In [1]:
```
'''
    Author: A.Shrikant
'''
```

Out[1]:
```
'\n    Author: A.Shrikant\n'
```

In [2]:
```
# Attributes Information:

# label: Label for the SMS message could be either 'ham' or 'spam'.
# message: SMS message.
# length: Number of characters in the SMS message.
# punct: Number of punctuations in the SMS message.
```

In [3]:
```
import os
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
```

In [4]:
```
df = pd.read_csv('dataset/spam.tsv', sep='\t')
```

In [5]:
```
df.head()
```

Out[5]:

	label	message	length	punct
0	ham	Go until jurong point, crazy.. Available only ...	111	9
1	ham	Ok lar... Joking wif u oni...	29	6
2	spam	Free entry in 2 a wkly comp to win FA Cup fina...	155	6
3	ham	U dun say so early hor... U c already then say...	49	6
4	ham	Nah I don't think he goes to usf, he lives aro...	61	2

In [6]:
```
df.iloc[0].message
```

Out[6]:
```
'Go until jurong point, crazy.. Available only in bugis n great world la e buffet... Cine there got amore wat...'
```

In [7]:
```
len(df.iloc[0].message)
```

Out[7]:
```
111
```

In [8]:
```
df.iloc[4].message
```

Out[8]:
```
"Nah I don't think he goes to usf, he lives around here though"
```

In [9]:
```
len(df.iloc[4].message)
```

Out[9]:
```
61
```

In [10]:
```
df.shape
```

Out[10]:
```
(5572, 4)
```

In [11]:
```
# Not removing the duplicate rows becasue the duplicates are very less in comparision to the #rows in the dataset.
df.duplicated().sum()
```

Out[11]:
```
403
```

In [12]:
```
# Unique rows:
5572-403
```

Out[12]:
```
5169
```

In [13]:
```
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 5572 entries, 0 to 5571
Data columns (total 4 columns):
 #   Column   Non-Null Count  Dtype 
---  ------   --------------  ----- 
 0   label    5572 non-null   object
 1   message  5572 non-null   object
 2   length   5572 non-null   int64 
 3   punct    5572 non-null   int64 
dtypes: int64(2), object(2)
memory usage: 174.2+ KB
```

Dropping the 'length', 'punct' columns since they are not required for spam/ham classification:

In [14]:
```
df.drop(columns = ['length', 'punct'], inplace = True)
```

In [15]:
```
df
```

Out[15]:

	label	message
0	ham	Go until jurong point, crazy.. Available only ...
1	ham	Ok lar... Joking wif u oni...
2	spam	Free entry in 2 a wkly comp to win FA Cup fina...
3	ham	U dun say so early hor... U c already then say...
4	ham	Nah I don't think he goes to usf, he lives aro...
...	...	...
5567	spam	This is the 2nd time we have tried 2 contact u...
5568	ham	Will ü b going to esplanade fr home?
5569	ham	Pity, * was in mood for that. So...any other s...
5570	ham	The guy did some bitching but I acted like i'd...
5571	ham	Rofl. Its true to its name

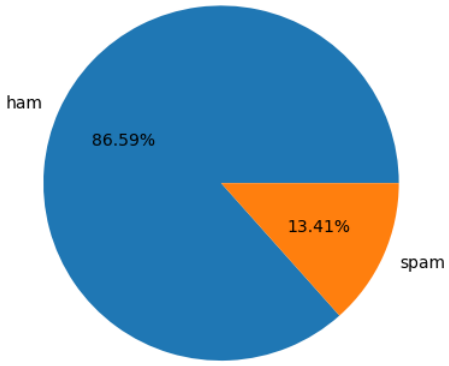
5572 rows × 2 columns

Checking Data imbalance:

In [16]:
```
df.label.value_counts()
```

Out[16]:
```
ham     4825
spam     747
Name: label, dtype: int64
```

In [17]:
```
plt.pie(df.label.value_counts(), labels=df.label.value_counts().index.values, autopct="%.2f%%")
plt.show()
```



Treating Data imbalance:

In [18]:
```
ham = df[df['label'] == 'ham']
ham
```

Out[18]:

	label	message
0	ham	Go until jurong point, crazy.. Available only ...
1	ham	Ok lar... Joking wif u oni...
3	ham	U dun say so early hor... U c already then say...
4	ham	Nah I don't think he goes to usf, he lives aro...
6	ham	Even my brother is not like to speak with me. ...
...	...	...
5565	ham	Huh y lei...
5568	ham	Will ü b going to esplanade fr home?
5569	ham	Pity, * was in mood for that. So...any other s...
5570	ham	The guy did some bitching but I acted like i'd...
5571	ham	Rofl. Its true to its name

4825 rows × 2 columns

In [19]:
```
spam = df[df['label'] == 'spam']
spam
```

Out[19]:

	label	message
2	spam	Free entry in 2 a wkly comp to win FA Cup fina...
5	spam	FreeMsg Hey there darling it's been 3 week's n...
8	spam	WINNER!! As a valued network customer you have...
9	spam	Had your mobile 11 months or more? U R entitle...
11	spam	SIX chances to win CASH! From 100 to 20,000 po...
...	...	...
5537	spam	Want explicit SEX in 30 secs? Ring 02073162414...
5540	spam	ASKED 3MOBILE IF 0870 CHATLINES INCLU IN FREE ...
5547	spam	Had your contract mobile 11 Mnths? Latest Moto...
5566	spam	REMINDER FROM O2: To get 2.50 pounds free call...
5567	spam	This is the 2nd time we have tried 2 contact u...

747 rows × 2 columns

In [20]:
```
ham.duplicated().sum()
```

Out[20]: 309

In [21]:
```
spam.duplicated().sum()
```

Out[21]: 94

In [22]:
```
# Performing Oversampling for the minority class 'spam' SMS using resampling with replacement strategy.

spam_resampled = spam.sample(ham.shape[0], replace=True)
spam_resampled
```

Out[22]:

	label	message
1613	spam	RT-KIng Pro Video Club>> Need help? info@ringt...
3174	spam	Dear Voucher Holder, To claim this weeks offer...
1207	spam	As a SIM subscriber, you are selected to recei...
5030	spam	I'd like to tell you my deepest darkest fantas...
650	spam	You have won ?1,000 cash or a ?2,000 prize! To...
...	...	...
3548	spam	Rock yr chik. Get 100's of filthy films &XXX p...
690	spam	<Forwarded from 448712404000>Please CALL 08712...
5482	spam	URGENT We are trying to contact you Last weeke...
4206	spam	IMPORTANT INFORMATION 4 ORANGE USER 0796XXXXXX...
1893	spam	CALL 09090900040 & LISTEN TO EXTREME DIRTY LIV...

4825 rows × 2 columns

In [23]:
```
spam_resampled.duplicated().sum()
```

Out[23]:
```
4173
```

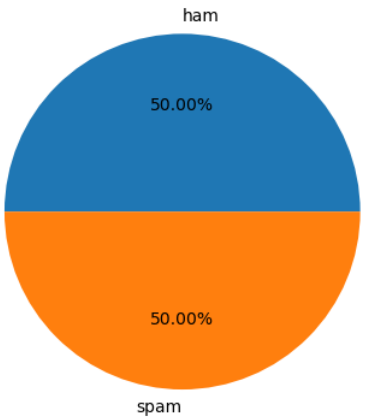
In [24]:
```
df1 = pd.concat([ham, spam_resampled], ignore_index=True)
df1
```

Out[24]:

	label	message
0	ham	Go until jurong point, crazy.. Available only ...
1	ham	Ok lar... Joking wif u oni...
2	ham	U dun say so early hor... U c already then say...
3	ham	Nah I don't think he goes to usf, he lives aro...
4	ham	Even my brother is not like to speak with me. ...
...	...	...
9645	spam	Rock yr chik. Get 100's of filthy films &XXX p...
9646	spam	<Forwarded from 448712404000>Please CALL 08712...
9647	spam	URGENT We are trying to contact you Last weeke...
9648	spam	IMPORTANT INFORMATION 4 ORANGE USER 0796XXXXXX...
9649	spam	CALL 09090900040 & LISTEN TO EXTREME DIRTY LIV...

9650 rows × 2 columns

In [25]:
```
plt.pie(df1.label.value_counts(), labels=df1.label.value_counts().index.values, autopct="%.2f%%")
plt.show()
```



In [26]:
```
import re
import nltk
```

Terminologies related to Natural Language Processing:

Linguistics - It is the scientific study of the language. It includes studying the vocabulary of the language, sentence formation, grammar, phonetics, etymology.

Phonetics: Study about human speech sounds like how human produce sounds and how they perceive it.

Etymology: Study about the origin of words/phrases and tracing out their developments and relationships.

Morphology: The study of the different forms, words may have in particular their inflected forms.

Inflect a Word: Change the form of (a word) to express a particular grammatical function or attribute, typically tense, mood, person, number, and gender. **Example**:

- **alumnus**: a male graduate, **alumni**: a group of male graduates, **alumna**: a female graduate, **alumnae**: a group of female graduates
- run, running, ran

Root form of a word: The base word without any prefix or suffix. **Example**: running, its root word is run.

Word Stem: A stem word, often simply referred to as a "stem," is the base or root form of a word to which prefixes and suffixes can be added to create new words or inflected forms. It's the part of a word that carries the core meaning and can stand alone as a word in its own right.

Examples:

- In the word **"happiness"** the stem word is **"happi"**.
- For the word **"running"** the stem word is **"run"**.
- For the word **"programming"** the stem word is **"program"**
- For the word **"programmer"** the stem word is **"programm"**
- For the word **"alumnus"** the stem word is **"alumnu"**
- For the word **"alumni"** the stem word is **"alumni"**
- For the word **"alumnae"** the stem word is **"alumna"**

Note: Stem word need not be always meaningful.

Lemma: A lemma, in linguistics, is the base or dictionary form of a word. It is the form of a word that is typically listed in dictionaries and glossaries. Lemmas are used as a standard reference point for analyzing and categorizing words within a language. **Examples**:

- In the word **"mice"** the lemma is **"mouse"**.
- For the word **"alumni"** the lemma is **"alumnus"**
- For the word **"universally"** the lemma is **"universally"**

Corpus: It refers to a large and structured collection of texts or spoken language data that is systematically gathered and stored for linguistic analysis and research.

Tokenization: Breaking down a piece of text into individual words. This is the second step of text processing and is done after removing the punctuations from the text.

Text Normalization Technique:

Stemming:

Stemming is a technique used to reduce an inflected word down to its word stem i.e. inflected forms of a word are reduced to their base form. This is like normalizing the word so that different inflected forms of the same base word could be clubbed together with the base form of the word from which the core meaning for those different inflected forms come from.

Advantage of Stemming:

- Stemming reduces dimensionality of the text data i.e it reduces the number of unique words in the dictionary we get after pre-processing the text documents, as a result the text processing algorithms speed increases.

Lemmatization:

Lemmatization is another technique used to reduce inflected words down to their root word. Unlike Stemming Lemmatization always produces a **lemma** for the word being reduced, which is the dictionary form of that original word.

Applying the text pre-processing steps:

Step 1: Removing the punctuation marks from each SMS message.

Step 2: Case Normalization(Converting the text into lower case).

Step 3. Removing the 'stopwords' i.e. words that do not contain much information from each of the SMS message.

Step 4: Performing message normalization by applying techniques like Stemming or Lemmatization.

Step 5: Tokenizing(breaking down a piece of text into individual words) each of the SMS messages.

Step 6: Converting SMS messages into a matrix of token counts where each column represent a unique word obtained after Tokenization of each SMS message, a row represent an SMS message also known as 'Bag of Words' and the cell represents the #count of that word/token in that corresponding SMS message.

In [27]:
```
nltk.download('stopwords')
```

```
[nltk_data] Downloading package stopwords to
[nltk_data]     C:\Users\user\AppData\Roaming\nltk_data...
[nltk_data]   Package stopwords is already up-to-date!
```

Out[27]: True

In [28]:
```
nltk.download('punkt')
```

```
[nltk_data] Downloading package punkt to
[nltk_data]     C:\Users\user\AppData\Roaming\nltk_data...
[nltk_data]   Package punkt is already up-to-date!
```

Out[28]: True

In [29]:
```
import string
from nltk.corpus import stopwords
from nltk.stem.porter import PorterStemmer
from nltk.tokenize import word_tokenize
```

In [30]:
```
ps = PorterStemmer()
```

In [31]:
```
import string
```

In [32]:
```
corpus = []

for i in range(0, len(df1)):
#     msg_no_punct = re.sub('[^a-zA-Z]', ' ', df1['message'][i])
    msg_no_punct = df1['message'][i].translate(str.maketrans("", "", string.punctuation))
    msg_no_punct = msg_no_punct.lower()
    word_tokens = word_tokenize(msg_no_punct)
#     noralized_words = [ps.stem(word) for word in msg_no_punct.split() if not word in stopwords.words('english')]
    noralized_words = [ps.stem(word) for word in word_tokens if not word in stopwords.words('english')]
    noralized_msg = ' '.join(noralized_words)
    corpus.append(noralized_msg)
```

In [33]:
```
corpus
```

Out[33]:
```
['go jurong point crazi avail bugi n great world la e buffet cine got amor wat',
 'ok lar joke wif u oni',
 'u dun say earli hor u c alreadi say',
 'nah dont think goe usf live around though',
 'even brother like speak treat like aid patent',
 'per request mell mell oru minnaminungint nurungu vettam set callertun caller press 9 copi friend callertun',
 'im gon na home soon dont want talk stuff anymor tonight k ive cri enough today',
 'ive search right word thank breather promis wont take help grant fulfil promis wonder bless time',
 'date sunday',
 'oh kim watch',
 'eh u rememb 2 spell name ye v naughti make v wet',
 'fine that\x92 way u feel that\x92 way gota b',
 'serious spell name',
 '‘ go tri 2 month ha ha joke',
 'ü pay first lar da stock comin',
 'aft finish lunch go str lor ard 3 smth lor u finish ur lunch alreadi',
 'fffffffff alright way meet sooner',
 'forc eat slice im realli hungri tho suck mark get worri know im sick turn pizza lol',
 'lol alway convinc',
```

In [34]:
```
from sklearn.feature_extraction.text import CountVectorizer
```

In [35]:
```
cv = CountVectorizer()
```

In [36]:
```
x = cv.fit_transform(corpus).toarray()
x
```

Out[36]:
```
array([[0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       ...,
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0]], dtype=int64)
```

In [37]:
```
x.shape
```

Out[37]:
```
(9650, 8091)
```

In [38]:
```
df1
```

Out[38]:

	label	message
0	ham	Go until jurong point, crazy.. Available only ...
1	ham	Ok lar... Joking wif u oni...
2	ham	U dun say so early hor... U c already then say...
3	ham	Nah I don't think he goes to usf, he lives aro...
4	ham	Even my brother is not like to speak with me. ...
...	...	...
9645	spam	Rock yr chik. Get 100's of filthy films &XXX p...
9646	spam	<Forwarded from 448712404000>Please CALL 08712...
9647	spam	URGENT We are trying to contact you Last weeke...
9648	spam	IMPORTANT INFORMATION 4 ORANGE USER 0796XXXXXX...
9649	spam	CALL 09090900040 & LISTEN TO EXTREME DIRTY LIV...

9650 rows × 2 columns

In [39]:
```
df1.label = df1.label.astype('category').cat.codes
```

In [40]:
```
df1
```

Out[40]:

	label	message
0	0	Go until jurong point, crazy.. Available only ...
1	0	Ok lar... Joking wif u oni...
2	0	U dun say so early hor... U c already then say...
3	0	Nah I don't think he goes to usf, he lives aro...
4	0	Even my brother is not like to speak with me. ...
...	...	...
9645	1	Rock yr chik. Get 100's of filthy films &XXX p...
9646	1	<Forwarded from 448712404000>Please CALL 08712...
9647	1	URGENT We are trying to contact you Last weeke...
9648	1	IMPORTANT INFORMATION 4 ORANGE USER 0796XXXXXX...
9649	1	CALL 09090900040 & LISTEN TO EXTREME DIRTY LIV...

9650 rows × 2 columns

Splitting Training and Test data:

In [41]:
```
from sklearn.model_selection import train_test_split
```

In [42]:
```
x_train, x_test, y_train, y_test = train_test_split(x, df1.label, test_size = 0.25, random_state = 1234 )
```

In [43]:
```
x_train
```

Out[43]:
```
array([[0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       ...,
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0]], dtype=int64)
```

In [44]:
```
y_train
```

Out[44]:
```
8284    1
6074    1
2071    0
7200    1
2488    0
       ..
664     0
7540    1
7221    1
1318    0
8915    1
Name: label, Length: 7237, dtype: int8
```

In [45]:
```
x_test
```

Out[45]:
```
array([[0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       ...,
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0],
       [0, 0, 0, ..., 0, 0, 0]], dtype=int64)
```

In [46]:
```
y_test
```

Out[46]:
```
3119    0
4700    0
3293    0
3013    0
7273    1
       ..
6356    1
6554    1
370     0
801     0
4898    1
Name: label, Length: 2413, dtype: int8
```

Building the Bernoulli Naive Bayes based model:

Bernoulli Naive Bayes is a generative model that is used for the task of binary classification when all the feature variables in feature vector are binary.

i.e. $x^{(i)} = [f_1, f_2, \ldots, f_d]^T$ where $f_j \in \{0,1\}$ for $j = 1, 2, \ldots, d$

For each feature vector $x^{(i)}$ there is a label $y^{(i)} \in \{0,1\}$

So our data set is: $D = \{(x^{(i)}, y^{(i)}); i \in [1, 2, \ldots, n]\}$

Parameters in Bernoulli Naive Bayes are: p, p_j^0, p_j^1

where: p is the apriori probability of the the i-th datapoint being classified as belonging to class 1 i.e. $p = P(y^{(i)=1})$

p_j^0 is the probability of the j-th feature variable in the feature vector being 1 given that the feature vector has label 0 i.e. $p_j^0 = P(x_j = 1|y = 0)$

p_j^1 is the probability of the j-th feature variable in the feature vector being 1 given that the feature vector has label 1 i.e. $p_j^1 = P(x_j = 1|y = 1)$

Assumptions in Bernoulli Naive Bayes:

1. Given a class label all the features are independent of each other. This is known as the **class conditional independence** assumption.

2. All the training instances are independent of each other.

The likelihood function for the Bernoulli Naive Bayes model is:

$$L(p, p_j^0, p_j^1|\{(x^{(i)}, y^{(i)}); i \in [1, 2, \ldots, n]\}) = \prod_{i=1}^{n} [p.\,(p_j^1)^{x_j^{(i)}}.\,(1 - p_j^1)^{1-x_j^{(i)}}]^{y^{(i)}}.\,[(1 - p).\,(p_j^0)^{x_j^{(i)}}.\,(1 - p_j^0)^{1-x_j^{(i)}}]^{1-y^{(i)}}$$

From the maximum likelihood estimate we get the estimate for the parameters in Bernoulli Naive Bayes:

$$p = \frac{\sum_{i=1}^{n} y^{(i)}}{n}$$ **= Fraction of data points belonging to class 1**

$$p_j^0 = \frac{\sum_{i=1}^{n} x_j^{(i)}.\,(1 - y^{(i)})}{\sum_{i=1}^{n} (1 - y^{(i)})}$$

= Fraction of data points among the data points labelled as 0 where the j-th feature variable in the feature vector is 1

$$p_j^1 = \frac{\sum_{i=1}^{n} x_j^{(i)}.\,(y^{(i)})}{\sum_{i=1}^{n} y^{(i)}}$$

= Fraction of data points among the data points labelled as 1 where the j-th feature variable in the feature vector is 1

From **Bayes theorem** we know that: $P(y^{(i)}|x^{(i)})P(x^{(i)}) = P(x^{(i)}|y^{(i)})P(y^{(i)})$

This implies: $P(y^{(i)} = 0|x^{(i)}) = \frac{P(x^{(i)}|y^{(i)} = 0)P(y^{(i)} = 0)}{P(x^{(i)})}$

$P(y^{(i)} = 1|x^{(i)}) = \frac{P(x^{(i)}|y^{(i)} = 1)P(y^{(i)} = 1)}{P(x^{(i)})}$

Decision rule in Bernoulli Naive Bayes:

Classify as 1 if $P(y^{(i)} = 1|x^{(i)}) \geq P(y^{(i)} = 0|x^{(i)})$ else classify as 0.

i.e. Classify 1 if $P(x^{(i)}|y^{(i)} = 1)P(y^{(i)} = 1) \geq P(x^{(i)}|y^{(i)} = 0)P(y^{(i)} = 0)$ else classify as 0.

i.e. Classify 1 if $p. \prod_{j=1}^{d} [(p_j^1)^{x_j^{(i)}}.\,(1 - p_j^1)^{1-x_j^{(i)}}] \geq (1 - p). \prod_{j=1}^{d} [(p_j^0)^{x_j^{(i)}}.\,(1 - p_j^0)^{1-x_j^{(i)}}]$ else classify as 0.

In [47]:
```
from sklearn.naive_bayes import BernoulliNB
```

In [48]:
```
bernoulli_nb = BernoulliNB()
```

In [49]:
```
bernoulli_nb.fit(x_train, y_train)
```

Out[49]:
```
BernoulliNB()
```

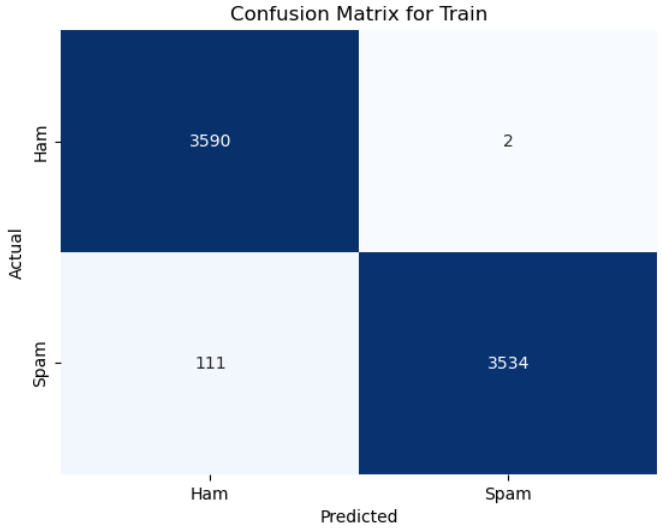
In [50]:
```
y_pred_train_bernoulli_nb = bernoulli_nb.predict(x_train)
y_pred_test_bernoulli_nb = bernoulli_nb.predict(x_test)
```

In [51]:
```
from sklearn.metrics import classification_report, accuracy_score, confusion_matrix
```

In [52]:
```
# https://stackoverflow.com/questions/54506626/how-to-understand-seaborns-heatmap-annotation-format

def draw_confusion_matrix(y_true, y_pred, c_matrix_for):
    labels = ['Ham', 'Spam']
    sns.heatmap(confusion_matrix(y_true, y_pred), annot=True, fmt='.4g', xticklabels=labels,
            yticklabels=labels, cmap='Blues', cbar=False)
    plt.xlabel('Predicted')
    plt.ylabel('Actual')
    plt.title(f'Confusion Matrix for {c_matrix_for}')
    plt.show()
```

In [53]:
```
draw_confusion_matrix(y_train, y_pred_train_bernoulli_nb, c_matrix_for='Train')
```



In [54]:
```
print("Train report - bernoulli naive bayes:")
print(classification_report(y_train, y_pred_train_bernoulli_nb))
print("Test report - bernoulli naive bayes:")
print(classification_report(y_test, y_pred_test_bernoulli_nb))
```

```
Train report - bernoulli naive bayes:
              precision    recall  f1-score   support

           0       0.97      1.00      0.98      3592
           1       1.00      0.97      0.98      3645

    accuracy                           0.98      7237
   macro avg       0.98      0.98      0.98      7237
weighted avg       0.98      0.98      0.98      7237

Test report - bernoulli naive bayes:
              precision    recall  f1-score   support

           0       0.97      1.00      0.99      1233
           1       1.00      0.97      0.99      1180

    accuracy                           0.99      2413
   macro avg       0.99      0.99      0.99      2413
weighted avg       0.99      0.99      0.99      2413
```

In [55]:
```
print("Train accuracy - bernoulli naive bayes:", accuracy_score(y_train, y_pred_train_bernoulli_nb))
print("Test accuracy - bernoulli naive bayes:", accuracy_score(y_test, y_pred_test_bernoulli_nb))
```

```
Train accuracy - bernoulli naive bayes: 0.9843857952190134
Test accuracy - bernoulli naive bayes: 0.9863240779113137
```

Building the Multinomial Naive Bayes based model:

Multinomial Naive Bayes is a generative model that is used for the task of binary classification of text documents. In this case all the feature variables in feature vector can take values from $\{1, 2, \ldots, |V|\}$ where $|V|$ is the dictionary size. These values of the feature variables represent the indexes mapping to the words in the dictionary. Also the #feature variables in each feature vector can also vary because the length of each text document can vary.

$$\text{i.e. } x^{(i)} = [x_1^{(i)}, x_2^{(i)}, \ldots, x_1^{(d_i)}]^T \text{where } x_j^{(i)} = k \in \{1, 2, ..., |\text{V}|\} \text{ for } j = 1, 2, \ldots, d_i$$

d_i represents the #feature variables in the i-th training instance/text document.

For each feature vector $x^{(i)}$ there is a label $y^{(i)} \in \{0,1\}$

So our data set is: $D = \{(x^{(i)}, y^{(i)}); i \in [1, 2, \ldots, n]\}$

Parameters in Multinomial Naive Bayes are: p, p_k^0, p_k^1

where: p is the apriori probability of the the i-th datapoint being classified as belonging to class 1 i.e. $p = P(y^{(i)=1})$

p_k^0 is the probability of the j-th feature variable in the feature vector taking the value k given that the feature vector has label 0 i.e. $p_k^0 = P(x_j = k|y = 0)$

p_k^1 is the probability of the j-th feature variable in the feature vector taking the value k given that the feature vector has label 1 i.e. $p_k^1 = P(x_j = k|y = 1)$

And $k \in \{1, 2, ..., |V|\}$

Assumptions in Multinomial Naive Bayes:

1. Given a class label the probability of any feature variable in the feature vector taking the value k i.e. $P(x_j^{(i)} = k|y^{(i)})$ is same for $j = 1, 2, \ldots, d_i$.

2. All the training instances/text documents are independent of each other.

The likelihood function for the Multinomial Naive Bayes model is:

$L(p, p_k^0, p_k^1|\{(x^{(i)}, y^{(i)}); i \in [1, 2, \ldots, n]\})$

$$= \prod_{i=1}^{n} \{ \prod_{j=1}^{d_i} [(p_k^1)^{s_j^{(i)}} . (1 - p_k^1)^{1-s_j^{(i)}}]^{y^{(i)}} . [(p_k^0)^{s_j^{(i)}} . (1 - p_k^0)^{1-s_j^{(i)}}]^{1-y^{(i)}} \} . p^{y^{(i)}} . (1 - p)^{1-y^{(i)}}$$

where $s_j^{(i)} = \mathbb{1}(x_j^{(i)} = k)$ and $\mathbb{1}$ is the indicator function.

From the maximum likelihood estimate we get the estimate for the parameters in Multinomial Naive Bayes:

$$p = \frac{\sum_{i=1}^{n} y^{(i)}}{n}$$ **= Fraction of data points belonging to class 1**

$$p_j^0 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{d_i} \mathbb{1}(x_j^{(i)} = k) . (1 - y^{(i)})}{\sum_{i=1}^{n} (1 - y^{(i)}) . d_i}$$

= Fraction of k-th index word among the documents labelled as 0.

$$p_j^1 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{d_i} \mathbb{1}(x_j^{(i)} = k) . y^{(i)}}{\sum_{i=1}^{n} y^{(i)} . d_i}$$

= Fraction of k-th index word among the documents labelled as 1.

Decision rule in Multinomial Naive Bayes:

Classify as 1 if $P(y^{(i)} = 1|x^{(i)}) \geq P(y^{(i)} = 0|x^{(i)})$ else classify as 0.

i.e. Classify as 1 if $P(x^{(i)}|y^{(i)} = 1)P(y^{(i)} = 1) \geq P(x^{(i)}|y^{(i)} = 0)P(y^{(i)} = 0)$ else classify as 0.

i.e. Classify as 1 if $p . \prod_{j=1}^{d_i} [(p_k^1)^{s_j^{(i)}} . (1 - p_k^1)^{1-s_j^{(i)}}] \geq (1 - p) . \prod_{j=1}^{d_i} [(p_k^0)^{s_j^{(i)}} . (1 - p_k^0)^{1-s_j^{(i)}}]$ else classify as 0.

where $s_j^{(i)} = \mathbb{1}(x_j^{(i)} = k)$ and $\mathbb{1}$ is the indicator function.

In [56]:
```
from sklearn.naive_bayes import MultinomialNB
```

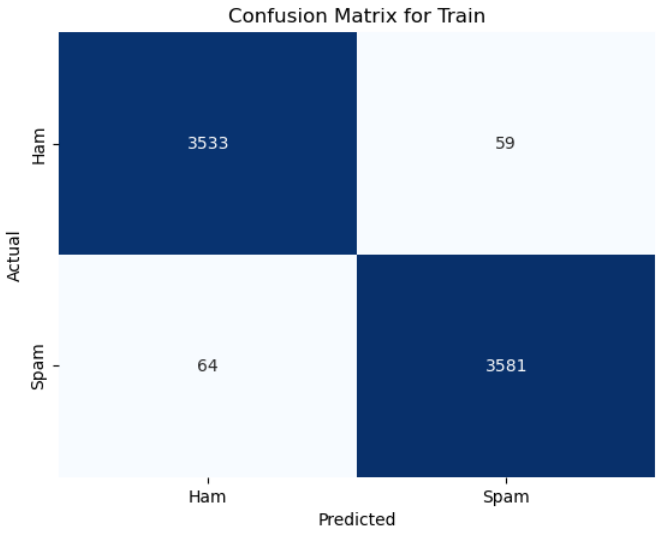
In [57]:
```
multinomial_nb = MultinomialNB()
```

In [58]:
```
multinomial_nb.fit(x_train, y_train)
```

Out[58]:
```
MultinomialNB()
```

In [59]:
```
y_pred_train_mulitinomial_nb = multinomial_nb.predict(x_train)
y_pred_test_mulitinomial_nb = multinomial_nb.predict(x_test)
```

In [60]:
```
draw_confusion_matrix(y_train, y_pred_train_mulitinomial_nb, c_matrix_for='Train')
```



In [61]:
```
print("Train report - multinomial naive bayes:")
print(classification_report(y_train, y_pred_train_mulitinomial_nb))
print("Test report - multinomial naive bayes:")
print(classification_report(y_test, y_pred_test_mulitinomial_nb))
```

```
Train report - multinomial naive bayes:
              precision    recall  f1-score   support

           0       0.98      0.98      0.98      3592
           1       0.98      0.98      0.98      3645

    accuracy                           0.98      7237
   macro avg       0.98      0.98      0.98      7237
weighted avg       0.98      0.98      0.98      7237

Test report - multinomial naive bayes:
              precision    recall  f1-score   support

           0       0.98      0.98      0.98      1233
           1       0.98      0.98      0.98      1180

    accuracy                           0.98      2413
   macro avg       0.98      0.98      0.98      2413
weighted avg       0.98      0.98      0.98      2413
```

In [62]:
```
print("Train accuracy - multinomial naive bayes:", accuracy_score(y_train, y_pred_train_mulitinomial_nb))
print("Test accuracy - multinomial naive bayes:", accuracy_score(y_test, y_pred_test_mulitinomial_nb))
```

```
Train accuracy - multinomial naive bayes: 0.9830040071852978
Test accuracy - multinomial naive bayes: 0.9801077496891836
```

In [63]:
```
multinomial_nb.class_count_
```

Out[63]:
```
array([3592., 3645.])
```

In [64]:
```
(y_train == 1).sum()
```

Out[64]:
```
3645
```

In [65]:
```
multinomial_nb.class_log_prior_
```

Out[65]:
```
array([-0.70049761, -0.68585039])
```

In [66]:
```
np.log(3592/(3592+3645))
```

Out[66]:
```
-0.7004976054440375
```

In [67]:
```
multinomial_nb.feature_count_
```

Out[67]:
```
array([[ 0.,  0.,  0., ...,  0.,  2.,  0.],
       [13.,  7.,  8., ...,  0.,  0.,  0.]])
```

In [68]:
```
multinomial_nb.feature_count_.shape
```

Out[68]:
```
(2, 8091)
```

In [69]:
```
multinomial_nb.n_features_in_
```

Out[69]:
```
8091
```

In [70]:
```
multinomial_nb.coef_
```

```
C:\Users\user\anaconda3\lib\site-packages\sklearn\utils\deprecation.py:103: FutureWarning: Attribute `coef_` was deprecated in version 0.24
and will be removed in 1.1 (renaming of 0.26).
  warnings.warn(msg, category=FutureWarning)
```

Out[70]:
```
array([[ -8.46453054,  -9.02414633,  -8.90636329, ..., -11.10358787,
        -11.10358787, -11.10358787]])
```

In [71]:
```
multinomial_nb.coef_.shape
```

Out[71]:
```
(1, 8091)
```

Conclusion:

For the Naive Bayes based classifier:

- Train accuracy: **98.44%**
- Test accuracy: **98.63%**
- Train macro-averaged f1-score: **98%**
- Test macro-averaged f1-score: **99%**

For the Multinomial Bayes based classifier:

- Train accuracy: **98.30%**
- Test accuracy: **98.01%**
- Train macro-averaged f1-score: **98%**
- Test macro-averaged f1-score: **98%**

Both Bernoulli Naive Bayes based classifier and Multinomial Naive Bayes based classifier are suitable for this SMS classification problem.