0021
16/09/09 21:45:52 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0021
16/09/09 21:45:52 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0021/
16/09/09 21:45:52 INFO mapreduce.Job: Running job: job_1473444507507_0021
16/09/09 21:45:58 INFO mapreduce.Job: Job job_1473444507507_0021 running in uber
 mode : false
16/09/09 21:45:58 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 21:46:07 INFO mapreduce.Job:  map 50% reduce 0%
16/09/09 21:46:08 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 21:46:13 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 21:46:14 INFO mapreduce.Job: Job job_1473444507507_0021 completed succe
ssfully
16/09/09 21:46:14 INFO mapreduce.Job: Counters: 50
        File System Counters
                FILE: Number of bytes read=180515
                FILE: Number of bytes written=716688
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=139858
                HDFS: Number of bytes written=108
                HDFS: Number of read operations=9
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Killed map tasks=1
                Launched map tasks=2
                Launched reduce tasks=1
                Data-local map tasks=2
                Total time spent by all maps in occupied slots (ms)=13432
                Total time spent by all reduces in occupied slots (ms)=4041
                Total time spent by all map tasks (ms)=13432
                Total time spent by all reduce tasks (ms)=4041
                Total vcore-seconds taken by all map tasks=13432
                Total vcore-seconds taken by all reduce tasks=4041
                Total megabyte-seconds taken by all map tasks=13754368
                Total megabyte-seconds taken by all reduce tasks=4137984
        Map-Reduce Framework
                Map input records=44
                Map output records=18690
                Map output bytes=143129
                Map output materialized bytes=180521
                Input split bytes=236
                Combine input records=0
                Combine output records=0
                Reduce input groups=3787
                Reduce shuffle bytes=180521
                Reduce input records=18690
                Reduce output records=11
                Spilled Records=37380
                Shuffled Maps =2
```

In [97]:
```
!hdfs dfs -cat /user/cloudera/results22_spam/part-00000
```

```
Top 10 counts from 3787 words:
the     698
to      565
and     390
your    356
a       346
of      336
you     332
in      235
for     203
com     151
```

### Top 10 tokens of HAM messages

In [98]:
```
!chmod a+x mapper21.py
!chmod a+x reducer22.py
!hdfs dfs -put ham_enronemail_1h.txt /user/shihyu
!hdfs dfs -rm -r results22_ham
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper21.py \
-reducer /home/cloudera/reducer22.py \
-input /user/shihyu/ham_enronemail_1h.txt \
-output results22_ham
```

```
put: `/user/shihyu/ham_enronemail_1h.txt': File exists
rm: `results22_ham': No such file or directory
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob6025724084762220367.jar tmpDir=null
16/09/09 21:50:37 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:50:37 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 21:50:38 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 21:50:38 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 21:50:38 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0022
16/09/09 21:50:38 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0022
16/09/09 21:50:38 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0022/
16/09/09 21:50:38 INFO mapreduce.Job: Running job: job_1473444507507_0022
16/09/09 21:50:46 INFO mapreduce.Job: Job job_1473444507507_0022 running in uber
 mode : false
16/09/09 21:50:46 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 21:50:54 INFO mapreduce.Job:  map 50% reduce 0%
16/09/09 21:50:55 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 21:51:00 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 21:51:01 INFO mapreduce.Job: Job job_1473444507507_0022 completed succe
ssfully
16/09/09 21:51:01 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=137520
                FILE: Number of bytes written=630692
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=93864
                HDFS: Number of bytes written=106
                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)=12500
                Total time spent by all reduces in occupied slots (ms)=4040
                Total time spent by all map tasks (ms)=12500
                Total time spent by all reduce tasks (ms)=4040
                Total vcore-seconds taken by all map tasks=12500
                Total vcore-seconds taken by all reduce tasks=4040
                Total megabyte-seconds taken by all map tasks=12800000
                Total megabyte-seconds taken by all reduce tasks=4136960
        Map-Reduce Framework
                Map input records=56
                Map output records=14221
                Map output bytes=109072
                Map output materialized bytes=137526
                Input split bytes=234
                Combine input records=0
                Combine output records=0
                Reduce input groups=2768
                Reduce shuffle bytes=137526
                Reduce input records=14221
                Reduce output records=11
                Spilled Records=28442
                Shuffled Maps =2
                Failed Shuffles=0
```

In [100]:
```
!hdfs dfs -cat /user/cloudera/results22_ham/part-00000
```

```
Top 10 counts from 2768 words:
the     549
to      398
ect     382
and     278
of      230
hou     206
a       196
in      182
for     170
on      135
```

## HW2.2.3 (Optional)

Using Hadoop MapReduce and your wordcount job (from HW2.2.1) determine the top-10 occurring tokens (most frequent tokens) using multiple reducers.

In [107]:
```
%%writefile mapper23.py
#!/usr/bin/python

import sys
import re
from csv import reader
WORD_RE = re.compile(r"[\w']+")

count = 0 #Running total of occurrances for the chosen word
sys.stderr.write("reporter:counter:Mapper,Script Count,1\n")
for line in reader(sys.stdin):
    sys.stderr.write("reporter:counter:Mapper,Line Count,1\n")
    try:
        int(line[0]) #check if the ID field is an integer, skip the record if not
    except ValueError:
        continue

    words = re.findall(WORD_RE, line[3])
    for word in words:
        print word.lower()+'\t1'
```

```
Overwriting mapper23.py
```

In [108]:
```
%%writefile reducer23.py
#!/usr/bin/python

import sys
tmp_word=''
count = 0 #Running total of occurrances for the chosen word
sys.stderr.write("reporter:counter:Reducer,Script Count,1\n")
for line in sys.stdin:
    line=line.strip().split('\t') #Parse line into a list of fields
    word,sub_count=line
    if tmp_word==word:
        count+=int(sub_count) #Extract chunk count from the second field of each i
ncoming line
    else:
        if tmp_word:
            sys.stderr.write("reporter:counter:Reducer,Line Count,1\n")
            print tmp_word+'\t'+str(count)
        tmp_word=word
        count=int(sub_count)
if tmp_word:
    sys.stderr.write("reporter:counter:Reducer,Line Count,1\n")
    print tmp_word+'\t'+str(count)
```

```
Overwriting reducer23.py
```

In [109]:
```
!chmod a+x mapper23.py
!chmod a+x reducer23.py



!hdfs dfs -rm -r results23
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D mapred.map.tasks=2 \
-D mapred.reduce.tasks=2 \
-mapper /home/cloudera/mapper23.py \
-reducer /home/cloudera/reducer23.py \
-input /user/shihyu/enronemail_1h.txt \
-output results23
!hdfs dfs -cat results23/* | head -10
```

```
Deleted results23
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob6434113247504200456.jar tmpDir=null
16/09/09 22:01:44 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 22:01:44 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 22:01:45 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 22:01:45 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 22:01:45 INFO Configuration.deprecation: mapred.reduce.tasks is depreca
ted. Instead, use mapreduce.job.reduces
16/09/09 22:01:45 INFO Configuration.deprecation: mapred.map.tasks is deprecated
. Instead, use mapreduce.job.maps
16/09/09 22:01:45 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0024
16/09/09 22:01:45 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0024
16/09/09 22:01:45 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0024/
16/09/09 22:01:45 INFO mapreduce.Job: Running job: job_1473444507507_0024
16/09/09 22:01:53 INFO mapreduce.Job: Job job_1473444507507_0024 running in uber
 mode : false
16/09/09 22:01:53 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 22:02:01 INFO mapreduce.Job:  map 50% reduce 0%
16/09/09 22:02:02 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 22:02:10 INFO mapreduce.Job:  map 100% reduce 50%
16/09/09 22:02:11 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 22:02:11 INFO mapreduce.Job: Job job_1473444507507_0024 completed succe
ssfully
16/09/09 22:02:11 INFO mapreduce.Job: Counters: 51
        File System Counters
                FILE: Number of bytes read=12
                FILE: Number of bytes written=474206
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=0
                HDFS: Number of read operations=12
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=4
        Job Counters
                Launched map tasks=2
                Launched reduce tasks=2
                Data-local map tasks=2
                Total time spent by all maps in occupied slots (ms)=11754
                Total time spent by all reduces in occupied slots (ms)=11915
                Total time spent by all map tasks (ms)=11754
                Total time spent by all reduce tasks (ms)=11915
                Total vcore-seconds taken by all map tasks=11754
                Total vcore-seconds taken by all reduce tasks=11915
                Total megabyte-seconds taken by all map tasks=12036096
                Total megabyte-seconds taken by all reduce tasks=12200960
        Map-Reduce Framework
                Map input records=100
                Map output records=0
                Map output bytes=0
                Map output materialized bytes=24
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=0
                Reduce shuffle bytes=24
                Reduce input records=0
```

### HW2.3.1 Learn a Multinomial Naive Bayes model

## Chinese Data Set

In [111]:
```
%%writefile ChineseExample_Train.txt
D1      1       Chinese Beijing Chinese
D2      1       Chinese Chinese Shanghai
D3      1       Chinese Macao
D4      0       Tokyo Japan Chinese
```

```
Overwriting ChineseExample_Train.txt
```

In [112]:
```
%%writefile mapper_t_ch.py
#!/usr/bin/python
import sys, re, string
# define regex for punctuation removal
regex = re.compile('[%s]' % re.escape(string.punctuation))
# input comes from STDIN (standard input)
for line in sys.stdin:
    # use contenty
    msg = line.split('\t', 2)
    if len(msg) < 3:
        continue
    msgID, isChina = msg[0], msg[1]

    # remove punctuations, only have white-space as delimiter
    words = regex.sub(' ', msg[-1].lower())
    # split the line into words
    words = words.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output);
        print '%s\t%d\t%s\t%s' % (word, 1, isChina, msgID)
```

```
Overwriting mapper_t_ch.py
```

In [117]:
```
%%writefile reducer_t_ch.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator
import numpy as np

tmp_word = None
smooth_factor = 0 # no smoothing
# because no smoothing, so count from zero for isChina and nonChina cases
tmp_count = [smooth_factor, smooth_factor]
msgIDs = {}
word = None
# key is words, values are word probability at isChina class and nonChina class, r
espectively
wordcount = {}

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper
    word, count, isChina, msgID = line.split('\t', 3)

    # convert to int
    try:
        count = int(count)
        isChina = int(isChina)
    except ValueError:
        continue

    # Used to count how many training items are at China category
    if msgID not in msgIDs:
        msgIDs[msgID] = isChina

    if tmp_word == word:
        tmp_count[isChina] += count
    else:
        if tmp_word:
            # count finish so save it
            wordcount[tmp_word] = tmp_count
        # begin new count for new word
        tmp_count = [smooth_factor, smooth_factor]
        tmp_count[isChina] = count
        tmp_word = word

# Last word count!
if tmp_word == word:
    wordcount[tmp_word] = tmp_count

# calculate NB parameters, and write to a file for the classification job
# prior probabilities
n_msg = len(msgIDs)
n_China = sum(msgIDs.values())
n_not_China = n_msg - n_China
print '%s\t%s\t%s' %('prior_prob', 1.0*n_not_China/n_msg, 1.0*n_China/n_msg)

# conditional probabilities for each class
n_total = np.sum(wordcount.values(), 0)
for (key,value) in zip(wordcount.keys(), wordcount.values()/(1.0*n_total)):
    print '%s\t%s\t%s' %(key, value[0], value[1])
```

```
Overwriting reducer_t_ch.py
```

**Systems test for Chinese data set**

In [119]:
```
!chmod a+x mapper_t_ch.py
!chmod a+x reducer_t_ch.py
#Systems test the mapper and reducer
!cat ChineseExample_Train.txt | ./mapper_t_ch.py | sort -k1,1 | ./reducer_t_ch.py
> Chinese_probabilities.txt
!cat Chinese_probabilities.txt
### They agree with hand calculated at HW2.3.2
```

```
prior_prob      0.25    0.75
beijing 0.0     0.125
chinese 0.333333333333  0.625
tokyo   0.333333333333  0.0
shanghai        0.0     0.125
japan   0.333333333333  0.0
macao   0.0     0.125
```

## HW2.3.2 Learn a multinomial naive Bayes model (with no smoothing) by hand

From formula

$$P(C|D) = \frac{P(D|C)P(C)}{P(D)},$$

where C represents category variable and D represents observation. Since our goal is to obtain $P(C|D)$, we have to evaluate $P(D|C)$ and $P(C)$ first.

Priori and conditional probabilities tables for Chinese Data Set:

| **Prob** | $c_1$ **= China** | $c_0$ **= not China** | |
|---|---|---|---|
| Prior, $P(C = c_i)$ | 3/4 | 1/4 | |
| $P(Chinese | C = c_i)$ | 5/8 | 1/3 |
| $P(Beijing | C = c_i)$ | 1/8 | 0 |
| $P(Shanghai | C = c_i)$ | 1/8 | 0 |
| $P(Macao | C = c_i)$ | 1/8 | 0 |
| $P(Tokyo | C = c_i)$ | 0 | 1/3 |
| $P(Japan | C = c_i)$ | 0 | 1/3 |

Classifier:

Given $D_5$ as observation, it can be classfied by comparing probabilities of $P(D_5|C = c_0)$ and $P(D_5|C = c_1)$. Since

%%latex

$$P(D_5|C = c_0) = P(Chinese|C = c_0)^3 P(Tokyo|C = c_0) P(Japan|C = c_0) = 1/243$$

and

%%latex

$$P(D_5|C = c_1) = P(Chinese|C = c_1)^3 P(Tokyo|C = c_1) P(Japan|C = c_1) = 0$$

Therefore,

%%latex \begin{align} P(C = c_0 | D_5) = \alpha *P(D_5 | C = c_0) P(C = c_0)* = *alpha* 1/243 * 1/4 \end{align}

and

%%latex \begin{align} P(C = c_1 | D_5) = \alpha *P(D_5 | C = c_1) P(C = c_1)* = *alpha* 0 * 3/4 \end{align}

Finally, since $P(C = c_0|D_5)$ is greter then $P(C = c_1|D_5)$, $D_5$ will be classified as non China. This classification result is totally different from smoothing case that presented at attached file.

## HW2.3.3 Learn a multinomial naive Bayes model (with no smoothing) for SPAM filtering

Save model as SPAM_Model_MNB.tsv.

In [120]:
```
%%writefile mapper_t_em.py
#!/usr/bin/python
import sys, re, string
# define regex for punctuation removal
regex = re.compile('[%s]' % re.escape(string.punctuation))
# input comes from STDIN (standard input)
for line in sys.stdin:
    # use email subject and body
    msg = line.split('\t', 2)
    if len(msg) <= 2:
        continue
    msgID, isSpam = msg[0], msg[1]

    # remove punctuations, only have white-space as delimiter
    words = regex.sub(' ', msg[-1].lower())
    # split the line into words
    words = words.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output);
        print '%s\t%d\t%s\t%s' % (word, 1, isSpam, msgID)
```

```
Overwriting mapper_t_em.py
```

In [121]:
```
%%writefile reducer_t_em.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator
import numpy as np

tmp_word = None
smooth_factor = 0 # no smoothing
# because no smoothing, so count from zero for isChina and nonChina cases
tmp_count = [smooth_factor, smooth_factor]
msgIDs = {}
word = None
# key is words, values are word probability at isChina class and nonChina class, r
espectively
wordcount = {}

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper
    word, count, isSpam, msgID = line.split('\t', 3)

    # convert to int
    try:
        count = int(count)
        isSpam = int(isSpam)
    except ValueError:
        continue

    # Used to count how many training items are at SPAM emails category
    if msgID not in msgIDs:
        msgIDs[msgID] = isSpam

    if tmp_word == word:
        tmp_count[isSpam] += count
    else:
        if tmp_word:
            # count finish so save it
            wordcount[tmp_word] = tmp_count
        # begin new count for new word
        tmp_count = [smooth_factor, smooth_factor]
        tmp_count[isSpam] = count
        tmp_word = word

# Last word count!
if tmp_word == word:
    wordcount[tmp_word] = tmp_count

# calculate NB parameters, and write to a file for the classification job
# prior probabilities
n_msg = len(msgIDs)
n_Spam = sum(msgIDs.values())
n_Ham = n_msg - n_Spam
print '%s\t%s\t%s' %('prior_prob', 1.0*n_Ham/n_msg, 1.0*n_Spam/n_msg)

# conditional probabilities for each class
n_total = np.sum(wordcount.values(), 0)
for (key,value) in zip(wordcount.keys(), wordcount.values()/(1.0*n_total)):
    print '%s\t%s\t%s' %(key, value[0], value[1])
```

```
Overwriting reducer_t_em.py
```

In [123]:
```
!chmod a+x mapper_t_em.py
!chmod a+x reducer_t_em.py
!hdfs dfs -rm -r prob_em
!rm SPAM_Model_MNB.tsv
# run training job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_t_em.py \
-reducer /home/cloudera/reducer_t_em.py \
-input /user/shihyu/enronemail_1h.txt \
-output prob_em
!hadoop fs -mv  prob_em/part-00000 /user/shihyu/SPAM_Model_MNB.tsv
!hadoop fs -get /user/shihyu/SPAM_Model_MNB.tsv

### output prob will be write in a file SPAM_Model_MNB.tsv.###
```

```
Deleted prob_em
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob1804159925030180330.jar tmpDir=null
16/09/09 22:31:31 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 22:31:31 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 22:31:32 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 22:31:32 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 22:31:32 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0026
16/09/09 22:31:33 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0026
16/09/09 22:31:33 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0026/
16/09/09 22:31:33 INFO mapreduce.Job: Running job: job_1473444507507_0026
16/09/09 22:31:40 INFO mapreduce.Job: Job job_1473444507507_0026 running in uber
 mode : false
16/09/09 22:31:40 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 22:31:48 INFO mapreduce.Job:  map 50% reduce 0%
16/09/09 22:31:49 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 22:31:55 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 22:31:55 INFO mapreduce.Job: Job job_1473444507507_0026 completed succe
ssfully
16/09/09 22:31:55 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=1172006
                FILE: Number of bytes written=2699652
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=173923
                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)=12593
                Total time spent by all reduces in occupied slots (ms)=4298
                Total time spent by all map tasks (ms)=12593
                Total time spent by all reduce tasks (ms)=4298
                Total vcore-seconds taken by all map tasks=12593
                Total vcore-seconds taken by all reduce tasks=4298
                Total megabyte-seconds taken by all map tasks=12895232
                Total megabyte-seconds taken by all reduce tasks=4401152
        Map-Reduce Framework
                Map input records=100
                Map output records=33203
                Map output bytes=1105594
                Map output materialized bytes=1172012
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=5408
                Reduce shuffle bytes=1172012
                Reduce input records=33203
                Reduce output records=5409
                Spilled Records=66406
                Shuffled Maps =2
                Failed Shuffles=0
                Merged Map outputs=2
```

Top 10 and bottom 10 model entries

In [134]:
```
### Buttom 10
!cat SPAM_Model_MNB.tsv | sort -k1,1 -r | head -n 10 > a
!cat a
```

```
sort: write failed: standard output: Broken pipe
sort: write error
zxs     0.0     5.29464711177e-05
zolam   0.0     0.000105892942235
zo      0.0     0.000105892942235
zk      0.0     5.29464711177e-05
zinc    0.0     5.29464711177e-05
zimin   0.000349259569712       0.0
zesto   0.0     0.000529464711177
zero    0.000209555741827       5.29464711177e-05
zadorozhny      0.00027940765577        0.0
zac     0.0     0.000105892942235
```

In [135]:
```
### Top 10
!cat SPAM_Model_MNB.tsv | sort -k1,1 | head -n 10 > a
!cat a
```

```
sort: write failed: standard output: Broken pipe
sort: write error
        0.00146689019279        0.0
0       0.0     0.000317678826706
00      0.00132718636491        0.000741250595648
000     0.00174629784856        0.00142955472018
001     0.000139703827885       5.29464711177e-05
0011    6.98519139424e-05       0.0
00450   0.0     5.29464711177e-05
0080    0.0     5.29464711177e-05
01      0.00125733445096        0.000370625297824
012     0.00027940765577        0.0
```

## HW 2.3.4 Classify Documents using the learnt Multinomial Naive Bayes model using Hadoop Streaming

Unit test your classifier map reduce job using the Chinese example. Input $D_5$, output $0$, not China.

In [141]:
```
%%writefile ChineseExample_Test.txt
D1      1       Chinese Beijing Chinese
D2      1       Chinese Chinese Shanghai
D3      1       Chinese Macao
D4      0       Tokyo Japan Chinese
D5      0       Chinese Chinese Chinese Tokyo Japan
```

```
Overwriting ChineseExample_Test.txt
```

In [146]:
```
!hdfs dfs -put Chinese_probabilities.txt /user/shihyu
```

```
put: `/user/shihyu/Chinese_probabilities.txt': File exists
```

In [152]:
```
%%writefile mapper_c_ch.py
#!/usr/bin/python
import sys, re, string, subprocess
# read the probabilities from Chinese_probabilities.txt
prob = {}
cat = subprocess.Popen(["hadoop", "fs", "-cat", "/user/shihyu/Chinese_probabilitie
s.txt"], stdout=subprocess.PIPE)
### Prepare key (word) values (conditional prob at each class) pair
for line in cat.stdout:
        word, p0, p1 = line.split()
        prob[word] = [p0, p1]

# get prior probability
prior = prob['prior_prob']

# define regex for punctuation removal
regex = re.compile('[%s]' % re.escape(string.punctuation))
# input comes from STDIN (standard input)
for line in sys.stdin:
    # use content
    msg = line.split('\t', 2)
    # skip strange message
    if len(msg) < 3:
        continue
    msgID, isChina = msg[0], msg[1]
    # remove punctuations, only have white-space as delimiter
    words = regex.sub(' ', msg[-1].lower())
    # split the line into words
    words = words.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output);

        print '%s\t%s\t%s\t%s\t%s\t%s' % (msgID, prob[word][0], prob[word][1], isC
hina, prior[0], prior[1])
```

```
Overwriting mapper_c_ch.py
```

In [160]:
```
%%writefile reducer_c_ch.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator, math
import numpy as np

tmp_msg = None
tmp_prob = [0, 0]
tmp_truth = 0
msgID = None
n_error = 0
n_msg = 0
n_zero = [0, 0]


print '%s\t%s\t%s' %('ID', 'TRUTH', 'PREDICTION')
# input comes from STDIN
for line in sys.stdin:
    #print line
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper_c.py
    msgID, p0, p1, isChina, pr0, pr1 = line.split('\t')
    prob = [float(p0), float(p1)]

    # convert count and spam flag (currently a string) to int
    try:
        isChina = int(isChina)
    except ValueError:
        continue

    # get posterior prob assume independence
    if tmp_msg == msgID:
        # by considering zero prob
        tmp_prob = np.sum([[math.log(x) if x>0 else float('-inf') for x in prob],
tmp_prob], 0)
    else:
        if tmp_msg:
            # count finish for current word, predict and print result
            pred = np.argmax(tmp_prob)
            n_error += pred != tmp_truth
            n_msg += 1
            n_zero[tmp_truth] += float('-inf') in tmp_prob
            print '%s\t%s\t%s' %(tmp_msg, tmp_truth, pred)

        # initialize new count for new word
        prior = [math.log(float(pr0)), math.log(float(pr1))]
        tmp_prob = np.sum([[math.log(x) if x>0 else float('-inf') for x in prob],
prior], 0)
        tmp_msg = msgID
        tmp_truth = isChina

# do not forget to print the last msg
if tmp_msg == msgID:
    pred = np.argmax(tmp_prob)
    n_error += pred != isChina
    n_msg += 1
    n_zero[tmp_truth] += float('-inf') in tmp_prob
    print '%s\t%s\t%s' %(msgID, tmp_truth, pred)

# calculate the overall error rate
print 'Error rate is: %.f' %(1.0*n_error/n_msg)
print 'Number of messages with zero probability: China(%d), non China(%d)' %(n_zer
```

```
Overwriting reducer_c_ch.py
```

In [161]:
```
# clean up HDFS
!chmod a+x mapper_c_ch.py
!chmod a+x reducer_c_ch.py
!hdfs dfs -put ChineseExample_Test.txt /user/shihyu

!hdfs dfs -rm -r Chinese_classification_results
# run classification job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_c_ch.py \
-reducer /home/cloudera/reducer_c_ch.py \
-input /user/shihyu/ChineseExample_Test.txt \
-output Chinese_classification_results
```

```
put: `/user/shihyu/ChineseExample_Test.txt': File exists
Deleted Chinese_classification_results
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob2950033205685806109.jar tmpDir=null
16/09/09 23:30:22 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 23:30:23 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/09 23:30:24 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/09 23:30:24 INFO mapreduce.JobSubmitter: number of splits:2
16/09/09 23:30:24 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0035
16/09/09 23:30:25 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0035
16/09/09 23:30:25 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0035/
16/09/09 23:30:25 INFO mapreduce.Job: Running job: job_1473444507507_0035
16/09/09 23:30:33 INFO mapreduce.Job: Job job_1473444507507_0035 running in uber
 mode : false
16/09/09 23:30:33 INFO mapreduce.Job:  map 0% reduce 0%
16/09/09 23:30:47 INFO mapreduce.Job:  map 33% reduce 0%
16/09/09 23:30:48 INFO mapreduce.Job:  map 100% reduce 0%
16/09/09 23:30:55 INFO mapreduce.Job:  map 100% reduce 100%
16/09/09 23:30:55 INFO mapreduce.Job: Job job_1473444507507_0035 completed succe
ssfully
16/09/09 23:30:56 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=573
                FILE: Number of bytes written=356873
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=453
                HDFS: Number of bytes written=139
                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)=26415
                Total time spent by all reduces in occupied slots (ms)=4321
                Total time spent by all map tasks (ms)=26415
                Total time spent by all reduce tasks (ms)=4321
                Total vcore-seconds taken by all map tasks=26415
                Total vcore-seconds taken by all reduce tasks=4321
                Total megabyte-seconds taken by all map tasks=27048960
                Total megabyte-seconds taken by all reduce tasks=4424704
        Map-Reduce Framework
                Map input records=5
                Map output records=16
                Map output bytes=535
                Map output materialized bytes=579
                Input split bytes=238
                Combine input records=0
                Combine output records=0
                Reduce input groups=5
                Reduce shuffle bytes=579
                Reduce input records=16
                Reduce output records=8
                Spilled Records=32
                Shuffled Maps =2
                Failed Shuffles=0
```

In [162]:
```
!hdfs dfs -cat Chinese_classification_results/part-00000
```

```
ID      TRUTH   PREDICTION
D1      1       1
D2      1       1
D3      1       1
D4      0       0
D5      0       0
Error rate is: 0
Number of messages with zero probability: China(3), non China(2)
```

### Classification for emails

In [180]:
```
%%writefile mapper_c_em.py
#!/usr/bin/python
import sys, re, string, subprocess
# read the probability prob_em from HDFS
prob = {}
cat = subprocess.Popen(["hadoop", "fs", "-cat", "/user/cloudera/prob_em/part-00000
"], stdout=subprocess.PIPE)
### Prepare key (word) values (conditional prob at each class) pair
for line in cat.stdout:
    word, p0, p1 = line.split()
    prob[word] = [p0, p1]
    print '%s\n' % (word)

# get prior probability
prior = prob['prior_prob']

# define regex for punctuation removal
regex = re.compile('[%s]' % re.escape(string.punctuation))
# input comes from STDIN (standard input)
for line in sys.stdin:
    # use subject and body
    msg = line.split('\t', 2)
    # skip bad message
    if len(msg) < 3:
        continue
    msgID, isSpam = msg[0], msg[1]
    # remove punctuations, only have white-space as delimiter
    words = regex.sub(' ', msg[-1].lower())
    # split the line into words
    words = words.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output);

        print '%s\t%s\t%s\t%s\t%s\t%s' % (msgID, prob[word][0], prob[word][1], isS
pam, prior[0], prior[1])
```

```
Overwriting mapper_c_em.py
```

In [192]:
```
%%writefile reducer_c_em.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator, math
import numpy as np

tmp_msg = None
tmp_prob = [0, 0]
tmp_truth = 0
msgID = None
n_error = 0
n_msg = 0
n_zero = [0, 0]

print '%s\t%s\t%s' %('EMAIL ID', 'TRUTH', 'PREDICTION')
# input comes from STDIN
for line in sys.stdin:
    #print line
    # remove leading and trailing whitespace
    line = line.strip()
    try:
        msgID, p0, p1, isSpam, pr0, pr1 = line.split('\t')
    except ValueError:

        continue



    prob = [float(p0), float(p1)]

    # convert count and spam flag (currently a string) to int
    try:
        isSpam = int(isSpam)
    except ValueError:

        continue

    if tmp_msg == msgID:
        tmp_prob = np.sum([[math.log(x) if x>0 else float('-inf') for x in prob],
tmp_prob], 0)
    else:
        if tmp_msg:
            # count finish for current word, predict and print result
            pred = np.argmax(tmp_prob)
            n_error += pred != tmp_truth
            n_msg += 1
            n_zero[tmp_truth] += float('-inf') in tmp_prob
            print '%s\t%s\t%s' %(tmp_msg, tmp_truth, pred)

        # initialize new count for new word
        prior = [math.log(float(pr0)), math.log(float(pr1))]
        tmp_prob = np.sum([[math.log(x) if x>0 else float('-inf') for x in prob],
prior], 0)
        tmp_msg = msgID
        tmp_truth = isSpam

# do not forget to print the last msg result if needed!
if tmp_msg == msgID:
    pred = np.argmax(tmp_prob)
    n_error += pred != isSpam
    n_msg += 1
    n_zero[tmp_truth] += float('-inf') in tmp_prob
    print '%s\t%s\t%s' %(msgID, tmp_truth, pred)
```

```
Overwriting reducer_c_em.py
```

In [186]:
```
!chmod a+x mapper_t_em.py
!chmod a+x reducer_t_em.py
!hdfs dfs -rm -r prob_em

# run training job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_t_em.py \
-reducer /home/cloudera/reducer_t_em.py \
-input /user/shihyu/enronemail_1h.txt \
-output prob_em

# clean up HDFS
!chmod a+x mapper_c_em.py
!chmod a+x reducer_c_em.py

!hdfs dfs -rm -r Emails_classification_results
# run classification job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_c_em.py \
-reducer /home/cloudera/reducer_c_em.py \
-input /user/shihyu/enronemail_1h.txt \
-output Emails_classification_results
```

```
Deleted prob_em
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob4653791537771942229.jar tmpDir=null
16/09/10 05:47:18 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 05:47:18 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 05:47:19 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/10 05:47:19 INFO mapreduce.JobSubmitter: number of splits:2
16/09/10 05:47:19 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0049
16/09/10 05:47:19 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0049
16/09/10 05:47:19 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0049/
16/09/10 05:47:19 INFO mapreduce.Job: Running job: job_1473444507507_0049
16/09/10 05:47:27 INFO mapreduce.Job: Job job_1473444507507_0049 running in uber
 mode : false
16/09/10 05:47:27 INFO mapreduce.Job:  map 0% reduce 0%
16/09/10 05:47:36 INFO mapreduce.Job:  map 100% reduce 0%
16/09/10 05:47:43 INFO mapreduce.Job:  map 100% reduce 100%
16/09/10 05:47:44 INFO mapreduce.Job: Job job_1473444507507_0049 completed succe
ssfully
16/09/10 05:47:44 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=1172006
                FILE: Number of bytes written=2699652
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=173923
                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)=13838
                Total time spent by all reduces in occupied slots (ms)=4599
                Total time spent by all map tasks (ms)=13838
                Total time spent by all reduce tasks (ms)=4599
                Total vcore-seconds taken by all map tasks=13838
                Total vcore-seconds taken by all reduce tasks=4599
                Total megabyte-seconds taken by all map tasks=14170112
                Total megabyte-seconds taken by all reduce tasks=4709376
        Map-Reduce Framework
                Map input records=100
                Map output records=33203
                Map output bytes=1105594
                Map output materialized bytes=1172012
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=5408
                Reduce shuffle bytes=1172012
                Reduce input records=33203
                Reduce output records=5409
                Spilled Records=66406
                Shuffled Maps =2
                Failed Shuffles=0
                Merged Map outputs=2
                GC time elapsed (ms)=144
```

In [187]:
```
!hdfs dfs -cat Emails_classification_results/part-00000
```

| EMAIL ID | TRUTH | PREDICTION | |
|---|---|---|---|
| 0001.1999-12-10.farmer | 0 | 0 | |
| 0001.1999-12-10.kaminski | | 0 | 0 |
| 0001.2000-01-17.beck | 0 | 0 | |
| 0001.2000-06-06.lokay | 0 | 0 | |
| 0001.2001-02-07.kitchen | 0 | 0 | |
| 0001.2001-04-02.williams | | 0 | 0 |
| 0002.1999-12-13.farmer | 0 | 0 | |
| 0002.2001-02-07.kitchen | 0 | 0 | |
| 0002.2001-05-25.SA_and_HP | | 1 | 1 |
| 0002.2003-12-18.GP | 1 | 1 | |
| 0002.2004-08-01.BG | 1 | 1 | |
| 0003.1999-12-10.kaminski | | 0 | 0 |
| 0003.1999-12-14.farmer | 0 | 0 | |
| 0003.2000-01-17.beck | 0 | 0 | |
| 0003.2001-02-08.kitchen | 0 | 0 | |
| 0003.2003-12-18.GP | 1 | 1 | |
| 0003.2004-08-01.BG | 1 | 1 | |
| 0004.1999-12-10.kaminski | | 0 | 0 |
| 0004.1999-12-14.farmer | 0 | 0 | |
| 0004.2001-04-02.williams | | 0 | 0 |
| 0004.2001-06-12.SA_and_HP | | 1 | 1 |
| 0004.2004-08-01.BG | 1 | 1 | |
| 0005.1999-12-12.kaminski | | 0 | 0 |
| 0005.1999-12-14.farmer | 0 | 0 | |
| 0005.2000-06-06.lokay | 0 | 0 | |
| 0005.2001-02-08.kitchen | 0 | 0 | |
| 0005.2001-06-23.SA_and_HP | | 1 | 1 |
| 0005.2003-12-18.GP | 1 | 1 | |
| 0006.1999-12-13.kaminski | | 0 | 0 |
| 0006.2001-02-08.kitchen | 0 | 0 | |
| 0006.2001-04-03.williams | | 0 | 0 |
| 0006.2001-06-25.SA_and_HP | | 1 | 1 |
| 0006.2003-12-18.GP | 1 | 1 | |
| 0006.2004-08-01.BG | 1 | 1 | |
| 0007.1999-12-13.kaminski | | 0 | 0 |
| 0007.1999-12-14.farmer | 0 | 0 | |
| 0007.2000-01-17.beck | 0 | 0 | |
| 0007.2001-02-09.kitchen | 0 | 0 | |
| 0007.2003-12-18.GP | 1 | 1 | |
| 0007.2004-08-01.BG | 1 | 1 | |
| 0008.2001-02-09.kitchen | 0 | 0 | |
| 0008.2001-06-12.SA_and_HP | | 1 | 1 |
| 0008.2001-06-25.SA_and_HP | | 1 | 1 |
| 0008.2003-12-18.GP | 1 | 1 | |
| 0008.2004-08-01.BG | 1 | 1 | |
| 0009.1999-12-13.kaminski | | 0 | 0 |
| 0009.1999-12-14.farmer | 0 | 0 | |
| 0009.2000-06-07.lokay | 0 | 0 | |
| 0009.2001-02-09.kitchen | 0 | 0 | |
| 0009.2001-06-26.SA_and_HP | | 1 | 1 |
| 0009.2003-12-18.GP | 1 | 1 | |
| 0010.1999-12-14.farmer | 0 | 0 | |
| 0010.1999-12-14.kaminski | | 0 | 0 |
| 0010.2001-02-09.kitchen | 0 | 0 | |
| 0010.2001-06-28.SA_and_HP | | 1 | 1 |
| 0010.2003-12-18.GP | 1 | 1 | |
| 0010.2004-08-01.BG | 1 | 1 | |
| 0011.1999-12-14.farmer | 0 | 0 | |
| 0011.2001-06-28.SA_and_HP | | 1 | 1 |
| 0011.2001-06-29.SA_and_HP | | 1 | 1 |
| 0011.2003-12-18.GP | 1 | 1 | |
| 0011.2004-08-01.BG | 1 | 1 | |
| 0012.1999-12-14.farmer | 0 | 0 | |

Plot a histogram of the posterior probabilities. Since the NB posterior probability is:

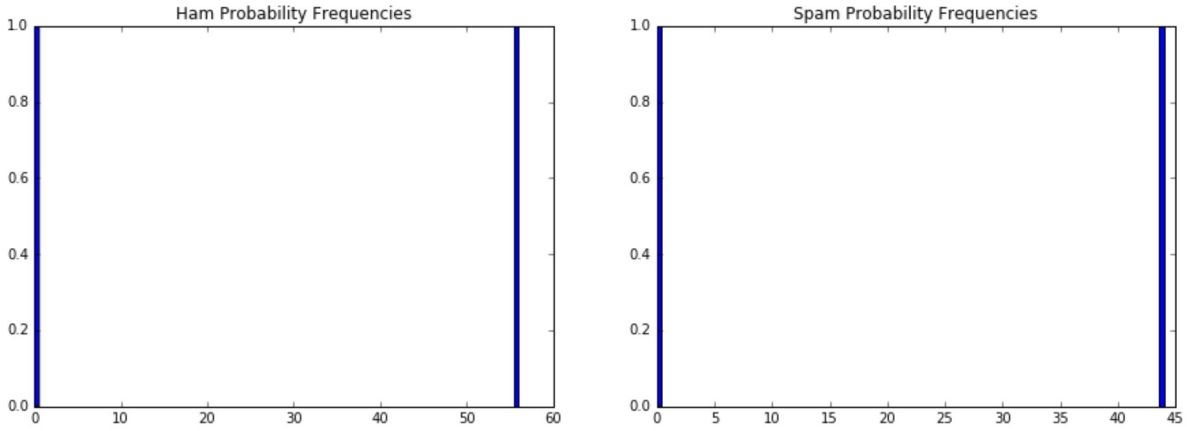
$$P(C = c_j \mid X_1, X_2, \ldots, X_n) = \frac{P(C = c_j) \prod_i P(X_i \mid C = c_i)}{\sum_k P(C = c_k) \prod_i P(X_i \mid C = c_k)}$$

where $C$ is email category and $X_i$ are wrods. The conditional probability of those words for the opposite category, $P(X_i \mid C = c_k)$, are zero, and this will make one term on the denominator become zero. Therefore, posterior probability is 1 for the category that contains all the words from same category, and 0 for the other category. Hisogram is shown below

In [218]:
```
%matplotlib inline
import numpy as np
import matplotlib.pyplot as plt
# 44 spam and 56 ham all has posterior probability of 1
spam = (0,44)
ham = (0,56)
plt.figure(figsize=(15,5))
p = plt.subplot(1, 2, 1)
p.hist(ham,100)
plt.title('Ham Probability Frequencies')

p = plt.subplot(1, 2, 2)
p.hist(spam,100)
plt.title('Spam Probability Frequencies')
```

Out[218]:
```
<matplotlib.text.Text at 0x7f78f1abf090>
```




## HW2.4 Use Laplace plus-one smoothing

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Repeat HW2.3 with the following modification: use Laplace plus-one smoothing.

In addition, compare the misclassifcation error rates for 2.3 versus 2.4 and explain the differences.

In [193]:
```
%%writefile reducer_t_em_s.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator
import numpy as np

tmp_word = None
smooth_factor = 1 # because smoothing
# because smoothing, so count from ONE
tmp_count = [smooth_factor, smooth_factor]
msgIDs = {}
word = None
# key is words, values are word probability at isChina class and nonChina class, r
espectively
wordcount = {}

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper
    word, count, isSpam, msgID = line.split('\t', 3)

    # convert to int
    try:
        count = int(count)
        isSpam = int(isSpam)
    except ValueError:
        continue

    # Used to count how many training items are at SPAM emails category
    if msgID not in msgIDs:
        msgIDs[msgID] = isSpam

    if tmp_word == word:
        tmp_count[isSpam] += count
    else:
        if tmp_word:
            # count finish so save it
            wordcount[tmp_word] = tmp_count
        # begin new count for new word
        tmp_count = [smooth_factor, smooth_factor]
        tmp_count[isSpam] = count
        tmp_word = word

# Last word count!
if tmp_word == word:
    wordcount[tmp_word] = tmp_count

# calculate NB parameters, and write to a file for the classification job
# prior probabilities
n_msg = len(msgIDs)
n_Spam = sum(msgIDs.values())
n_Ham = n_msg - n_Spam
print '%s\t%s\t%s' %('prior_prob', 1.0*n_Ham/n_msg, 1.0*n_Spam/n_msg)

# conditional probabilities for each class
n_total = np.sum(wordcount.values(), 0)
for (key,value) in zip(wordcount.keys(), wordcount.values()/(1.0*n_total)):
    print '%s\t%s\t%s' %(key, value[0], value[1])
```

```
Overwriting reducer_t_em_s.py
```

In [194]:
```
!chmod a+x mapper_t_em.py
!chmod a+x reducer_t_em_s.py
!hdfs dfs -rm -r prob_em

# run training job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_t_em.py \
-reducer /home/cloudera/reducer_t_em_s.py \
-input /user/shihyu/enronemail_1h.txt \
-output prob_em

# clean up HDFS
!chmod a+x mapper_c_em.py
!chmod a+x reducer_c_em.py

!hdfs dfs -rm -r Emails_classification_results_s
# run classification job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_c_em.py \
-reducer /home/cloudera/reducer_c_em.py \
-input /user/shihyu/enronemail_1h.txt \
-output Emails_classification_results_s
```

```
Deleted prob_em
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob5515545378449372430.jar tmpDir=null
16/09/10 06:03:36 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 06:03:36 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 06:03:37 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/10 06:03:38 INFO mapreduce.JobSubmitter: number of splits:2
16/09/10 06:03:38 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0053
16/09/10 06:03:38 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0053
16/09/10 06:03:38 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0053/
16/09/10 06:03:38 INFO mapreduce.Job: Running job: job_1473444507507_0053
16/09/10 06:03:44 INFO mapreduce.Job: Job job_1473444507507_0053 running in uber
 mode : false
16/09/10 06:03:44 INFO mapreduce.Job:  map 0% reduce 0%
16/09/10 06:03:52 INFO mapreduce.Job:  map 50% reduce 0%
16/09/10 06:03:53 INFO mapreduce.Job:  map 100% reduce 0%
16/09/10 06:04:01 INFO mapreduce.Job:  map 100% reduce 100%
16/09/10 06:04:01 INFO mapreduce.Job: Job job_1473444507507_0053 completed succe
ssfully
16/09/10 06:04:01 INFO mapreduce.Job: Counters: 50
        File System Counters
                FILE: Number of bytes read=1172006
                FILE: Number of bytes written=2699658
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=234964
                HDFS: Number of read operations=9
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Killed map tasks=1
                Launched map tasks=2
                Launched reduce tasks=1
                Data-local map tasks=2
                Total time spent by all maps in occupied slots (ms)=11916
                Total time spent by all reduces in occupied slots (ms)=4755
                Total time spent by all map tasks (ms)=11916
                Total time spent by all reduce tasks (ms)=4755
                Total vcore-seconds taken by all map tasks=11916
                Total vcore-seconds taken by all reduce tasks=4755
                Total megabyte-seconds taken by all map tasks=12201984
                Total megabyte-seconds taken by all reduce tasks=4869120
        Map-Reduce Framework
                Map input records=100
                Map output records=33203
                Map output bytes=1105594
                Map output materialized bytes=1172012
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=5408
                Reduce shuffle bytes=1172012
                Reduce input records=33203
                Reduce output records=5409
                Spilled Records=66406
                Shuffled Maps =2
                Failed Shuffles=0
```

In [195]:
```
!hdfs dfs -cat Emails_classification_results_s/part-00000
```

| EMAIL ID | TRUTH | PREDICTION | |
|---|---|---|---|
| 0001.1999-12-10.farmer | 0 | 0 | |
| 0001.1999-12-10.kaminski | | 0 | 0 |
| 0001.2000-01-17.beck | 0 | 0 | |
| 0001.2000-06-06.lokay | 0 | 0 | |
| 0001.2001-02-07.kitchen | 0 | 0 | |
| 0001.2001-04-02.williams | | 0 | 0 |
| 0002.1999-12-13.farmer | 0 | 0 | |
| 0002.2001-02-07.kitchen | 0 | 0 | |
| 0002.2001-05-25.SA_and_HP | | 1 | 1 |
| 0002.2003-12-18.GP | 1 | 1 | |
| 0002.2004-08-01.BG | 1 | 1 | |
| 0003.1999-12-10.kaminski | | 0 | 0 |
| 0003.1999-12-14.farmer | 0 | 0 | |
| 0003.2000-01-17.beck | 0 | 0 | |
| 0003.2001-02-08.kitchen | 0 | 0 | |
| 0003.2003-12-18.GP | 1 | 1 | |
| 0003.2004-08-01.BG | 1 | 1 | |
| 0004.1999-12-10.kaminski | | 0 | 0 |
| 0004.1999-12-14.farmer | 0 | 0 | |
| 0004.2001-04-02.williams | | 0 | 0 |
| 0004.2001-06-12.SA_and_HP | | 1 | 1 |
| 0004.2004-08-01.BG | 1 | 1 | |
| 0005.1999-12-12.kaminski | | 0 | 0 |
| 0005.1999-12-14.farmer | 0 | 0 | |
| 0005.2000-06-06.lokay | 0 | 0 | |
| 0005.2001-02-08.kitchen | 0 | 0 | |
| 0005.2001-06-23.SA_and_HP | | 1 | 1 |
| 0005.2003-12-18.GP | 1 | 1 | |
| 0006.1999-12-13.kaminski | | 0 | 0 |
| 0006.2001-02-08.kitchen | 0 | 0 | |
| 0006.2001-04-03.williams | | 0 | 0 |
| 0006.2001-06-25.SA_and_HP | | 1 | 1 |
| 0006.2003-12-18.GP | 1 | 1 | |
| 0006.2004-08-01.BG | 1 | 1 | |
| 0007.1999-12-13.kaminski | | 0 | 0 |
| 0007.1999-12-14.farmer | 0 | 0 | |
| 0007.2000-01-17.beck | 0 | 0 | |
| 0007.2001-02-09.kitchen | 0 | 0 | |
| 0007.2003-12-18.GP | 1 | 1 | |
| 0007.2004-08-01.BG | 1 | 1 | |
| 0008.2001-02-09.kitchen | 0 | 0 | |
| 0008.2001-06-12.SA_and_HP | | 1 | 1 |
| 0008.2001-06-25.SA_and_HP | | 1 | 1 |
| 0008.2003-12-18.GP | 1 | 1 | |
| 0008.2004-08-01.BG | 1 | 1 | |
| 0009.1999-12-13.kaminski | | 0 | 0 |
| 0009.1999-12-14.farmer | 0 | 0 | |
| 0009.2000-06-07.lokay | 0 | 0 | |
| 0009.2001-02-09.kitchen | 0 | 0 | |
| 0009.2001-06-26.SA_and_HP | | 1 | 1 |
| 0009.2003-12-18.GP | 1 | 1 | |
| 0010.1999-12-14.farmer | 0 | 0 | |
| 0010.1999-12-14.kaminski | | 0 | 0 |
| 0010.2001-02-09.kitchen | 0 | 0 | |
| 0010.2001-06-28.SA_and_HP | | 1 | 1 |
| 0010.2003-12-18.GP | 1 | 0 | |
| 0010.2004-08-01.BG | 1 | 1 | |
| 0011.1999-12-14.farmer | 0 | 0 | |
| 0011.2001-06-28.SA_and_HP | | 1 | 1 |
| 0011.2001-06-29.SA_and_HP | | 1 | 1 |
| 0011.2003-12-18.GP | 1 | 1 | |
| 0011.2004-08-01.BG | 1 | 1 | |
| 0012.1999-12-14.farmer | 0 | 0 | |

### HW2.4 Discussion: Since smoothing essentially add noise to the data, and thus introduce some misclassification on the training set.

## HW2.5 Ignore rare words

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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. Report the error and the change in error.

In [196]:
```
%%writefile reducer_t_em_I.py
#!/usr/bin/python
from operator import itemgetter
import sys, operator
import numpy as np

tmp_word = None
smooth_factor = 0 # no smoothing
# because no smoothing, so count from zero for isChina and nonChina cases
tmp_count = [smooth_factor, smooth_factor]
msgIDs = {}
word = None
# key is words, values are word probability at isChina class and nonChina class, r
espectively
wordcount = {}

# input comes from STDIN
for line in sys.stdin:
    # remove leading and trailing whitespace
    line = line.strip()

    # parse the input we got from mapper
    word, count, isSpam, msgID = line.split('\t', 3)

    # convert to int
    try:
        count = int(count)
        isSpam = int(isSpam)
    except ValueError:
        continue

    # Used to count how many training items are at SPAM emails category
    if msgID not in msgIDs:
        msgIDs[msgID] = isSpam

    if tmp_word == word:
        tmp_count[isSpam] += count
    else:
        if tmp_word:
            # count finish so save it
            wordcount[tmp_word] = tmp_count
        # begin new count for new word
        tmp_count = [smooth_factor, smooth_factor]
        tmp_count[isSpam] = count
        tmp_word = word

# Last word count!
if tmp_word == word:
    wordcount[tmp_word] = tmp_count

# calculate NB parameters, and write to a file for the classification job
# prior probabilities
n_msg = len(msgIDs)
n_Spam = sum(msgIDs.values())
n_Ham = n_msg - n_Spam
print '%s\t%s\t%s' %('prior_prob', 1.0*n_Ham/n_msg, 1.0*n_Spam/n_msg)

# conditional probabilities for each class
n_total = np.sum(wordcount.values(), 0)
for (key,value) in zip(wordcount.keys(), wordcount.values()/(1.0*n_total)):
    # only emit probability when the count (spam and ham together) is greater or e
qual than 3
    if sum(wordcount[key]) >= 3:
        print '%s\t%s\t%s' %(key, value[0], value[1])
```

```
Overwriting reducer_t_em_I.py
```

In [200]:
```
%%writefile mapper_c_em_I.py
#!/usr/bin/python
import sys, re, string, subprocess
# read the probability prob_em from HDFS
prob = {}
cat = subprocess.Popen(["hadoop", "fs", "-cat", "/user/cloudera/prob_em/part-00000
"], stdout=subprocess.PIPE)
### Prepare key (word) values (conditional prob at each class) pair
for line in cat.stdout:
    word, p0, p1 = line.split()
    prob[word] = [p0, p1]
    print '%s\n' % (word)

# get prior probability
prior = prob['prior_prob']

# define regex for punctuation removal
regex = re.compile('[%s]' % re.escape(string.punctuation))
# input comes from STDIN (standard input)
for line in sys.stdin:
    # use subject and body
    msg = line.split('\t', 2)
    # skip bad message
    if len(msg) < 3:
        continue
    msgID, isSpam = msg[0], msg[1]
    # remove punctuations, only have white-space as delimiter
    words = regex.sub(' ', msg[-1].lower())
    # split the line into words
    words = words.split()
    # increase counters
    for word in words:
        # write the results to STDOUT (standard output)
        # which has probability from training step
        if word in prob:
            print '%s\t%s\t%s\t%s\t%s\t%s' % (msgID, prob[word][0], prob[word][1],
 isSpam, prior[0], prior[1])
```

```
Overwriting mapper_c_em_I.py
```

In [201]:
```
!chmod a+x mapper_t_em.py
!chmod a+x reducer_t_em_I.py
!hdfs dfs -rm -r prob_em

# run training job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_t_em.py \
-reducer /home/cloudera/reducer_t_em_I.py \
-input /user/shihyu/enronemail_1h.txt \
-output prob_em

# clean up HDFS
!chmod a+x mapper_c_em_I.py
!chmod a+x reducer_c_em.py

!hdfs dfs -rm -r Emails_classification_results_I
# run classification job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_c_em_I.py \
-reducer /home/cloudera/reducer_c_em.py \
-input /user/shihyu/enronemail_1h.txt \
-output Emails_classification_results_I
```

```
Deleted prob_em
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob2597624802238306615.jar tmpDir=null
16/09/10 06:39:40 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 06:39:41 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 06:39:41 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/10 06:39:41 INFO mapreduce.JobSubmitter: number of splits:2
16/09/10 06:39:41 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0059
16/09/10 06:39:42 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0059
16/09/10 06:39:42 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0059/
16/09/10 06:39:42 INFO mapreduce.Job: Running job: job_1473444507507_0059
16/09/10 06:39:48 INFO mapreduce.Job: Job job_1473444507507_0059 running in uber
 mode : false
16/09/10 06:39:48 INFO mapreduce.Job:  map 0% reduce 0%
16/09/10 06:39:57 INFO mapreduce.Job:  map 100% reduce 0%
16/09/10 06:40:03 INFO mapreduce.Job:  map 100% reduce 100%
16/09/10 06:40:04 INFO mapreduce.Job: Job job_1473444507507_0059 completed succe
ssfully
16/09/10 06:40:04 INFO mapreduce.Job: Counters: 49
        File System Counters
                FILE: Number of bytes read=1172006
                FILE: Number of bytes written=2699658
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=217093
                HDFS: Number of bytes written=66986
                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)=12983
                Total time spent by all reduces in occupied slots (ms)=4557
                Total time spent by all map tasks (ms)=12983
                Total time spent by all reduce tasks (ms)=4557
                Total vcore-seconds taken by all map tasks=12983
                Total vcore-seconds taken by all reduce tasks=4557
                Total megabyte-seconds taken by all map tasks=13294592
                Total megabyte-seconds taken by all reduce tasks=4666368
        Map-Reduce Framework
                Map input records=100
                Map output records=33203
                Map output bytes=1105594
                Map output materialized bytes=1172012
                Input split bytes=226
                Combine input records=0
                Combine output records=0
                Reduce input groups=5408
                Reduce shuffle bytes=1172012
                Reduce input records=33203
                Reduce output records=1877
                Spilled Records=66406
                Shuffled Maps =2
                Failed Shuffles=0
                Merged Map outputs=2
                GC time elapsed (ms)=206
```

In [203]:
```
!hdfs dfs -cat Emails_classification_results_I/part-00000
```

| EMAIL ID | TRUTH | PREDICTION | |
|---|---|---|---|
| 0001.1999-12-10.farmer | 0 | 0 | |
| 0001.1999-12-10.kaminski | | 0 | 0 |
| 0001.2000-01-17.beck | 0 | 0 | |
| 0001.2000-06-06.lokay | 0 | 0 | |
| 0001.2001-02-07.kitchen | 0 | 0 | |
| 0001.2001-04-02.williams | | 0 | 0 |
| 0002.1999-12-13.farmer | 0 | 0 | |
| 0002.2001-02-07.kitchen | 0 | 0 | |
| 0002.2001-05-25.SA_and_HP | | 1 | 1 |
| 0002.2003-12-18.GP | 1 | 1 | |
| 0002.2004-08-01.BG | 1 | 1 | |
| 0003.1999-12-10.kaminski | | 0 | 0 |
| 0003.1999-12-14.farmer | 0 | 0 | |
| 0003.2000-01-17.beck | 0 | 0 | |
| 0003.2001-02-08.kitchen | 0 | 0 | |
| 0003.2003-12-18.GP | 1 | 1 | |
| 0003.2004-08-01.BG | 1 | 1 | |
| 0004.1999-12-10.kaminski | | 0 | 0 |
| 0004.1999-12-14.farmer | 0 | 0 | |
| 0004.2001-04-02.williams | | 0 | 0 |
| 0004.2001-06-12.SA_and_HP | | 1 | 1 |
| 0004.2004-08-01.BG | 1 | 1 | |
| 0005.1999-12-12.kaminski | | 0 | 0 |
| 0005.1999-12-14.farmer | 0 | 0 | |
| 0005.2000-06-06.lokay | 0 | 0 | |
| 0005.2001-02-08.kitchen | 0 | 0 | |
| 0005.2001-06-23.SA_and_HP | | 1 | 1 |
| 0005.2003-12-18.GP | 1 | 1 | |
| 0006.1999-12-13.kaminski | | 0 | 0 |
| 0006.2001-02-08.kitchen | 0 | 0 | |
| 0006.2001-04-03.williams | | 0 | 0 |
| 0006.2001-06-25.SA_and_HP | | 1 | 1 |
| 0006.2003-12-18.GP | 1 | 1 | |
| 0006.2004-08-01.BG | 1 | 1 | |
| 0007.1999-12-13.kaminski | | 0 | 0 |
| 0007.1999-12-14.farmer | 0 | 0 | |
| 0007.2000-01-17.beck | 0 | 0 | |
| 0007.2001-02-09.kitchen | 0 | 0 | |
| 0007.2003-12-18.GP | 1 | 1 | |
| 0007.2004-08-01.BG | 1 | 1 | |
| 0008.2001-02-09.kitchen | 0 | 0 | |
| 0008.2001-06-12.SA_and_HP | | 1 | 1 |
| 0008.2001-06-25.SA_and_HP | | 1 | 1 |
| 0008.2003-12-18.GP | 1 | 1 | |
| 0008.2004-08-01.BG | 1 | 1 | |
| 0009.1999-12-13.kaminski | | 0 | 0 |
| 0009.1999-12-14.farmer | 0 | 0 | |
| 0009.2000-06-07.lokay | 0 | 0 | |
| 0009.2001-02-09.kitchen | 0 | 0 | |
| 0009.2001-06-26.SA_and_HP | | 1 | 1 |
| 0009.2003-12-18.GP | 1 | 1 | |
| 0010.1999-12-14.farmer | 0 | 0 | |
| 0010.1999-12-14.kaminski | | 0 | 0 |
| 0010.2001-02-09.kitchen | 0 | 0 | |
| 0010.2001-06-28.SA_and_HP | | 1 | 1 |
| 0010.2003-12-18.GP | 1 | 0 | |
| 0010.2004-08-01.BG | 1 | 1 | |
| 0011.1999-12-14.farmer | 0 | 0 | |
| 0011.2001-06-28.SA_and_HP | | 1 | 1 |
| 0011.2001-06-29.SA_and_HP | | 1 | 1 |
| 0011.2003-12-18.GP | 1 | 1 | |
| 0011.2004-08-01.BG | 1 | 1 | |
| 0012.1999-12-14.farmer | 0 | 0 | |

### HW2.5 Discussion:

Similar to smoothing, ignoring small frequency words will remove some that only belong to one category. Hence, the training error increases a bit. Compared to smoothing case, training error is smaller.

## HW2.6 Benchmark your code with the Python SciKit-Learn

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In [214]:
```
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.naive_bayes import MultinomialNB, BernoulliNB

X_train = []
Y_train = []

# read file
with open('enronemail_1h.txt', 'rU') as infile:
    for line in infile.readlines():
        try:
            email_id, label, subject, body = line.split('\t')
            X_train.append(subject + ' ' + body)
        except ValueError:
            email_id, label, body = line.split('\t')
            X_train.append(body)
        # extract only words from the combined subject and body text
        Y_train.append(int(label))

# Use the TfidVectorizer to create the feature vectors
vectorizer = TfidfVectorizer(token_pattern = "[\w']+")
vf = vectorizer.fit(X_train,Y_train)

clf_M = MultinomialNB()
clf_M.fit(vf.fit_transform(X_train), Y_train)
training_error_mnb = 1.0 - clf_M.score(vf.fit_transform(X_train), Y_train)

clf_B = BernoulliNB()
clf_B.fit(vf.fit_transform(X_train), Y_train)
training_error_bnb = 1.0 - clf_B.score(vf.fit_transform(X_train), Y_train)

print 'SK- multinomial NB error rate is : %.4f' %training_error_mnb
print 'SK- Bernoulli   NB error rate is : %.4f' %training_error_bnb
```

```
SK- multinomial NB error rate is : 0.0000
SK- Bernoulli   NB error rate is : 0.1800
```

### HW 2.6.1 Bernoulli Naive Bayes (OPTIONAL: note this exercise is a stretch HW and optional)

From SK-Learn, we have Multinomial NB with 0% error rate, and Bernoulli NB with 18% error rate. The difference is made by the properties of classifiers. Bernoulli NB classifier will focuses on the appearance of word, while Multinomial NB classifier will reflect the frequency of the word. At this example, Bernoulli classifier is better since, as for SPAM detection, the appearance of some words (keywords) is more important than the frequency.

### HW2.6.1 Results: See execution above, performance summary:

| | Training Error |
|---|---|
| SK-Learn Multinomial NB | 0% |
| SK-Learn Bernoulli NB | 18% |
| Multinomial NB (HW2.4) | 2% |
| Multinomial NB (HW2.5) | 1% |

### HW2.6 Discussion:

Since Bernoulli NB classifier emphaised on the appearance of word, while Multinomial NB classifier emphasizes on the frequency of the word, one would like to choose Bernoulli classifier for SPAM detection by focusing keywords appearing in SPAM emails.

## HW2.7 Preprocess the Entire Spam Dataset (OPTIONAL)

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In [179]:
```
# Put the download folder at the same place of this notebook
from os import listdir
from os.path import isfile, join

# function to read one folder into text
def readmail(path, isSpam, handler):
    files = [f for f in listdir(path) if isfile(join(path, f))]
    for file_name in files:
        id = '.'.join(file_name.split('.')[:-2])
        f = open(path+file_name, 'r')
        mail = f.read().split('\n', 1)
        subject = mail[0].strip('Subject:').strip()
        body = ' '.join(mail[1].split()).strip()
        row = '%s\t%s\t%s\t%s' %(id, isSpam, subject, 'NA' if not body else body)
        f.close()
        handler.write(row + '\n')

# read two folder separately
text_file = open("train-Enron-1.txt", "w")
readmail('./enron1-Training-Data-RAW/ham/', '0', text_file)
readmail('./enron1-Training-Data-RAW/spam/', '1', text_file)
text_file.close()
print 'File train-Enron-1.txt was generated!'

!hdfs dfs -rm /user/shihyu/train-Enron-1.txt
!hdfs dfs -put train-Enron-1.txt /user/shihyu
print 'train-Enron-1.txt is uploaded to hdfs.'
```

```
File train-Enron-1.txt was generated!
rm: `/user/shihyu/train-Enron-1.txt': No such file or directory
train-Enron-1.txt is uploaded to hdfs.
```

# HW2.8 Build and evaluate a NB classifier on the Entire Spam Dataset (OPTIONAL)

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In [211]:
```
# clean up HDFS
!hdfs dfs -rm -r Emails_8_classification_results
!hdfs dfs -rm -r prob_em

# run trainning job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_t_em.py \
-reducer /home/cloudera/reducer_t_em_I.py \
-input /user/shihyu/train-Enron-1.txt \
-output prob_em

# run classification job
!hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-mapper /home/cloudera/mapper_c_em_I.py \
-reducer /home/cloudera/reducer_c_em.py \
-input /user/shihyu/train-Enron-1.txt \
-output Emails_8_classification_results
```

```
rm: `Emails_8_classification_results': No such file or directory
Deleted prob_em
packageJobJar: [] [/usr/lib/hadoop-mapreduce/hadoop-streaming-2.6.0-cdh5.8.0.jar
] /tmp/streamjob2182033911936835284.jar tmpDir=null
16/09/10 07:03:56 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 07:03:56 INFO client.RMProxy: Connecting to ResourceManager at /0.0.0.0
:8032
16/09/10 07:03:56 INFO mapred.FileInputFormat: Total input paths to process : 1
16/09/10 07:03:57 WARN hdfs.DFSClient: Caught exception
java.lang.InterruptedException
        at java.lang.Object.wait(Native Method)
        at java.lang.Thread.join(Thread.java:1281)
        at java.lang.Thread.join(Thread.java:1355)
        at org.apache.hadoop.hdfs.DFSOutputStream$DataStreamer.closeResponder(DF
SOutputStream.java:862)
        at org.apache.hadoop.hdfs.DFSOutputStream$DataStreamer.endBlock(DFSOutpu
tStream.java:600)
        at org.apache.hadoop.hdfs.DFSOutputStream$DataStreamer.run(DFSOutputStre
am.java:789)
16/09/10 07:03:57 INFO mapreduce.JobSubmitter: number of splits:2
16/09/10 07:03:57 INFO mapreduce.JobSubmitter: Submitting tokens for job: job_14
73444507507_0061
16/09/10 07:03:57 INFO impl.YarnClientImpl: Submitted application application_14
73444507507_0061
16/09/10 07:03:57 INFO mapreduce.Job: The url to track the job: http://quickstar
t.cloudera:8088/proxy/application_1473444507507_0061/
16/09/10 07:03:57 INFO mapreduce.Job: Running job: job_1473444507507_0061
16/09/10 07:04:05 INFO mapreduce.Job: Job job_1473444507507_0061 running in uber
 mode : false
16/09/10 07:04:05 INFO mapreduce.Job:  map 0% reduce 0%
16/09/10 07:04:15 INFO mapreduce.Job:  map 50% reduce 0%
16/09/10 07:04:16 INFO mapreduce.Job:  map 100% reduce 0%
16/09/10 07:04:26 INFO mapreduce.Job:  map 100% reduce 100%
16/09/10 07:04:26 INFO mapreduce.Job: Job job_1473444507507_0061 completed succe
ssfully
16/09/10 07:04:27 INFO mapreduce.Job: Counters: 50
        File System Counters
                FILE: Number of bytes read=28116899
                FILE: Number of bytes written=56589444
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=5413593
                HDFS: Number of bytes written=576332
                HDFS: Number of read operations=9
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
        Job Counters
                Killed map tasks=1
                Launched map tasks=2
                Launched reduce tasks=1
                Data-local map tasks=2
                Total time spent by all maps in occupied slots (ms)=16575
                Total time spent by all reduces in occupied slots (ms)=8133
                Total time spent by all map tasks (ms)=16575
                Total time spent by all reduce tasks (ms)=8133
                Total vcore-seconds taken by all map tasks=16575
                Total vcore-seconds taken by all reduce tasks=8133
                Total megabyte-seconds taken by all map tasks=16972800
                Total megabyte-seconds taken by all reduce tasks=8328192
        Map-Reduce Framework
                Map input records=5172
                Map output records=848224
```

In [ ]:
```
!hdfs dfs -cat Emails_8_classification_results/part-00000
```

Since the result is too long, so I do not show total result about entries. Since Hadoop is executed successfully, for this train-Enron-1.txt data set, rrror rate is : 0.008509, and the Number of messages with zero probability are spam(1360), ham(3590).

## HW2.8.1 OPTIONAL

In [217]:
```
from sklearn.naive_bayes import BernoulliNB
from sklearn.naive_bayes import MultinomialNB
from sklearn.feature_extraction.text import *

import csv, re, string
import numpy as np

# read email message, and organize training data
f = open('train-Enron-1.txt', 'r')
txt = f.read().strip()
f.close()
emails = txt.split('\n')
train_label = [msg.strip().split('\t', 2)[1] for msg in emails]
train_data = [msg.strip().split('\t', 2)[-1] for msg in emails]
# removing the funky characters
regex = re.compile('[%s]' % re.escape(string.punctuation))
train_data = [' '.join(regex.sub(' ', msg).split()).decode('latin-1') for msg in t
rain_data]

# read test data
with open('enronemail_1h.txt', 'r') as f:
    reader = csv.reader(f, delimiter="\t")
    emails = list(reader)
test_label = [msg[1] for msg in emails]
test_data = [msg[2]+msg[3] if len(msg)==4 else msg[2] for msg in emails]


# feature vectorization
Vectorizeration = CountVectorizer()
Train = Vectorizeration.fit_transform(train_data)
Test = Vectorizeration.transform(test_data)

# multinomial Naive Bayes Classifier from sklearn
clf_M = MultinomialNB()
clf_M.fit(Train, train_label)
pred_mnb = clf_M.predict(Test)
training_error_mnb = 1.0*sum(pred_mnb != test_label) / len(test_label)

# Bernoulli Naive Bayes Classifier from sklearn
clf_B = BernoulliNB()
clf_B.fit(Train, train_label)
pred_bnb = clf_B.predict(Test)
training_error_bnb = 1.0*sum(pred_bnb != test_label) / len(test_label)

print 'SK- multinomial NB error rate is : %.4f' %training_error_mnb
print 'SK- Bernoulli   NB error rate is : %.4f' %training_error_bnb
```

```
SK- multinomial NB error rate is : 0.0200
SK- Bernoulli   NB error rate is : 0.1900
```

### HW2.8.1 Discussion: Performance comparison shown by following table.

| | Training Error |
|---|---|
| SK-Learn Multinomial NB | 0.02 |
| SK-Learn Bernoulli NB | 0.19 |
| Multinomial NB (HW2.4) | 0.02 |
| Multinomial NB (HW2.5) | 0.01 |

In [ ]: