Twitter Sentiment Analysis

Problem Statement

The task is to build a model that will determine the tone (neutral, positive, negative) of the text. To do this, you will need to train the model on the existing data (train.csv). The resulting model will have to determine the class (neutral, positive, negative) of new texts (test data that were not used to build the model) with maximum accuracy.

Performance metric

Source: https://www.kaggle.com/competitions/twitter-sentiment-analysis2/overview/evaluation (https://www.kaggle.com/competitions/twitter-sentiment-analysis2/overview/evaluation)

Metric: F1-score

Loading the required libraries

In [2]:

```
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
from wordcloud import WordCloud
import nltk
from nltk.corpus import stopwords
import warnings
warnings.filterwarnings("ignore")
from sklearn.feature_extraction.text import CountVectorizer
from nltk.stem.snowball import SnowballStemmer
import re
from sklearn.preprocessing import StandardScaler
from sklearn.model_selection import GridSearchCV
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import confusion_matrix
from sklearn.metrics import f1_score
from sklearn.ensemble import RandomForestClassifier
from sklearn.feature_extraction.text import TfidfVectorizer
import pickle
from tqdm import tqdm
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix
import seaborn as sns
from sklearn.naive_bayes import MultinomialNB
from sklearn.ensemble import RandomForestClassifier
from sklearn.ensemble import GradientBoostingClassifier
from sklearn.svm import LinearSVC
from tabulate import tabulate
import tensorflow as tf
from tensorflow.keras.layers import Dense,Input,Activation
from tensorflow.keras.models import Model
import random as rn
from sklearn.metrics import f1_score, roc_auc_score
from tensorflow.keras.callbacks import LearningRateScheduler
from tensorflow.keras.callbacks import EarlyStopping
import datetime
import os
import tensorflow_addons as tfa
from tensorflow.keras import backend as K
import tensorflow_hub as hub
import tensorflow_text as text
```

Data source: https://www.kaggle.com/competitions/twitter-sentiment-analysis2/data (https://www.kaggle.com/competitions/twitter-sentiment-analysis2/data)

Data description:

File descriptions

train.csv - the training set

test.csv - the test set

Data fields:

ItemID - id of tweet

SentimentText - text of the tweet

Sentiment - sentiment

0 - negative

1 - positive

Loading the data

In [3]:

```
train = pd.read_csv(r"D:\Twitter Sentiment Analysis\Dataset\train.csv", encoding='latin-1')
train.head(4)
```

Out[3]:

	ItemID	Sentiment	SentimentText
0	1	0	is so sad for my APL frie...
1	2	0	I missed the New Moon trail...
2	3	1	omg its already 7:30 :O
3	4	0	.. Omgaga. Im sooo im gunna CRy. I'...

In [4]:

```
print(train.shape)
```

```
(99989, 3)
```

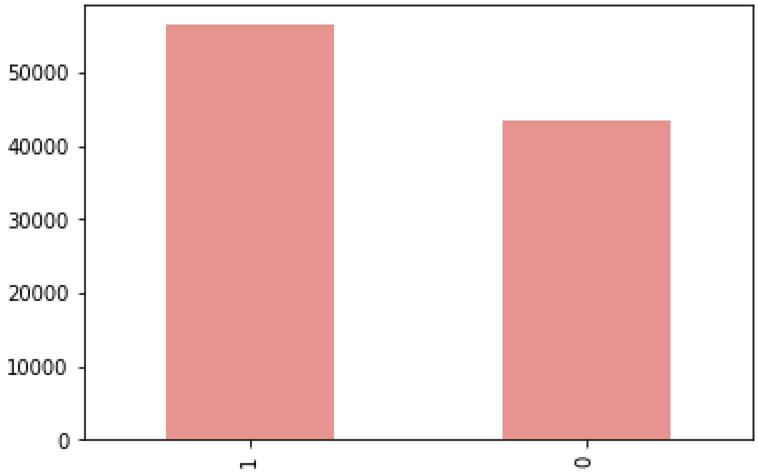
Data Visualization

```
In [5]: print("Null data in the train dataset:\n", train.isnull().any())
```

```
Null data in the train dataset:
 ItemID           False
Sentiment        False
SentimentText    False
dtype: bool
```

```
In [6]: train['Sentiment'].value_counts().plot.bar(color='#e8948e', figsize=(6,4))
```

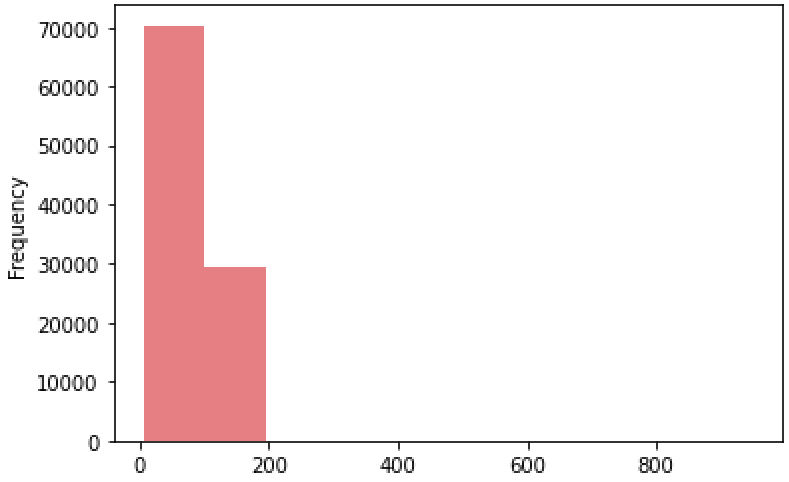
```
Out[6]: <AxesSubplot:>
```



Since, the dataset is slightly imbalanced and is large enough resulting in the increase of training time for deep learning models we will use random sampling to makee both class labels equal

```
In [18]: train['SentimentText'].str.len().plot.hist(color='#E57F84', figsize=(6,4))
```

```
Out[18]: <AxesSubplot:ylabel='Frequency'>
```



In [19]:

```
nltk.download('stopwords')
stop_words = set(stopwords.words('english'))
```

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

In [20]:

```
stop_words.remove('not')
stop_words.remove('no')
print("Stop Words :\n", stop_words)
```

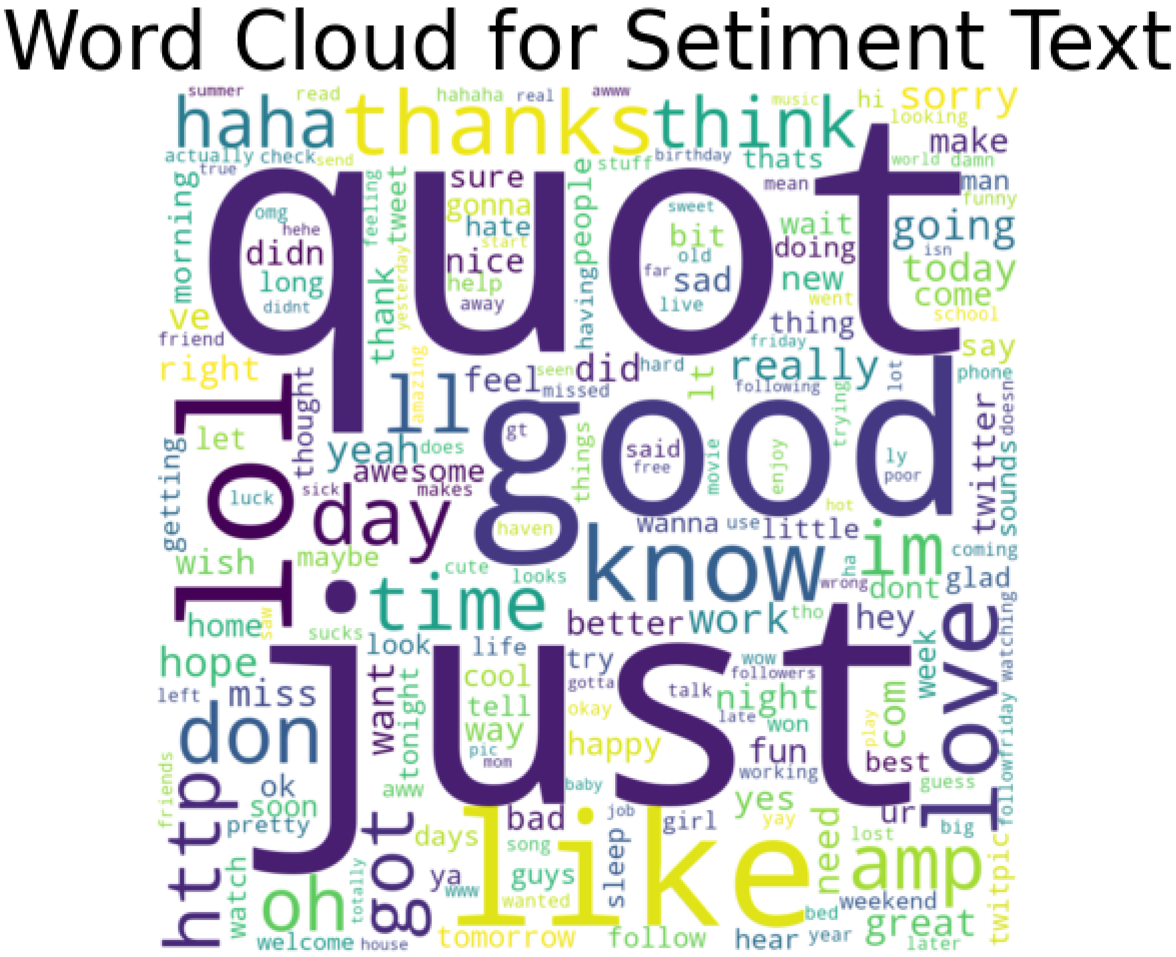
```
Stop Words :
 {'at', 'will', 'am', 'has', 'aren', 'if', 'as', 'off', "shouldn't", 'yoursel
f', 'or', 'than', 'me', 'your', 'out', 'mightn', 'did', 'had', 'these', 'an
d', 'to', 'down', 'd', "mightn't", 'is', 'do', 'after', 'again', 'on', 'abov
e', 'more', 'what', "don't", 'his', 'where', 'wasn', "shan't", 's', 'for', 'r
e', 'yourselves', "won't", "haven't", 'between', 'from', "couldn't", 'ma', 'o
ur', 'through', "should've", 'until', 'her', "weren't", 'she', 'mustn', "was
n't", 've', 'doesn', 'being', 'very', 'hasn', 'once', 'why', 'herself', 'jus
t', 'it', 'itself', 'm', 'he', 'by', 'didn', 'shan', 'don', "that'll", "yo
u'd", 'does', "didn't", 'isn', 'before', 'weren', 'during', 'been', 'other',
"aren't", 'how', 'any', 'each', 'was', 'too', 'i', "it's", "hasn't", 'now',
'they', 'himself', 'an', 'themselves', "you've", 'then', 'some', 'y', 'here',
'theirs', 'myself', 'those', 'o', "isn't", 'against', "wouldn't", 'own', 'wou
ldn', 'yours', 'over', 'under', 'hers', 'most', "you're", 'whom', 'about', "m
ustn't", 'nor', 'such', 'll', 'ain', 'few', 'haven', 'them', 'be', 'were',
'a', 't', 'of', 'won', 'all', 'that', 'both', 'their', 'have', 'we', 'hadn',
'needn', "you'll", 'you', 'its', 'below', 'while', "doesn't", 'should', 'havi
ng', 'the', 'couldn', "she's", 'further', 'there', 'so', 'same', 'up', 'in',
'because', 'with', 'my', 'him', 'which', 'doing', 'ours', 'ourselves', 'onl
y', "needn't", 'but', 'when', "hadn't", 'shouldn', 'into', 'this', 'are', 'wh
o', 'can'}
```

In [21]:

```
cv = CountVectorizer(stop_words='english')
words = cv.fit_transform(train['SentimentText'])

sum_words = words.sum(axis=0)

word_freq = [(word, sum_words[0,i]) for word,i in cv.vocabulary_.items()]
word_freq = sorted(word_freq, key=lambda x:x[1], reverse=True)
```

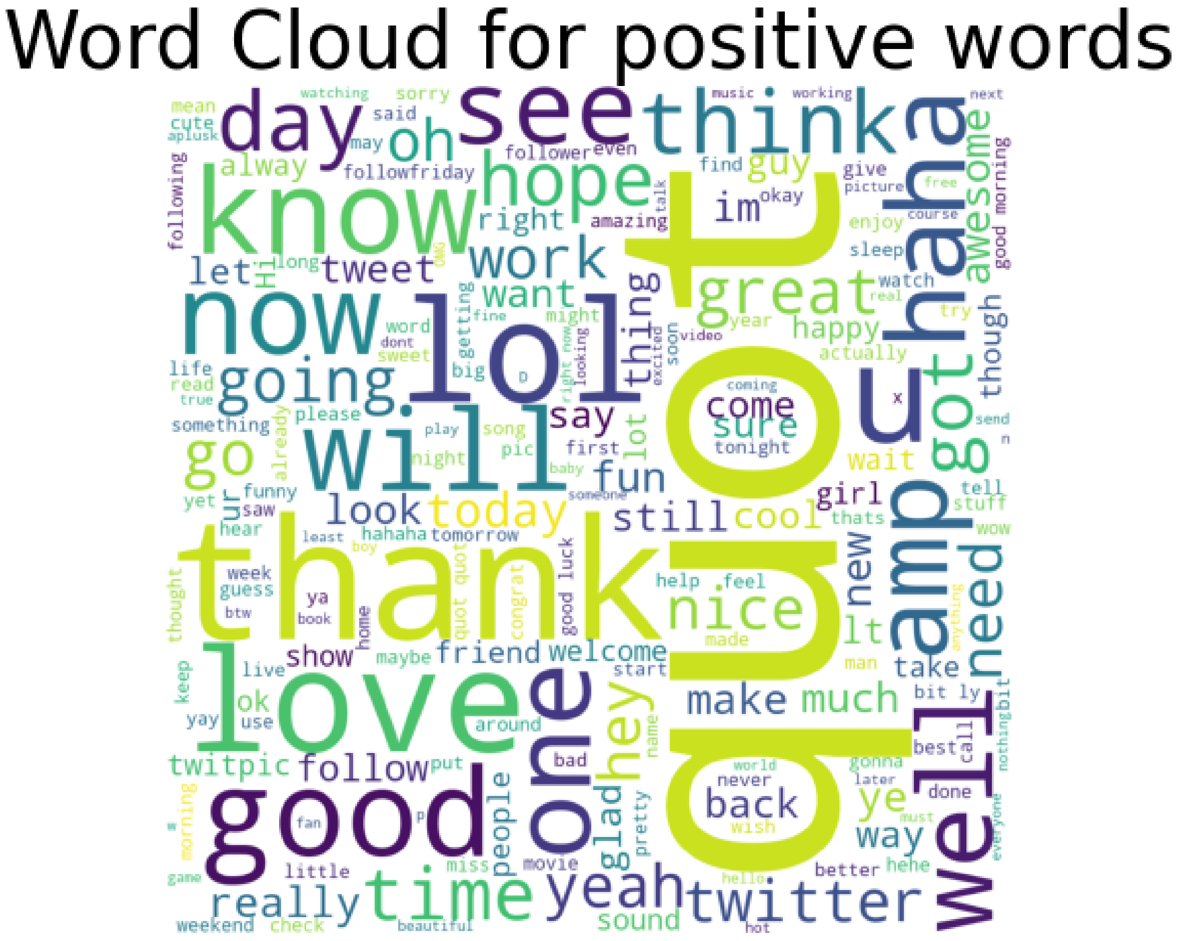
```
In [22]: wc = WordCloud(background_color='White', width = 1000, height = 1000).generate
         _from_frequencies(dict(word_freq))
         plt.figure(figsize=(8, 8))
         plt.axis('off')
         plt.imshow(wc, interpolation = 'bilinear')
         plt.title("Word Cloud for Setiment Text", fontsize=40)
```

```
Out[22]: Text(0.5, 1.0, 'Word Cloud for Setiment Text')
```



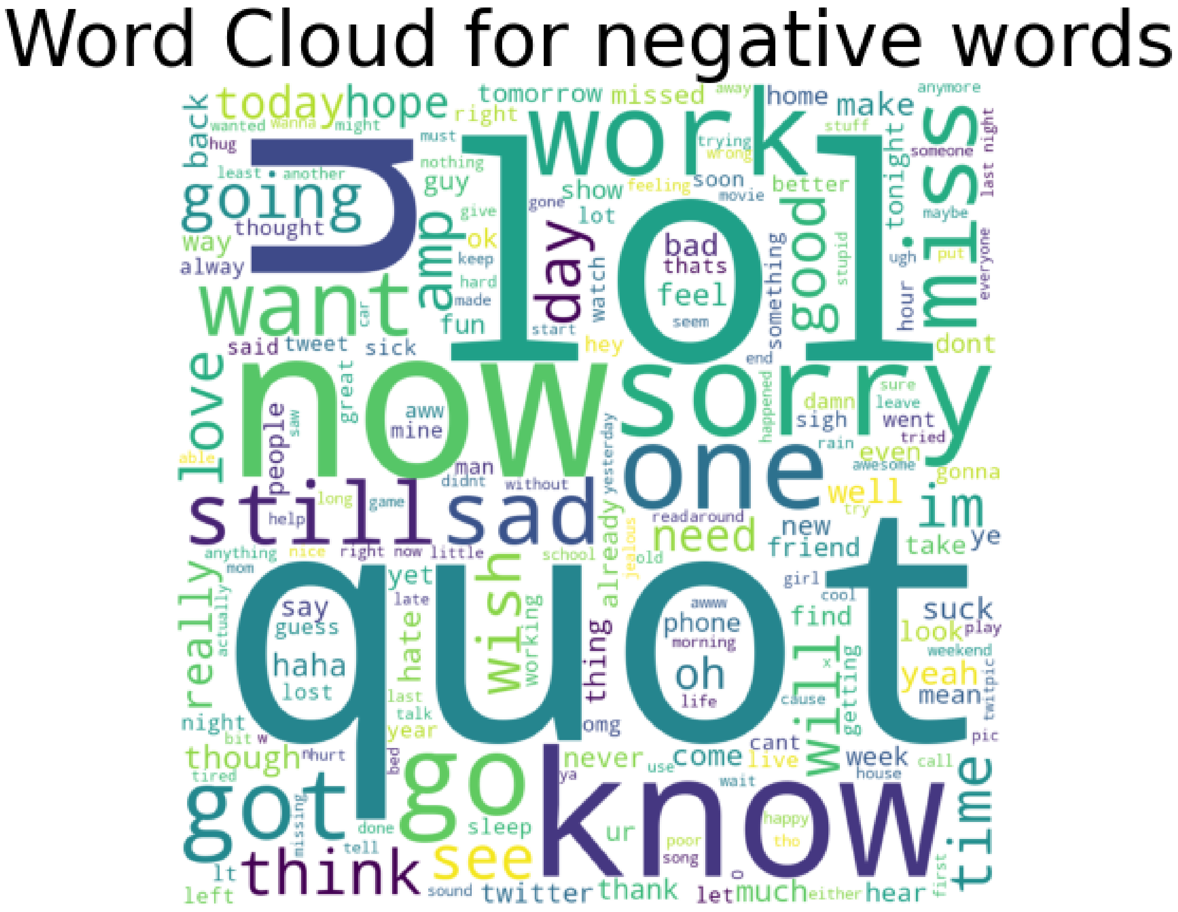
```
In [23]: positive_words = ' '.join([word for word in train['SentimentText'][train['Sent
         iment']==1]])
         positive_wc = WordCloud(background_color='White', width = 1000, height = 1000)
         .generate(positive_words)
         plt.figure(figsize=(8, 8))
         plt.axis('off')
         plt.imshow(positive_wc)
         plt.title("Word Cloud for positive words", fontsize=40)
```

```
Out[23]: Text(0.5, 1.0, 'Word Cloud for positive words')
```



```
In [24]: negative_words = ' '.join([word for word in train['SentimentText'][train['Sent
         iment']==0]])
         negative_wc = WordCloud(background_color='White', width = 1000, height = 1000)
         .generate(negative_words)
         plt.figure(figsize=(8, 8))
         plt.axis('off')
         plt.imshow(negative_wc)
         plt.title("Word Cloud for negative words", fontsize=40)
```

```
Out[24]: Text(0.5, 1.0, 'Word Cloud for negative words')
```



Data cleaning and preprocessing

```
In [25]: snow_stemmer = SnowballStemmer(language='english')
         nltk.download('wordnet')

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

Out[25]: True
```

```
In [26]: lemmatizer = nltk.stem.WordNetLemmatizer()
```

In [27]:

```
def decontracted(phrase):
    phrase = re.sub(r"won't", "will not", phrase)
    phrase = re.sub(r"can\'t", "can not", phrase)
    phrase = re.sub(r"n\'t", " not", phrase)
    phrase = re.sub(r"\'re", " are", phrase)
    phrase = re.sub(r"\'s", " is", phrase)
    phrase = re.sub(r"\'d", " would", phrase)
    phrase = re.sub(r"\'ll", " will", phrase)
    phrase = re.sub(r"\'t", " not", phrase)
    phrase = re.sub(r"\'ve", " have", phrase)
    phrase = re.sub(r"\'m", " am", phrase)
    return phrase
```

In [28]:

```
def text_preprocessing(text):
    text = re.sub('@[^\s]+', '', text)
    text = re.sub('((www\.[^\s]+)|(https?://[^\s]+))', ' ', text)
    text = re.sub('[^a-zA-Z\n]', ' ', text)
    text = re.sub('\s+',' ', text)
    text = re.sub("\n", " ", text)
    text = re.sub("\t", " ", text)
    text = re.sub(",", ", ", text)
    #text = ' '.join(words for words in text.split(" ") if len(words)>2)
    text = ' '.join(words for words in text.split(" "))
    text = decontracted(text)
    text = re.sub(r'(.)\1{3,}',r'\1', text)
    text = re.sub(r'[^\w\s]', '', text)
    return text.strip().lower()
```

In [29]:

```
def stop_and_stem(text):
    text = ' '.join(words.lower() for words in text.split(" ") if words not in
stop_words)
    word_list = nltk.word_tokenize(text)
    text = ' '.join(snow_stemmer.stem(word) for word in word_list)
    text = ' '.join(words for words in text.split(" ") if len(words)>2)
    return text
```

In [30]:

```
def stop_and_lemmatize(text):
    text = ' '.join(words.lower() for words in text.split(" ") if words not in
stop_words)
    word_list = nltk.word_tokenize(text)
    text = ' '.join(lemmatizer.lemmatize(word) for word in word_list)
    text = ' '.join(words for words in text.split(" ") if len(words)>2)
    return text
```

In [106]:

```
def gt_2(text):
    text = ' '.join(words for words in text.split(" ") if len(words)>2)
    return text
```

In [31]:

```
train["clean_SentimentText"] = train["SentimentText"].apply(text_preprocessing
)
```

In [107]:

```
train["preprocessed_SentimentText"] = train["clean_SentimentText"].apply(gt_2)
```

In [32]:

```
train["stemmed_SentimentText"] = train["clean_SentimentText"].apply(stop_and_s
tem)
```

In [33]:

```
train["lemmatized_SentimentText"] = train["clean_SentimentText"].apply(stop_an
d_lemmatize)
```

In [108]:

```
train.head(2)
```

Out[108]:

	ItemID	Sentiment	SentimentText	clean_SentimentText	stemmed_SentimentText	lem
0	1	0	is so sad for my APL frie...	is so sad for my apl friend	sad apl friend	sad
1	2	0	I missed the New Moon trail...	i missed the new moon trailer	miss new moon trailer	miss

In [35]:

```
train[['SentimentText','clean_SentimentText','stemmed_SentimentText', 'lemmati
zed_SentimentText']][0:10:2]
```

Out[35]:

	SentimentText	clean_SentimentText	stemmed_SentimentText	lemmatize
0	is so sad for my APL frie...	is so sad for my apl friend	sad apl friend	sad apl frier
2	omg its already 7:30 :O	omg its already o	omg alreadi	omg alread
4	i think mi bf is cheating on me!!! ...	i think mi bf is cheating on me t t	think cheat	think cheati
6	Juuuuuuuuuuuuuuuuussssst Chillin!!	just chillin	chillin	chillin
8	handed in my uniform today . i miss you ...	handed in my uniform today i miss you already	hand uniform today miss alreadi	handed unit already

In [36]:

```
print("Before text processing =", train["SentimentText"][0])
print("After text processing =", train["clean_SentimentText"][0])
```

```
Before text processing =                      is so sad for my APL frien
d.............
After text processing = is so sad for my apl friend
```

In [37]:

```
Y = train[['Sentiment']]
X = train[['lemmatized_SentimentText']]
```

In [38]:

```
print(X.shape)
print(Y.shape)
```

```
(99989, 1)
(99989, 1)
```

In [39]:

```
X.head(2)
```

Out[39]:

	lemmatized_SentimentText
0	sad apl friend
1	missed new moon trailer

In [40]:

```
Y.head(2)
```

Out[40]:

	Sentiment
0	0
1	0

Splitting the data

In [41]:

```
X_train, X_test, Y_train, Y_test = train_test_split(X,Y, test_size=0.33, strat
ify=Y)
```

In [42]:

```
print(X_train.shape)
print(Y_train.shape)
print(X_test.shape)
print(Y_test.shape)
```

```
(66992, 1)
(66992, 1)
(32997, 1)
(32997, 1)
```

In [43]:

```
X_train.head(2)
```

Out[43]:

	lemmatized_SentimentText
48200	mouthing said stupid people like think one gre...
19182	quot everyone become great quot one still isnt...

In [44]:
```
X_test.head(2)
```

Out[44]:

	lemmatized_SentimentText
84535	reply
28022	thank much look resource

In [45]:
```
tfidf_vectorizer = TfidfVectorizer(min_df=8, ngram_range=(1,3))
X_train_tfidf = tfidf_vectorizer.fit_transform(X_train['lemmatized_SentimentTe
xt'].values)
X_test_tfidf = tfidf_vectorizer.transform(X_test['lemmatized_SentimentText'].v
alues)
```

In [46]:
```
print(X_train_tfidf.shape)
print(X_test_tfidf.shape)
```

```
(66992, 7590)
(32997, 7590)
```

In [47]:
```
with open(r'D:\Twitter Sentiment Analysis\Dataset\glove_vectors', 'rb') as f:
    model = pickle.load(f)
    glove_words =  set(model.keys())
```

In [48]:
```
dictionary = dict(zip(tfidf_vectorizer.get_feature_names(), list(tfidf_vectori
zer.idf_)))
tfidf_words = set(tfidf_vectorizer.get_feature_names())
```

In [49]:

```
X_train_w2v = []; # the avg-w2v for each sentence/review is stored in this lis
t
for sentence in tqdm(X_train['lemmatized_SentimentText'].values): # for each r
eview/sentence
    vector = np.zeros(300) # as word vectors are of zero length
    tf_idf_weight =0; # num of words with a valid vector in the sentence/revie
w
    for word in sentence.split(): # for each word in a review/sentence
        if (word in glove_words) and (word in tfidf_words):
            vec = model[word] # getting the vector for each word
            # here we are multiplying idf value(dictionary[word]) and the tf v
alue((sentence.count(word)/len(sentence.split())))
            tf_idf = dictionary[word]*(sentence.count(word)/len(sentence.split
())) # getting the tfidf value for each word
            vector += (vec * tf_idf) # calculating tfidf weighted w2v
            tf_idf_weight += tf_idf
    if tf_idf_weight != 0:
        vector /= tf_idf_weight
    X_train_w2v.append(vector)

print(len(X_train_w2v))
print(len(X_train_w2v[0]))
```

```
100%|████████████████████████████████████████████████████████████████████████
█| 66992/66992 [00:02<00:00, 32658.81it/s]

66992
300
```

In [50]:

```
X_test_w2v = []; # the avg-w2v for each sentence/review is stored in this list
for sentence in tqdm(X_test['lemmatized_SentimentText'].values): # for each review/sentence
    vector = np.zeros(300) # as word vectors are of zero length
    tf_idf_weight =0; # num of words with a valid vector in the sentence/review
    for word in sentence.split(): # for each word in a review/sentence
        if (word in glove_words) and (word in tfidf_words):
            vec = model[word] # getting the vector for each word
            # here we are multiplying idf value(dictionary[word]) and the tf value((sentence.count(word)/len(sentence.split())))
            tf_idf = dictionary[word]*(sentence.count(word)/len(sentence.split())) # getting the tfidf value for each word
            vector += (vec * tf_idf) # calculating tfidf weighted w2v
            tf_idf_weight += tf_idf
    if tf_idf_weight != 0:
        vector /= tf_idf_weight
    X_test_w2v.append(vector)

print(len(X_test_w2v))
print(len(X_test_w2v[0]))
```

```
100%|████████████████████████████████████████████████████████████████████
█| 32997/32997 [00:00<00:00, 33079.78it/s]

32997
300
```

Machine Learning Models

Logisitic Regression

In [51]:

```
parameters = {"C":[10**-x for x in range(-2,2)]}

model = LogisticRegression(penalty='l2', random_state=0)
clf_log = GridSearchCV(model, parameters, cv=10, n_jobs=-1)
clf_log.fit(X_train_w2v,Y_train)

print("Best estimator=", clf_log.best_estimator_)
print("Best score =", clf_log.best_score_)
```

```
Best estimator= LogisticRegression(C=0.1, random_state=0)
Best score = 0.7131746128292706
```

In [52]:

```
parameters = {"C":[10**-x for x in range(-4,5)]}

model = LogisticRegression(penalty='l2', random_state=0)
clf_log = GridSearchCV(model, parameters, cv=10, n_jobs=-1)
clf_log.fit(X_train_tfidf,Y_train)

print("Best estimator=", clf_log.best_estimator_)
print("Best score =", clf_log.best_score_)
```

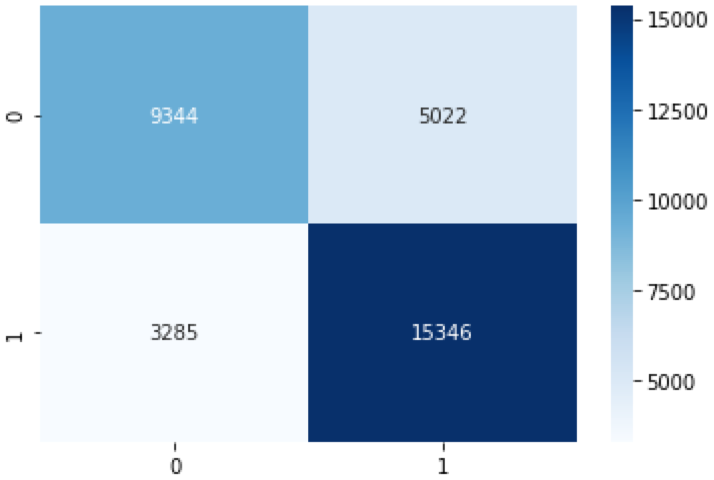
```
Best estimator= LogisticRegression(C=1, random_state=0)
Best score = 0.7501193673370719
```

In [53]:

```
model_log = LogisticRegression(C= clf_log.best_params_['C'], penalty='l2', random_state=0)
model_log.fit(X_train_tfidf, Y_train)

Y_pred = model_log.predict(X_test_tfidf)

f1_score_log = f1_score(Y_test, Y_pred)
print("The f1 score for logistice regression model is ", f1_score_log)

cm_log = confusion_matrix(Y_test, Y_pred)
print("The confusion matrix on the test dataset for logistic regression:")
#print(cm_log)
sns.heatmap(cm_log, annot=True, fmt='d', cmap='Blues')
```

```
The f1 score for logistice regression model is  0.7869945383214954
The confusion matrix on the test dataset for logistic regression:
```

Out[53]: <AxesSubplot:>



Naive Bayes

In [54]:

```
multiNB = MultinomialNB()
parameters = {'alpha':[10 ** x for x in range(-3, 3)]}
clf_NB = GridSearchCV(multiNB, parameters, cv=10, n_jobs=-1)
clf_NB.fit(X_train_tfidf, Y_train)

print("Best estimator=", clf_NB.best_estimator_)
print("Best score =", clf_NB.best_score_)
```

```
Best estimator= MultinomialNB(alpha=1)
Best score = 0.7439543638725317
```

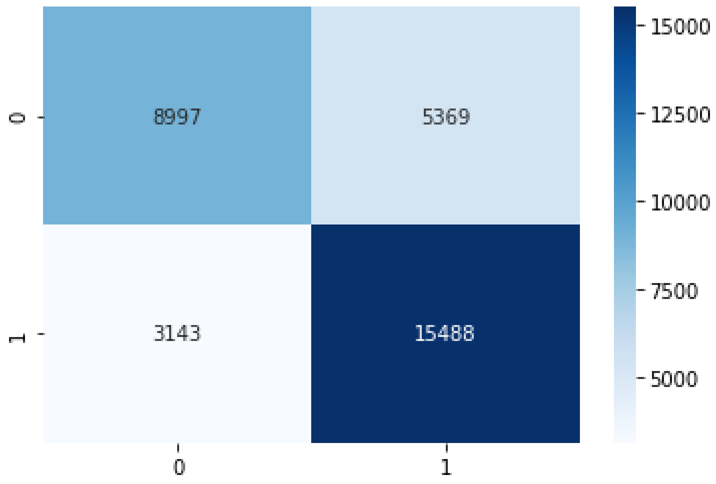
In [55]:

```
model_NB = MultinomialNB(alpha= clf_NB.best_params_['alpha'])
model_NB.fit(X_train_tfidf, Y_train)

Y_pred = model_NB.predict(X_test_tfidf)

f1_score_NB = f1_score(Y_test, Y_pred)
print("The f1 score for Naive Bayes model is ", f1_score_NB)

cm_NB = confusion_matrix(Y_test, Y_pred)
print("The confusion matrix on the test dataset for Naive Bayes:")
#print(cm_NB)
sns.heatmap(cm_NB, annot=True, fmt='d', cmap='Blues')
```

```
The f1 score for Naive Bayes model is  0.7844408427876822
The confusion matrix on the test dataset for Naive Bayes:
```

Out[55]:

```
<AxesSubplot:>
```



Random Forest

In [56]:

```
model_RF = RandomForestClassifier()
parameters={'min_samples_split':[10,12,14], 'n_estimators':[100, 200, 350]}
clf_RF = GridSearchCV(model_RF, parameters, cv=10, n_jobs=-1)
clf_RF.fit(X_train_tfidf, Y_train)

print("Best estimator=", clf_RF.best_estimator_)
print("Best score=", clf_RF.best_score_)
```

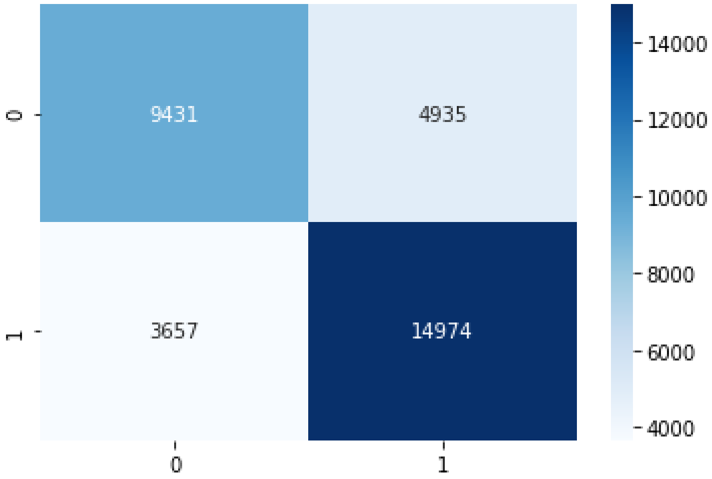
```
Best estimator= RandomForestClassifier(min_samples_split=10, n_estimators=35
0)
Best score= 0.7357594272257164
```

In [57]:

```
model_RF = RandomForestClassifier(min_samples_split= clf_RF.best_params_['min_
samples_split'], n_estimators= clf_RF.best_params_['n_estimators'])
model_RF.fit(X_train_tfidf, Y_train)

Y_pred = model_RF.predict(X_test_tfidf)

f1_score_RF = f1_score(Y_test, Y_pred)
print("The f1 score for Random Forest model is ", f1_score_RF)

cm_RF = confusion_matrix(Y_test, Y_pred)
print("The confusion matrix on the test dataset for Random Forest:")
#print(cm_RF)
sns.heatmap(cm_RF, annot=True, fmt='d', cmap='Blues')
```

```
The f1 score for Random Forest model is  0.7770627919045148
The confusion matrix on the test dataset for Random Forest:
```

Out[57]: <AxesSubplot:>



Gradient Boosting Decision Trees

In [58]:

```
model_GBDT = GradientBoostingClassifier()
parameters = {'learning_rate':[0.1, 0.3, 0.4], 'n_estimators':[200, 300, 500]}
clf_GBDT = GridSearchCV(model_GBDT, parameters, cv=10, n_jobs=-1)
clf_GBDT.fit(X_train_tfidf, Y_train)

print("Best estimator=", clf_GBDT.best_estimator_)
print("Best score=", clf_GBDT.best_score_)
```

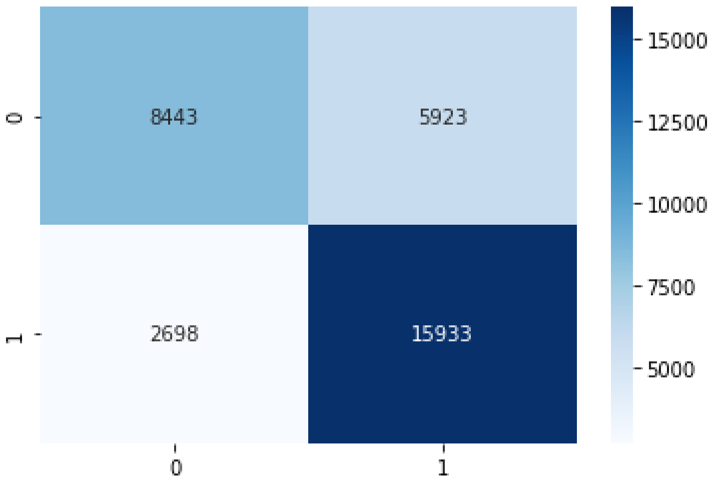
```
Best estimator= GradientBoostingClassifier(learning_rate=0.3, n_estimators=50
0)
Best score= 0.7374164555636507
```

In [59]:

```
model_GBDT = GradientBoostingClassifier(learning_rate= clf_GBDT.best_params_[
'learning_rate'], n_estimators= clf_GBDT.best_params_['n_estimators'])
model_GBDT.fit(X_train_tfidf, Y_train)

Y_pred = model_GBDT.predict(X_test_tfidf)

f1_score_GBDT = f1_score(Y_test, Y_pred)
print("The f1 score for Gradient Boosting Decision Tree model is ", f1_score_G
BDT)

cm_GBDT = confusion_matrix(Y_test, Y_pred)
print("The confusion matrix on the test dataset for Gradient Boosting Decision
Tree:")
#print(cm_GBDT)
sns.heatmap(cm_GBDT, annot=True, fmt='d', cmap='Blues')
```

```
The f1 score for Gradient Boosting Decision Tree model is  0.7870674537505866
The confusion matrix on the test dataset for Gradient Boosting Decision Tree:
```

Out[59]: `<AxesSubplot:>`



Linear SVC

In [60]:

```
model_SVC = LinearSVC()
parameters = {"C":[0.001, 0.01, 0.1, 1, 10]}
clf_SVC = GridSearchCV(model_SVC, parameters, cv=10, n_jobs=-1)
clf_SVC.fit(X_train_tfidf, Y_train)

print("Best estimator= ", clf_SVC.best_estimator_)
print("Best score= ", clf_SVC.best_score_)
```

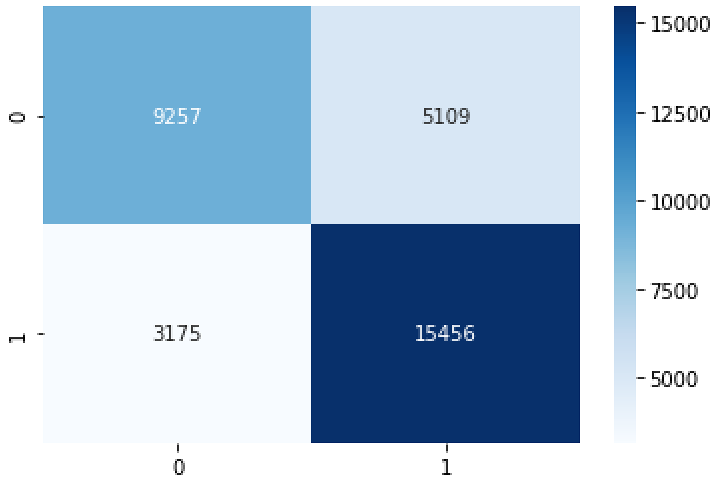
```
Best estimator=  LinearSVC(C=0.1)
Best score=  0.7502835709495514
```

In [61]:

```
model_SVC = LinearSVC(C=clf_SVC.best_params_["C"])
model_SVC.fit(X_train_tfidf,Y_train)

Y_pred = model_SVC.predict(X_test_tfidf)

f1_score_SVC = f1_score(Y_test, Y_pred)
print("The f1 score for Gradient linear SVC model is ", f1_score_SVC)

cm_SVC = confusion_matrix(Y_test, Y_pred)
print("The confusion matrix on the test dataset for linear SVC:")
#print(cm_SVC)
sns.heatmap(cm_SVC, annot=True, fmt='d', cmap='Blues')
```

```
The f1 score for Gradient linear SVC model is  0.7886519032554343
The confusion matrix on the test dataset for linear SVC:
```

Out[61]: <AxesSubplot:>



Deep Learning Models

Data preprocessing

In [109]:

```
#Y = train[['Sentiment']]
#X = train[['clean_SentimentText']]
X = train[['preprocessed_SentimentText']]
```

In [110]:

```
X_train, X_test, Y_train, Y_test = train_test_split(X,Y, test_size=0.20, strat
ify=Y)
X_train, X_cv, Y_train, Y_cv = train_test_split(X_train,Y_train, test_size=0.2
0, stratify=Y_train)
```

In [111]:

```
print(X_train.shape, Y_train.shape)
print(X_cv.shape, Y_cv.shape)
print(X_test.shape, Y_test.shape)
```

```
(63992, 1) (63992, 1)
(15999, 1) (15999, 1)
(19998, 1) (19998, 1)
```

In [113]:

```
tokenizer = tf.keras.preprocessing.text.Tokenizer(filters='!"#$%&()*+,-/:;<=>?
@[\\]^`{|}~\t\n')
tokenizer.fit_on_texts(X_train['preprocessed_SentimentText'])

X_train_seq = tokenizer.texts_to_sequences(X_train['preprocessed_SentimentTex
t'])
X_cv_seq = tokenizer.texts_to_sequences(X_cv['preprocessed_SentimentText'])
X_test_seq = tokenizer.texts_to_sequences(X_test['preprocessed_SentimentText'
])

word_index = tokenizer.word_index
result     = [len(x.split()) for x in X_train['preprocessed_SentimentText']]

print("Text informations:")
print("Max length:   {}".format(np.max(result)))
print("Min length:   {}".format(np.min(result)))
print("Mean length:  {}".format(np.mean(result)))
```

```
Text informations:
Max length:   84
Min length:   0
Mean length:  9.180772596574572
```

In [114]:

```
max_length= int(np.max(result))
print(max_length)
```

```
84
```

In [115]:

```
Q3_len = int(X_train['preprocessed_SentimentText'].str.split().apply(len).describe()['75%'])
X_train['preprocessed_SentimentText'].str.split().apply(len).describe()
```

Out[115]:

```
count    63992.000000
mean         9.180773
std          5.233915
min          0.000000
25%          5.000000
50%          8.000000
75%         13.000000
max         84.000000
Name: preprocessed_SentimentText, dtype: float64
```

In [116]:

```
X_train_pad = tf.keras.preprocessing.sequence.pad_sequences(X_train_seq, maxlen=max_length)
X_cv_pad = tf.keras.preprocessing.sequence.pad_sequences(X_cv_seq, maxlen=max_length)
X_test_pad = tf.keras.preprocessing.sequence.pad_sequences(X_test_seq, maxlen=max_length)
```

In [117]:

```
print(X_train_pad.shape)
print(X_cv_pad.shape)
print(X_test_pad.shape)
```

```
(63992, 84)
(15999, 84)
(19998, 84)
```

In [120]:

```
%%time

#Reference from https://blog.keras.io/using-pre-trained-word-embeddings-in-a-keras-model.html
glove_file = r'D:\Twitter Sentiment Analysis\Dataset/glove.840B.300d.pkl'
glove = np.load(glove_file, allow_pickle=True)

EMBEDDING_DIM=300
embedding_matrix = np.zeros((len(word_index) + 1, EMBEDDING_DIM))
for word, i in word_index.items():
    embedding_vector = glove.get(word)
    if embedding_vector is not None:
        # words not found in embedding index will be all-zeros.
        embedding_matrix[i] = embedding_vector
print(embedding_matrix.shape)
```

```
(36910, 300)
Wall time: 7.76 s
```

In [121]:

```
def Recall(y_true, y_pred):
    y_true = K.ones_like(y_true)
    true_positives = K.sum(K.round(K.clip(y_true * y_pred, 0, 1)))
    all_positives = K.sum(K.round(K.clip(y_true, 0, 1)))

    recall = true_positives / (all_positives + K.epsilon())
    return recall

def Precision(y_true, y_pred):
    y_true = K.ones_like(y_true)
    true_positives = K.sum(K.round(K.clip(y_true * y_pred, 0, 1)))

    predicted_positives = K.sum(K.round(K.clip(y_pred, 0, 1)))
    precision = true_positives / (predicted_positives + K.epsilon())
    return precision

def F1_score(y_true, y_pred):
    precision = Precision(y_true, y_pred)
    recall = Recall(y_true, y_pred)
    return 2*((precision*recall)/(precision+recall+K.epsilon()))
```

Sequential model using RNN with pre-trained word embeddings

In [122]:

```
tf.random.set_seed(0)
np.random.seed(0)
```

In [124]:

```
tf.compat.v1.keras.backend.get_session()
```

Out[124]:

```
<tensorflow.python.client.session.Session at 0x2325a2a7c18>
```

In [125]:

```
def build_rnn():
    model = tf.keras.models.Sequential()
    model.add(tf.keras.layers.Input(shape=max_length))
    model.add(tf.keras.layers.Embedding(len(tokenizer.word_index)+1, EMBEDDING_DIM, weights=[embedding_matrix], input_length=max_length, trainable=True))
    #model.add(tf.keras.layers.SimpleRNN(32, return_sequences=True, recurrent_dropout=0.5, bias_regularizer='L2'))
    model.add(tf.keras.layers.SimpleRNN(512, return_sequences=True, recurrent_dropout=0.3))
    model.add(tf.keras.layers.SimpleRNN(512, recurrent_dropout=0.3))
    model.add(tf.keras.layers.Dense(len(Y_train.columns), activation='sigmoid'))

    model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy', F1_score, Precision, Recall])
    return model
```

In [126]:

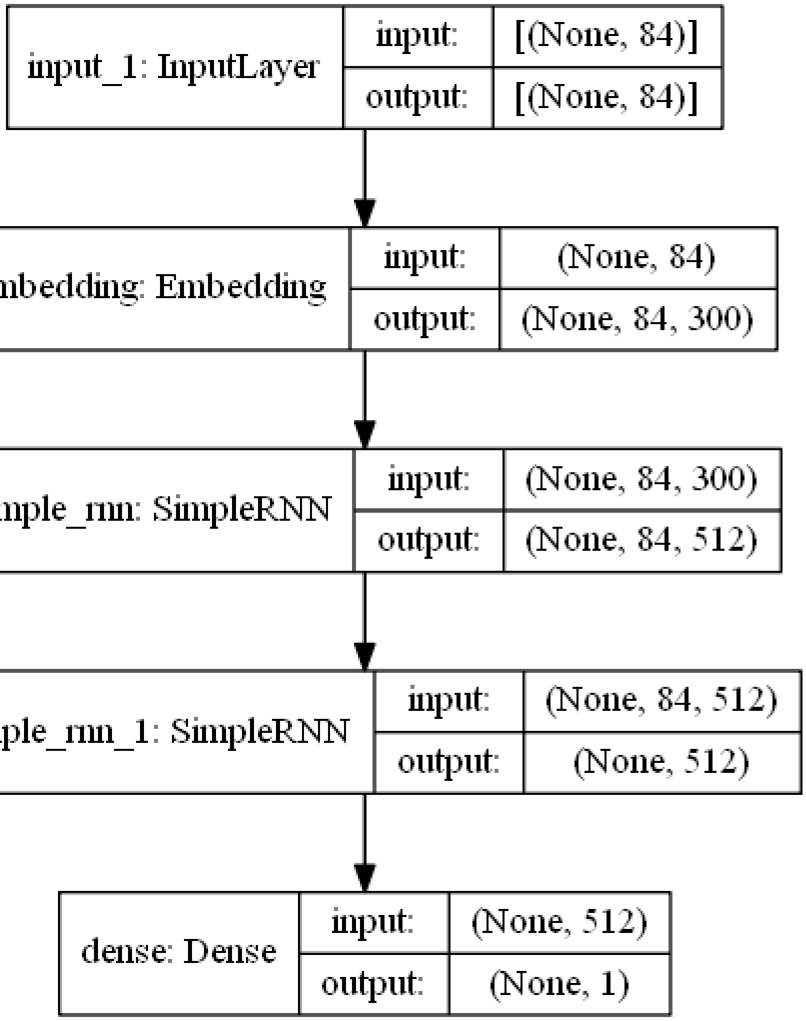
```
model_rnn = build_rnn()
model_rnn.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
embedding (Embedding)        (None, 84, 300)           11073000  
_________________________________________________________________
simple_rnn (SimpleRNN)       (None, 84, 512)           416256    
_________________________________________________________________
simple_rnn_1 (SimpleRNN)     (None, 512)               524800    
_________________________________________________________________
dense (Dense)                (None, 1)                 513       
=================================================================
Total params: 12,014,569
Trainable params: 12,014,569
Non-trainable params: 0
_________________________________________________________________
```

In [127]:

```
tf.keras.utils.plot_model(model_rnn,to_file='modelRNN.png', show_shapes=True,
show_layer_names=True)
```

Out[127]:



In [128]:

```
checkpoint_path = "D:\Twitter Sentiment Analysis"
checkpoint_dir = os.path.dirname(checkpoint_path)
file_path=os.path.join(checkpoint_dir, "Twitter Sentiment Analysis", "checkpoi
nt", "weights-{epoch:02d}-{val_F1_score:.4f}")

earlystop = EarlyStopping(monitor='val_loss', patience=2, verbose=1)

model_checkpoint_callback = tf.keras.callbacks.ModelCheckpoint(filepath=file_p
ath, save_weights_only=True, monitor='val_F1_score', mode='max', save_best_onl
y=True)

log_dir = os.path.join(checkpoint_dir, "Twitter Sentiment Analysis", "logs",'f
it', datetime.datetime.now().strftime("%Y%m%d-%H%M%S"))
tensorboard_callback = tf.keras.callbacks.TensorBoard(log_dir=log_dir,histogra
m_freq=1, write_graph=True)
```

In [129]:

```
%%time
rnn_hist = model_rnn.fit(X_train_pad, Y_train, epochs=10, validation_data=(X_c
v_pad, Y_cv), batch_size=64,
                         callbacks=[earlystop, model_checkpoint_callback, tens
orboard_callback])
```

```
Epoch 1/10
1000/1000 [==============================] - 729s 728ms/step - loss: 0.5686 -
accuracy: 0.7041 - F1_score: 0.7247 - Precision: 1.0000 - Recall: 0.5849 - va
l_loss: 0.5175 - val_accuracy: 0.7544 - val_F1_score: 0.7610 - val_Precision:
1.0000 - val_Recall: 0.6162
Epoch 2/10
1000/1000 [==============================] - 798s 798ms/step - loss: 0.5032 -
accuracy: 0.7510 - F1_score: 0.7283 - Precision: 0.9990 - Recall: 0.5893 - va
l_loss: 0.5339 - val_accuracy: 0.7455 - val_F1_score: 0.7086 - val_Precision:
1.0000 - val_Recall: 0.5505
Epoch 3/10
1000/1000 [==============================] - 807s 807ms/step - loss: 0.5137 -
accuracy: 0.7519 - F1_score: 0.7338 - Precision: 0.9970 - Recall: 0.5961 - va
l_loss: 0.6212 - val_accuracy: 0.7055 - val_F1_score: 0.5328 - val_Precision:
1.0000 - val_Recall: 0.3653
Epoch 00003: early stopping
Wall time: 38min 55s
```

In [130]:

```
for metric, values in rnn_hist.history.items():
    print(metric, ":", values)
```

```
loss : [0.5685679912567139, 0.5031551718711853, 0.5136750936508179]
accuracy : [0.7040567398071289, 0.750968873500824, 0.7518908381462097]
F1_score : [0.7246702313423157, 0.7283213138580322, 0.7338063716888428]
Precision : [1.0, 0.9990000128746033, 0.996999979019165]
Recall : [0.5849397778511047, 0.5893124938011169, 0.5961004495620728]
val_loss : [0.5175146460533142, 0.5338994860649109, 0.6211705803871155]
val_accuracy : [0.754422128200531, 0.7455465793609619, 0.7054815888404846]
val_F1_score : [0.7609983682632446, 0.7085798382759094, 0.5328055620193481]
val_Precision : [1.0, 1.0, 1.0]
val_Recall : [0.6161696314811707, 0.5505436658859253, 0.36533334851264954]
```

In [131]:

```
loss_rnn, accuracy_rnn, f1_score_rnn, precision_rnn, recall_rnn = model_rnn.evaluate(X_test_pad, Y_test, verbose=0)
print('F1 score for RNN model: %f' % f1_score_rnn)
```

```
F1 score for RNN model: 0.513728
```

In [132]:

```
%load_ext  tensorboard
```

In [133]:

```
# Clear any logs from previous runs
!rm -rf ./logs/
```

```
'rm' is not recognized as an internal or external command,
operable program or batch file.
```

```
In [134]: %tensorboard --logdir="D:\Twitter Sentiment Analysis\logs\fit"
```

Index of C:\

Name	Size	Date Modified
$MfeDeepRem/		2/15/22, 9:03:27 PM
$Recycle.Bin/		3/16/22, 9:15:18 PM
$SysReset/		11/30/21, 9:53:17 PM
$WinREAgent/		6/16/22, 2:28:42 AM
Apps/		12/2/20, 8:00:32 PM
dell/		2/14/21, 12:03:01 PM
Documents and Settings/		12/13/20, 11:44:42 AM
Drivers/		12/2/20, 7:26:26 PM
hp_lj1020_Full_Solution/		3/23/21, 12:06:48 AM
Intel/		6/13/22, 1:40:22 PM
Kruti Dev Fonts(FontBharat.blogspot.com)/		3/22/21, 10:48:22 PM
LJP1100_P1560_P1600_Full_Solution/		1/8/22, 4:47:45 PM
Microsoft Malware Detection/		3/18/22, 4:44:17 AM
MSOCache/		3/26/21, 12:56:21 PM
OneDriveTemp/		2/14/21, 11:41:35 AM
PerfLogs/		6/5/21, 5:40:48 PM
Program Files/		6/12/22, 6:35:49 PM
Program Files (x86)/		2/21/22, 11:05:44 PM
ProgramData/		6/14/22, 11:05:18 PM
Recovery/		10/23/21, 5:51:57 PM
System Volume Information/		5/17/22, 5:10:25 PM
Tomcat/		10/18/21, 10:43:37 PM
Users/		10/23/21, 5:26:51 PM
Windows/		6/18/22, 11:17:17 AM
dell.sdr	28.1 kB	12/2/20, 7:36:02 PM
DumpStack.log	12.0 kB	6/13/22, 1:40:21 PM
DumpStack.log.tmp	12.0 kB	6/18/22, 12:20:17 PM
hiberfil.sys	12.7 GB	6/27/22, 12:13:54 AM
pagefile.sys	48.8 GB	6/18/22, 12:20:17 PM
swapfile.sys	16.0 MB	6/18/22, 12:20:17 PM

Stacked LSTMs with pre-trained word embeddings

In [135]:

```
def build_LSTM():
    model = tf.keras.models.Sequential()
    model.add(tf.keras.layers.Input(shape=max_length, ))
    model.add(tf.keras.layers.Embedding(len(tokenizer.word_index)+1, EMBEDDING
_DIM, weights=[embedding_matrix], input_length=max_length, trainable=True))
    model.add(tf.keras.layers.LSTM(512, return_sequences=True, recurrent_dropo
ut=0.3))
    model.add(tf.keras.layers.LSTM(512, recurrent_dropout=0.3))
    model.add(tf.keras.layers.Dense(len(Y_train.columns), activation='sigmoid'
))

    model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accu
racy', F1_score, Precision, Recall])

    return model
```

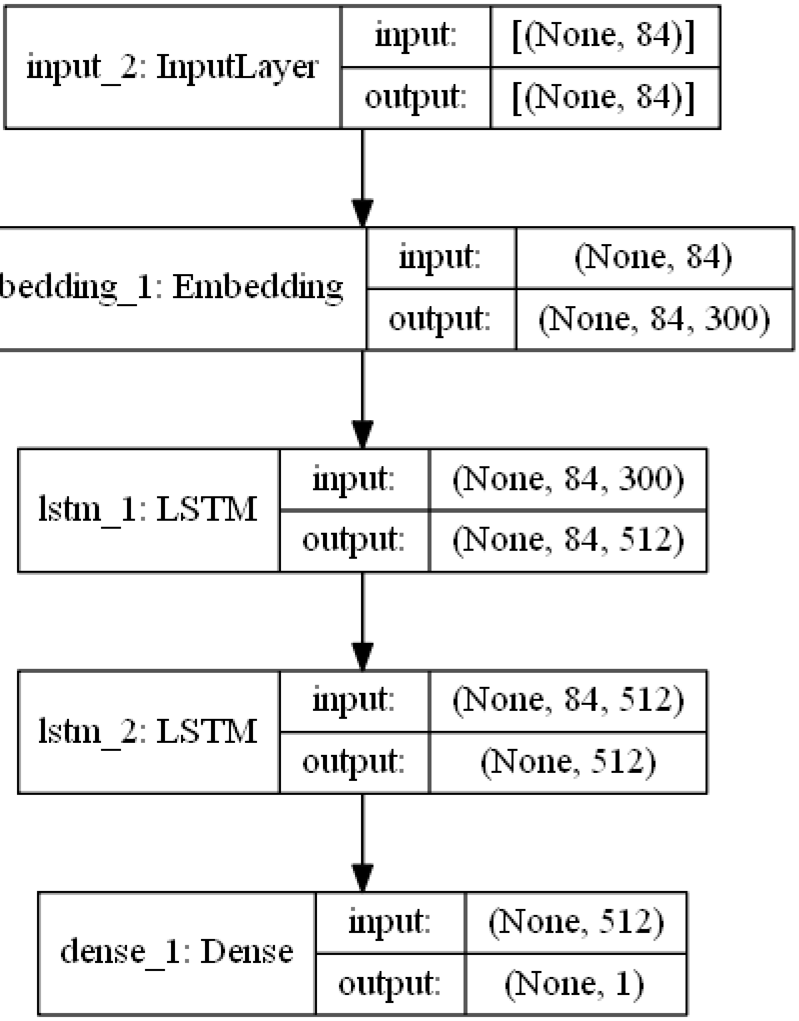
In [136]:

```
model_LSTM = build_LSTM()
model_LSTM.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
embedding_1 (Embedding)      (None, 84, 300)           11073000  
_________________________________________________________________
lstm_1 (LSTM)                (None, 84, 512)           1665024   
_________________________________________________________________
lstm_2 (LSTM)                (None, 512)               2099200   
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 513       
=================================================================
Total params: 14,837,737
Trainable params: 14,837,737
Non-trainable params: 0
_________________________________________________________________
```

```
In [137]: tf.keras.utils.plot_model(model_LSTM,to_file='model_LSTM.png', show_shapes=Tru
          e, show_layer_names=True)
```

Out[137]:



```
In [139]: LSTM_hist = model_LSTM.fit(X_train_pad, Y_train, epochs=10, validation_data=(X
          _cv_pad, Y_cv), batch_size=64,
                                     callbacks=[earlystop, model_checkpoint_callback, te
          nsorboard_callback])
```

```
Epoch 1/10
1000/1000 [==============================] - 5990s 6s/step - loss: 0.4920 - a
ccuracy: 0.7573 - F1_score: 0.7286 - Precision: 1.0000 - Recall: 0.5786 - val
_loss: 0.4658 - val_accuracy: 0.7768 - val_F1_score: 0.7355 - val_Precision:
1.0000 - val_Recall: 0.5838
Epoch 2/10
1000/1000 [==============================] - 5448s 5s/step - loss: 0.4015 - a
ccuracy: 0.8142 - F1_score: 0.7232 - Precision: 1.0000 - Recall: 0.5703 - val
_loss: 0.4880 - val_accuracy: 0.7695 - val_F1_score: 0.7103 - val_Precision:
1.0000 - val_Recall: 0.5532
Epoch 3/10
1000/1000 [==============================] - 28814s 29s/step - loss: 0.2892 -
accuracy: 0.8715 - F1_score: 0.7241 - Precision: 1.0000 - Recall: 0.5703 - va
l_loss: 0.5642 - val_accuracy: 0.7554 - val_F1_score: 0.7288 - val_Precision:
1.0000 - val_Recall: 0.5754
Epoch 00003: early stopping
```

In [140]:

```
loss_lstm, accuracy_lstm, f1_score_lstm, precision_lstm, recall_lstm = model_L
STM.evaluate(X_test_pad, Y_test, verbose=0)
print('F1 score for LSTM model: %f' % f1_score_lstm)
```

```
F1 score for LSTM model: 0.720554
```

In [141]:

```
# Clear any logs from previous runs
!rm -rf ./logs/
```

```
'rm' is not recognized as an internal or external command,
operable program or batch file.
```

```
In [142]: %tensorboard --logdir="D:\Twitter Sentiment Analysis\logs\fits"
```

Index of C:\

Name	Size	Date Modified
$MfeDeepRem/		2/15/22, 9:03:27 PM
$Recycle.Bin/		3/16/22, 9:15:18 PM
$SysReset/		11/30/21, 9:53:17 PM
$WinREAgent/		6/16/22, 2:28:42 AM
Apps/		12/2/20, 8:00:32 PM
dell/		2/14/21, 12:03:01 PM
Documents and Settings/		12/13/20, 11:44:42 AM
Drivers/		12/2/20, 7:26:26 PM
hp_lj1020_Full_Solution/		3/23/21, 12:06:48 AM
Intel/		6/13/22, 1:40:22 PM
Kruti Dev Fonts(FontBharat.blogspot.com)/		3/22/21, 10:48:22 PM
LJP1100_P1560_P1600_Full_Solution/		1/8/22, 4:47:45 PM
Microsoft Malware Detection/		3/18/22, 4:44:17 AM
MSOCache/		3/26/21, 12:56:21 PM
OneDriveTemp/		2/14/21, 11:41:35 AM
PerfLogs/		6/5/21, 5:40:48 PM
Program Files/		6/12/22, 6:35:49 PM
Program Files (x86)/		2/21/22, 11:05:44 PM
ProgramData/		6/14/22, 11:05:18 PM
Recovery/		10/23/21, 5:51:57 PM
System Volume Information/		5/17/22, 5:10:25 PM
Tomcat/		10/18/21, 10:43:37 PM
Users/		10/23/21, 5:26:51 PM
Windows/		6/18/22, 11:17:17 AM
dell.sdr	28.1 kB	12/2/20, 7:36:02 PM
DumpStack.log	12.0 kB	6/13/22, 1:40:21 PM
DumpStack.log.tmp	12.0 kB	6/18/22, 12:20:17 PM
hiberfil.sys	12.7 GB	6/27/22, 12:13:54 AM
pagefile.sys	48.8 GB	6/18/22, 12:20:17 PM
swapfile.sys	16.0 MB	6/18/22, 12:20:17 PM

Stacked GRUs with pre-trained word embeddings

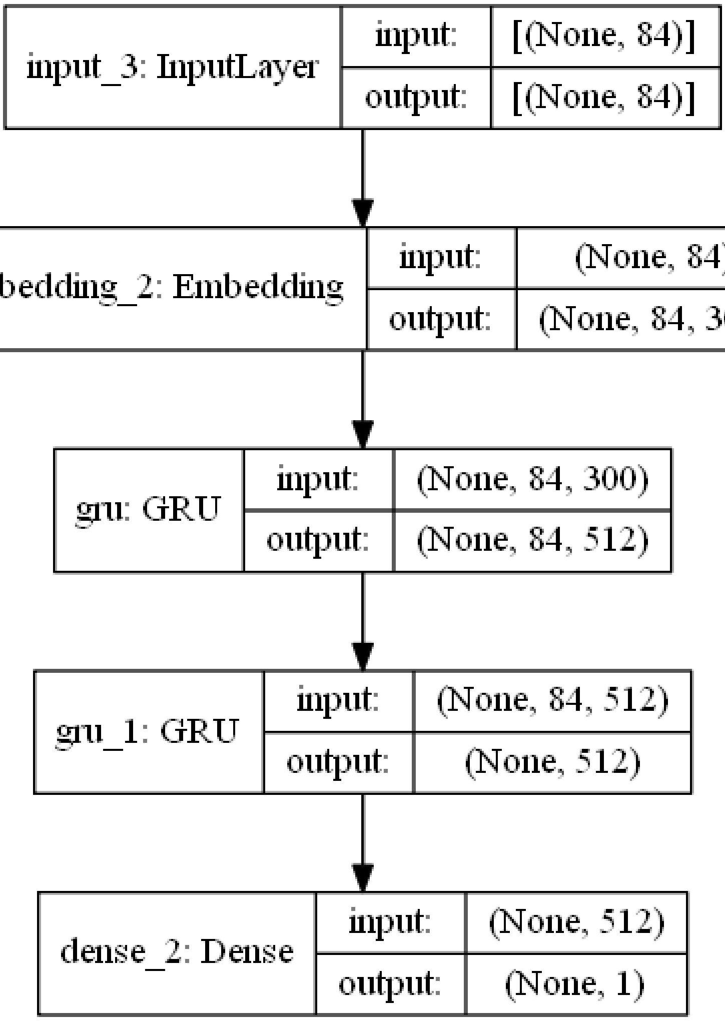
In [143]:
```
def build_GRU():
    model = tf.keras.models.Sequential()
    model.add(tf.keras.layers.Input(shape=max_length, ))
    model.add(tf.keras.layers.Embedding(len(tokenizer.word_index)+1, EMBEDDING
_DIM, weights=[embedding_matrix], input_length=max_length, trainable=True))
    model.add(tf.keras.layers.GRU(512, return_sequences=True, recurrent_dropou
t=0.3))
    model.add(tf.keras.layers.GRU(512, recurrent_dropout=0.3))
    model.add(tf.keras.layers.Dense(len(Y_train.columns), activation='sigmoid'
))

    model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accu
racy', F1_score, Precision, Recall])

    return model
```

In [144]:
```
model_GRU = build_GRU()
model_GRU.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
embedding_2 (Embedding)      (None, 84, 300)           11073000  
_________________________________________________________________
gru (GRU)                    (None, 84, 512)           1250304   
_________________________________________________________________
gru_1 (GRU)                  (None, 512)               1575936   
_________________________________________________________________
dense_2 (Dense)              (None, 1)                 513       
=================================================================
Total params: 13,899,753
Trainable params: 13,899,753
Non-trainable params: 0
_________________________________________________________________
```

```
In [147]:  tf.keras.utils.plot_model(model_GRU,to_file='model_GRU.png', show_shapes=True
           , show_layer_names=True)
```

Out[147]:



```
In [149]:  GRU_hist = model_GRU.fit(X_train_pad, Y_train, epochs=5, validation_data=(X_cv
           _pad, Y_cv), batch_size=64,
                                    callbacks=[earlystop, model_checkpoint_callback, tens
           orboard_callback])
```

```
Epoch 1/5
1000/1000 [==============================] - 6655s 7s/step - loss: 0.4923 - a
ccuracy: 0.7576 - F1_score: 0.7303 - Precision: 0.9990 - Recall: 0.5806 - val
_loss: 0.4672 - val_accuracy: 0.7739 - val_F1_score: 0.7527 - val_Precision:
1.0000 - val_Recall: 0.6056
Epoch 2/5
1000/1000 [==============================] - 6626s 7s/step - loss: 0.3939 - a
ccuracy: 0.8186 - F1_score: 0.7223 - Precision: 1.0000 - Recall: 0.5687 - val
_loss: 0.4868 - val_accuracy: 0.7701 - val_F1_score: 0.7400 - val_Precision:
1.0000 - val_Recall: 0.5896
Epoch 3/5
1000/1000 [==============================] - 7357s 7s/step - loss: 0.2787 - a
ccuracy: 0.8776 - F1_score: 0.7238 - Precision: 1.0000 - Recall: 0.5700 - val
_loss: 0.5802 - val_accuracy: 0.7506 - val_F1_score: 0.7338 - val_Precision:
1.0000 - val_Recall: 0.5815
Epoch 00003: early stopping
```

In [150]:

```
loss_GRU, accuracy_GRU, f1_score_GRU, precision_GRU, recall_GRU = model_GRU.ev
aluate(X_test_pad, Y_test, verbose=0)
print('F1 score for GRU model: %f' % f1_score_GRU)
```

```
F1 score for GRU model: 0.725504
```

Bidirectional RNN

In [156]:

```
def build_biRNN():
    model = tf.keras.models.Sequential()
    model.add(tf.keras.layers.Input(shape=max_length, ))
    model.add(tf.keras.layers.Embedding(len(tokenizer.word_index)+1, EMBEDDING
_DIM, weights=[embedding_matrix], input_length=max_length, trainable=True))
    #model.add(tf.keras.layers.Bidirectional(tf.keras.layers.SimpleRNN(512, re
turn_sequences=True, recurrent_dropout=0.3)))
    model.add(tf.keras.layers.Bidirectional(tf.keras.layers.SimpleRNN(512, rec
urrent_dropout=0.3)))
    model.add(tf.keras.layers.Dense(len(Y_train.columns), activation='sigmoid'
))

    model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accu
racy', F1_score, Precision, Recall])

    return model
```

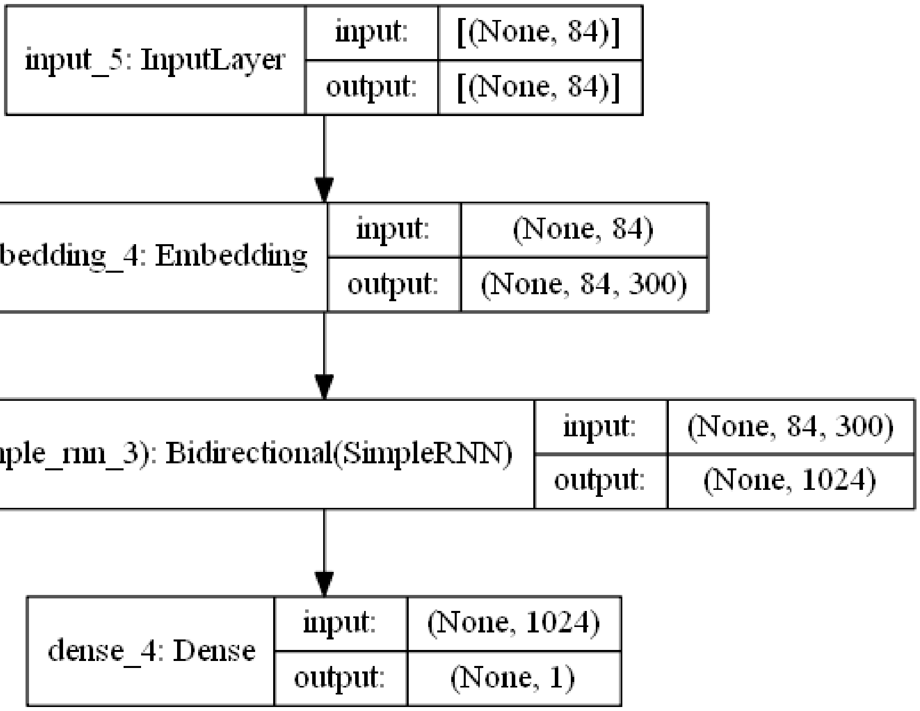
In [157]:

```
model_biRNN = build_biRNN()
model_biRNN.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
embedding_4 (Embedding)      (None, 84, 300)           11073000  
_________________________________________________________________
bidirectional_2 (Bidirection (None, 1024)              832512    
_________________________________________________________________
dense_4 (Dense)              (None, 1)                 1025      
=================================================================
Total params: 11,906,537
Trainable params: 11,906,537
Non-trainable params: 0
_________________________________________________________________
```

In [158]:
```
tf.keras.utils.plot_model(model_biRNN,to_file='model_biRNN.png', show_shapes=T
rue, show_layer_names=True)
```

Out[158]:



In [160]:
```
biRNN_hist = model_biRNN.fit(X_train_pad, Y_train, epochs=10, validation_data=
(X_cv_pad, Y_cv), batch_size=64,
                               callbacks=[earlystop, model_checkpoint_callback
, tensorboard_callback])
```

```
Epoch 1/10
1000/1000 [==============================] - 1982s 2s/step - loss: 0.6101 - a
ccuracy: 0.6713 - F1_score: 0.7356 - Precision: 1.0000 - Recall: 0.6037 - val
_loss: 0.6180 - val_accuracy: 0.6779 - val_F1_score: 0.4708 - val_Precision:
1.0000 - val_Recall: 0.3103
Epoch 2/10
1000/1000 [==============================] - 2032s 2s/step - loss: 0.5187 - a
ccuracy: 0.7426 - F1_score: 0.7306 - Precision: 1.0000 - Recall: 0.5876 - val
_loss: 0.5140 - val_accuracy: 0.7514 - val_F1_score: 0.7595 - val_Precision:
1.0000 - val_Recall: 0.6144
Epoch 3/10
1000/1000 [==============================] - 1998s 2s/step - loss: 0.5042 - a
ccuracy: 0.7562 - F1_score: 0.7280 - Precision: 1.0000 - Recall: 0.5830 - val
_loss: 0.5479 - val_accuracy: 0.7381 - val_F1_score: 0.7348 - val_Precision:
1.0000 - val_Recall: 0.5830
Epoch 4/10
1000/1000 [==============================] - 1651s 2s/step - loss: 0.4291 - a
ccuracy: 0.8052 - F1_score: 0.7226 - Precision: 1.0000 - Recall: 0.5707 - val
_loss: 0.5413 - val_accuracy: 0.7470 - val_F1_score: 0.7050 - val_Precision:
1.0000 - val_Recall: 0.5464
Epoch 00004: early stopping
```

In [161]:

```
loss_biRNN, accuracy_biRNN, f1_score_biRNN, precision_biRNN, recall_biRNN = model_biRNN.evaluate(X_test_pad, Y_test, verbose=0)
print('F1 score for bidirectional RNN model: %f' % f1_score_biRNN)
```

```
F1 score for bidirectional RNN model: 0.699530
```

In [151]:

```
def build_biLSTM():
    model = tf.keras.models.Sequential()
    model.add(tf.keras.layers.Input(shape=max_length, ))
    model.add(tf.keras.layers.Embedding(len(tokenizer.word_index)+1, EMBEDDING_DIM, weights=[embedding_matrix], input_length=max_length, trainable=True))
    model.add(tf.keras.layers.Bidirectional(tf.keras.layers.SimpleRNN(512, return_sequences=True, recurrent_dropout=0.3)))
    model.add(tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(512, recurrent_dropout=0.3)))
    model.add(tf.keras.layers.Dense(len(Y_train.columns), activation='sigmoid'))

    model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy', F1_score, Precision, Recall])

    return model
```

In [152]:

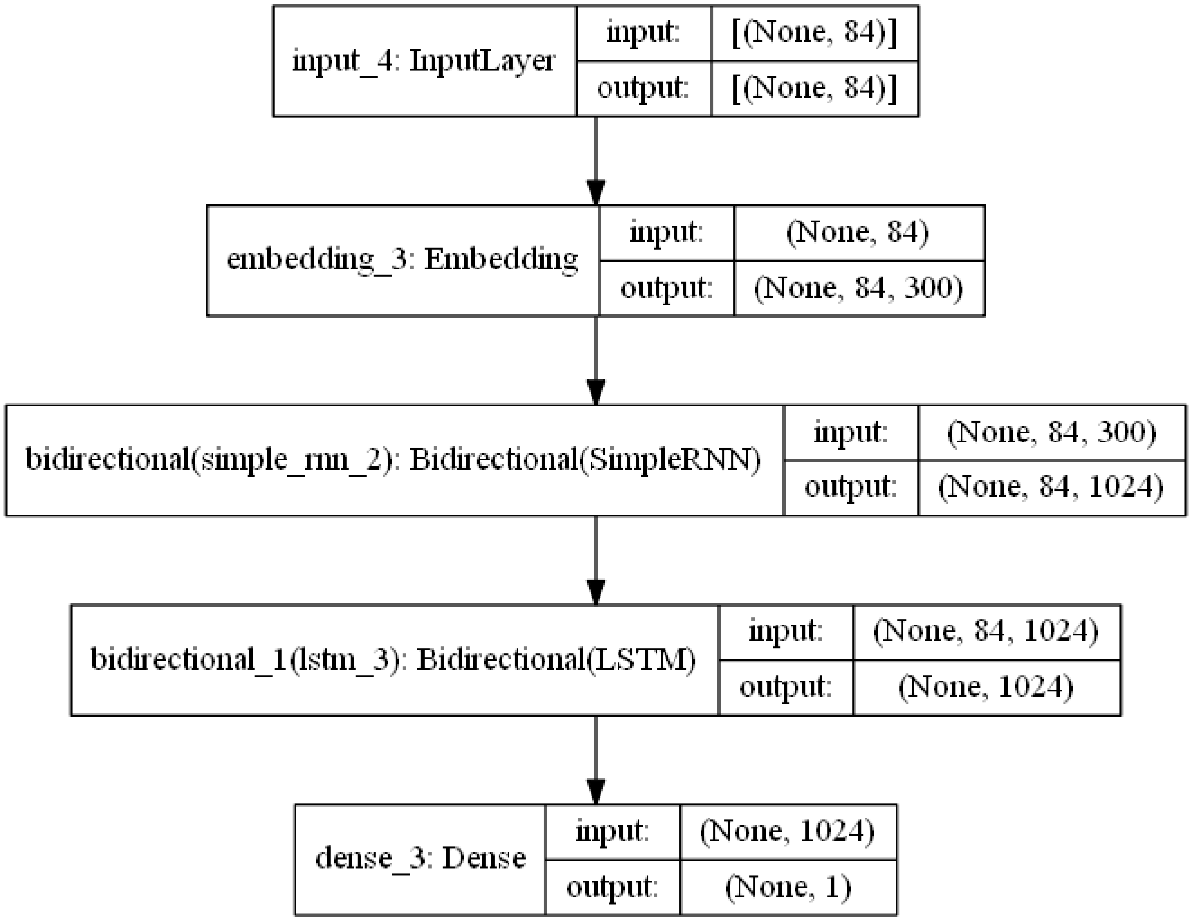
```
model_biLSTM = build_biLSTM()
model_biLSTM.summary()
```

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
embedding_3 (Embedding)      (None, 84, 300)           11073000
_________________________________________________________________
bidirectional (Bidirectional (None, 84, 1024)          832512
_________________________________________________________________
bidirectional_1 (Bidirection (None, 1024)              6295552
_________________________________________________________________
dense_3 (Dense)              (None, 1)                 1025
=================================================================
Total params: 18,202,089
Trainable params: 18,202,089
Non-trainable params: 0
_________________________________________________________________
```

In [153]:

```
tf.keras.utils.plot_model(model_biLSTM,to_file='model_biLSTM.png', show_shapes
=True, show_layer_names=True)
```

Out[153]:



input_4: InputLayer | input: [(None, 84)] | output: [(None, 84)]

embedding_3: Embedding | input: (None, 84) | output: (None, 84, 300)

bidirectional(simple_rnn_2): Bidirectional(SimpleRNN) | input: (None, 84, 300) | output: (None, 84, 1024)

bidirectional_1(lstm_3): Bidirectional(LSTM) | input: (None, 84, 1024) | output: (None, 1024)

dense_3: Dense | input: (None, 1024) | output: (None, 1)

In [154]:
```
biRLSTM_hist = model_biLSTM.fit(X_train_pad, Y_train, epochs=10, validation_da
ta=(X_cv_pad, Y_cv), batch_size=64,
                               callbacks=[earlystop, model_checkpoint_callback
, tensorboard_callback])
```

```
Epoch 1/10
1000/1000 [==============================] - 15409s 15s/step - loss: 0.5437 -
accuracy: 0.7210 - F1_score: 0.7272 - Precision: 0.9990 - Recall: 0.5834 - va
l_loss: 0.5169 - val_accuracy: 0.7514 - val_F1_score: 0.6405 - val_Precision:
1.0000 - val_Recall: 0.4735
Epoch 2/10
1000/1000 [==============================] - 45553s 46s/step - loss: 0.4479 -
accuracy: 0.7886 - F1_score: 0.7184 - Precision: 1.0000 - Recall: 0.5656 - va
l_loss: 0.4987 - val_accuracy: 0.7663 - val_F1_score: 0.7372 - val_Precision:
1.0000 - val_Recall: 0.5859
Epoch 3/10
1000/1000 [==============================] - 16117s 16s/step - loss: 0.3895 -
accuracy: 0.8217 - F1_score: 0.7173 - Precision: 1.0000 - Recall: 0.5630 - va
l_loss: 0.5203 - val_accuracy: 0.7574 - val_F1_score: 0.7510 - val_Precision:
1.0000 - val_Recall: 0.6035
Epoch 4/10
1000/1000 [==============================] - 15619s 16s/step - loss: 0.3406 -
accuracy: 0.8473 - F1_score: 0.7184 - Precision: 1.0000 - Recall: 0.5640 - va
l_loss: 0.5644 - val_accuracy: 0.7489 - val_F1_score: 0.7017 - val_Precision:
1.0000 - val_Recall: 0.5427
Epoch 00004: early stopping
```

In [155]:
```
loss_biLSTM, accuracy_biLSTM, f1_score_biLSTM, precision_biLSTM, recall_biLSTM
= model_biLSTM.evaluate(X_test_pad, Y_test, verbose=0)
print('F1 score for bidirectional LSTM model: %f' % f1_score_biLSTM)
```

```
F1 score for bidirectional LSTM model: 0.696684
```

BERT

In [67]:
```
bert_preprocessor = hub.KerasLayer("https://tfhub.dev/tensorflow/bert_en_uncas
ed_preprocess/1")
bert_encoder = hub.KerasLayer("https://tfhub.dev/tensorflow/bert_en_uncased_L-
12_H-768_A-12/3", trainable=True)
```

In [68]:
```
"""bert_preprocess = hub.KerasLayer("https://tfhub.dev/tensorflow/bert_en_unca
sed_preprocess/3")
bert_encoder = hub.KerasLayer("https://tfhub.dev/tensorflow/bert_en_uncased_L-
12_H-768_A-12/4")"""
```

Out[68]:
```
'bert_preprocess = hub.KerasLayer("https://tfhub.dev/tensorflow/bert_en_uncas
ed_preprocess/3")\nbert_encoder = hub.KerasLayer("https://tfhub.dev/tensorflo
w/bert_en_uncased_L-12_H-768_A-12/4")'
```

In [94]:

```
# Bert layers
text_input = tf.keras.layers.Input(shape=(), dtype=tf.string, name='text')
preprocessed_text = bert_preprocessor(text_input)
outputs = bert_encoder(preprocessed_text)
pooled_output = outputs["pooled_output"]      # [batch_size, 768].
sequence_output = outputs["sequence_output"]  # [batch_size, seq_length, 768].

# Neural network layers
#l = tf.keras.layers.Dropout(0.3, name="dropout")(outputs['pooled_output'])
l = tf.keras.layers.Dropout(0.3, name="dropout")(pooled_output)
l = tf.keras.layers.Dense(1, activation='sigmoid', name="output")(l)

# Use inputs and outputs to construct a final model
model_BERT = tf.keras.Model(inputs=[text_input], outputs = [l])
```

In [95]:

```
model_BERT.summary()
```

```
Model: "model_1"
____________________________________________________________________________
_____________________
Layer (type)                    Output Shape         Param #     Connected to
============================================================================
=====================
text (InputLayer)               [(None,)]            0

____________________________________________________________________________
_____________________
keras_layer (KerasLayer)        {'input_type_ids': ( 0           text[0][0]

____________________________________________________________________________
_____________________
keras_layer_1 (KerasLayer)      {'encoder_outputs':  109482241   keras_layer
[2][0]
                                                                 keras_layer
[2][1]
                                                                 keras_layer
[2][2]
____________________________________________________________________________
_____________________
dropout (Dropout)               (None, 768)          0           keras_layer_
1[2][13]
____________________________________________________________________________
_____________________
output (Dense)                  (None, 1)            769         dropout[0]
[0]
============================================================================
=====================
Total params: 109,483,010
Trainable params: 109,483,009
Non-trainable params: 1
____________________________________________________________________________
_____________________
```

```
In [96]: model_BERT.compile(loss='binary_crossentropy', optimizer='adam', metrics=['acc
         uracy', F1_score, Precision, Recall])
```

```
In [100]: BERT_hist = model_BERT.fit(X_train, Y_train, epochs=5, validation_data=(X_cv,
          Y_cv), batch_size=64
                    , callbacks=[earlystop, model_checkpoint_callback, tensorboard_callb
          ack])
```

```
Epoch 1/5
1000/1000 [==============================] - 49372s 49s/step - loss: 0.7161 -
accuracy: 0.5361 - F1_score: 0.8445 - Precision: 0.9950 - Recall: 0.7800 - va
l_loss: 0.6851 - val_accuracy: 0.5646 - val_F1_score: 1.0000 - val_Precision:
1.0000 - val_Recall: 1.0000
Epoch 2/5
1000/1000 [==============================] - 69878s 70s/step - loss: 0.6889 -
accuracy: 0.5538 - F1_score: 0.9471 - Precision: 1.0000 - Recall: 0.9217 - va
l_loss: 0.6849 - val_accuracy: 0.5646 - val_F1_score: 1.0000 - val_Precision:
1.0000 - val_Recall: 1.0000
Epoch 3/5
1000/1000 [==============================] - 64981s 65s/step - loss: 0.6868 -
accuracy: 0.5613 - F1_score: 0.9832 - Precision: 0.9990 - Recall: 0.9750 - va
l_loss: 0.6849 - val_accuracy: 0.5646 - val_F1_score: 1.0000 - val_Precision:
1.0000 - val_Recall: 1.0000
Epoch 4/5
1000/1000 [==============================] - 66188s 66s/step - loss: 0.6860 -
accuracy: 0.5645 - F1_score: 0.9996 - Precision: 1.0000 - Recall: 0.9992 - va
l_loss: 0.6852 - val_accuracy: 0.5646 - val_F1_score: 1.0000 - val_Precision:
1.0000 - val_Recall: 1.0000
Epoch 5/5
1000/1000 [==============================] - 50334s 50s/step - loss: 0.6859 -
accuracy: 0.5636 - F1_score: 0.9942 - Precision: 1.0000 - Recall: 0.9925 - va
l_loss: 0.6858 - val_accuracy: 0.5646 - val_F1_score: 1.0000 - val_Precision:
1.0000 - val_Recall: 1.0000
Epoch 00005: early stopping
```

```
In [102]: loss_BERT, accuracy_BERT, f1_score_BERT, precision_BERT, recall_BERT = model_B
          ERT.evaluate(X_test, Y_test, verbose=0)
          print('F1 score for BERT model: %f' % f1_score_BERT)
```

```
F1 score for BERT model: 1.000000
```

Summary

In [166]:

```
# assigning data
table_data = [("Logistic Regression", f1_score_log, "accuracy_lg")
              ,("Naive Bayes", f1_score_NB, "accuracy_NB")
              ,("Random Forest", f1_score_RF, "accuracy_RF")
              ,("Gradient Boosting Decision Trees", f1_score_GBDT, "accuracy_G
BDT")
              ,("Linear SVC", f1_score_SVC, "accuracy_SVC")
              ,("RNN", f1_score_rnn, accuracy_rnn)
              ,("LSTM", f1_score_lstm, accuracy_lstm)
              ,("GRU", f1_score_GRU, accuracy_GRU)
              ,("Bidirectional RNN", f1_score_biRNN, accuracy_biRNN)
              ,("Bidirectional LSTM", f1_score_biLSTM, accuracy_biLSTM)
              ,("BERT", f1_score_BERT, accuracy_BERT, accuracy_BERT)
             ]

# creating header
table_head = ["Model", "F1 Score", "Accuracy"]

# displaying the table
print(tabulate(table_data, headers=table_head, tablefmt="grid"))
```

```
+----------------------------------+------------+--------------------+
| Model                            |   F1 Score | Accuracy           |
+==================================+============+====================+
| Logistic Regression              |   0.786995 | accuracy_lg        |
+----------------------------------+------------+--------------------+
| Naive Bayes                      |   0.784441 | accuracy_NB        |
+----------------------------------+------------+--------------------+
| Random Forest                    |   0.777063 | accuracy_RF        |
+----------------------------------+------------+--------------------+
| Gradient Boosting Decision Trees |   0.787067 | accuracy_GBDT      |
+----------------------------------+------------+--------------------+
| Linear SVC                       |   0.788652 | accuracy_SVC       |
+----------------------------------+------------+--------------------+
| RNN                              |   0.513728 | 0.702170193195343  |
+----------------------------------+------------+--------------------+
| LSTM                             |   0.720554 | 0.7546254396438599 |
+----------------------------------+------------+--------------------+
| GRU                              |   0.725504 | 0.7545254230499268 |
+----------------------------------+------------+--------------------+
| Bidirectional RNN                |   0.69953  | 0.7496249675750732 |
+----------------------------------+------------+--------------------+
| Bidirectional LSTM               |   0.696684 | 0.7431243062019348 |
+----------------------------------+------------+--------------------+
| BERT                             |   1        | 0.5646564364433289 |
+----------------------------------+------------+--------------------+
```

Conclusion: As we can see from the above table, the f1 score of BERT is the highest but it does not have the highest accuracy.