

Project 2

Language Detection

CSE 6240

By: Adam Lieberman, Ravish Chawla, & Garrett Mallory

This document contains the pdf version of our hosted blog site. Due to HTML to PDF conversion, there is styling that is not preserved. We suggest viewing the hosted HTML site which can be found at www.ad1m.github.io/Language_Detection. At this link you will find Part 1, which contains background information on Long Short-Term Memory. In Part 2, you will find the a detailed description of building an LSTM model for language detection between English and French. Additionally, you will find the project extra in this section, where we explore multiple language models using LSTMs.

LSTMs

Posts

Apr 19, 2017

Part 1: Introduction to LSTMs

In this lesson you will learn about Long Short-Term Memory, why it is useful, some mathematics behind it, and will be presented with applications.

[Read More](#)

Apr 19, 2017

Part 2: Building an LSTM for Language Detection

In this lesson we will build an LSTM model for language detection using python, tensorflow, and keras. We will process the data, build the model, highlight the performance, and discuss some ways in which we could improve the model.

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Long Short Term Memory

Part 1: Motivation, History, Theory, & Application

By: Adam Lieberman, Ravish Chawla, & Garrett Mallory

Motivation

Suppose you are trying to train a neural network to understand the following sentence:

"Ryan drove the car."

This sentence clearly has a different connotation from the following sentence:

"The car drove Ryan."

The human brain immediately recognizes these differences. We can tell that in the first sentence a human drove the car, but in the second sentence there must be some artificial intelligence going on because the car is driving the human. Our brains have neurons with feedback connections, which can learn many behaviors and sequencing tasks. Thus, we can pick up on these differences very easily because we read each word in the sentence sequentially. We are picking up the context of each word from the words before it. Traditional neural networks would not differentiate the above two sentences, but a special type of network called a Long Short-Term Memory Network, a type of recurrent neural network, would be able to differentiate these two sentences. These types of networks are great for sequential tasks like stock market prediction, music generation, speech recognition, and language detection.

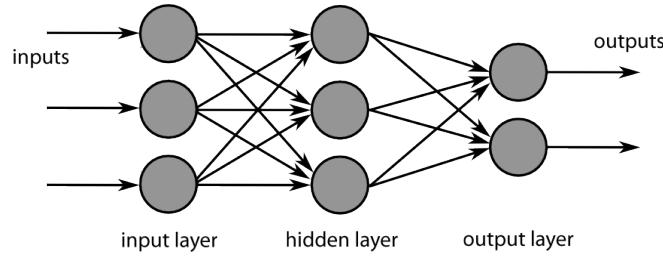
Prerequisites

Before we talk about Long Short-Term Memory Networks, let us briefly cover a few prerequisites:

Feed Forward Neural Networks:

The goal of a feed forward neural network is to approximate some function f^* . For example, let $y = f^*(x)$ be a classifier which maps x to a category y . The feed forward network defines a mapping $f(x; \theta) \rightarrow y$, which we can express as $f(x; \theta) = y$. This mapping learns the values of parameters of θ , which result in the best approximation to the function f^* .

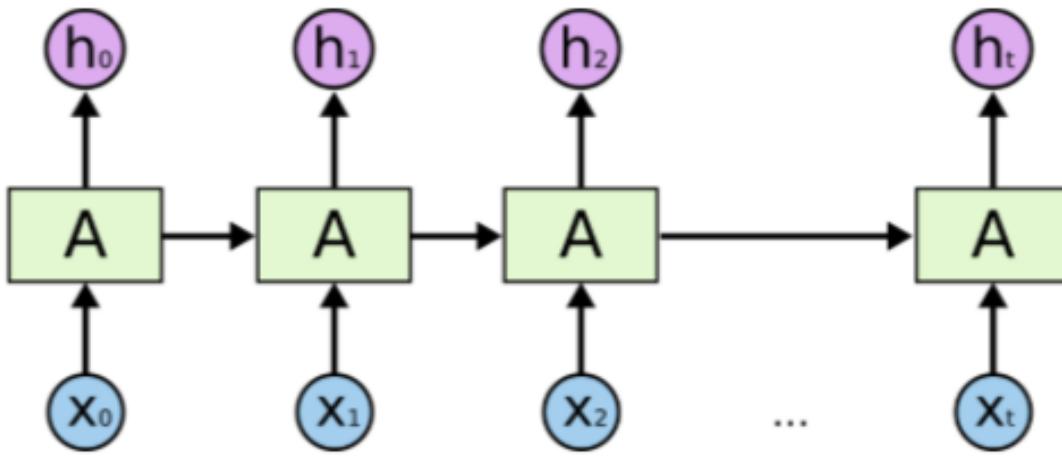
A feed forward network has inputs passing through hidden layers to generate outputs. Here, signals can only travel in the direction from input to output. The output layer does not affect the same or any other layer. We see an example as follows:



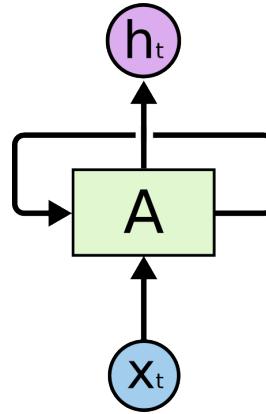
Above, we see that the input passes through the hidden layer which is then connected to the output layer to generate the outputs. The information is fed straight through, from left to right, never touching a given node twice.

Recurrent Neural Networks:

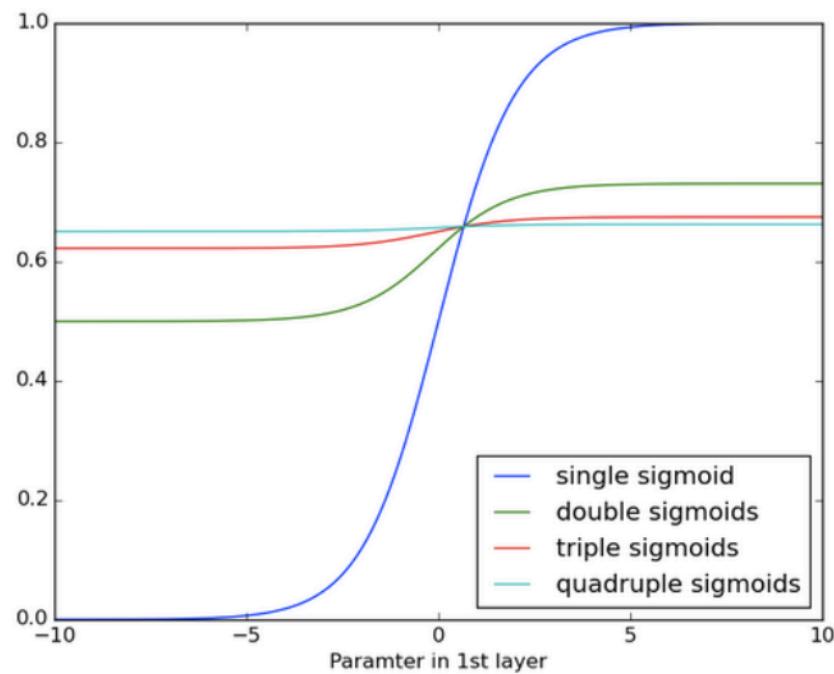
Recurrent neural networks (RNNs) are a family of neural networks for processing sequential data, a sequence of values $x^{(1)}, x^{(2)}, \dots, x^{(t)}$. In a traditional neural network, like the feed forward network above, we assume that all inputs and outputs are independent of each other. This is not the case for all tasks. If we are building a chat bot and want to predict the next word in reply, we need to know the words that came before it. Essentially, RNNs have memory. Every element in the sequence has the same task performed on it, with the output being dependant on the previous computations. An RNN looks as follows:



Here, we see that the sample x_t is generated based on x_0, x_1, \dots, x_{t-1} and the output, h_t , is dependent on what comes before it. We see that the network forms loops. The first input is passed into its hidden layer and generates some output h_0 . The second sequential input is passed into its hidden layer and so is the output from h_0 . The activation function in hidden layer h_1 is activated on the second sample and this is then added with h_0 . This process is then repeated until the last item in the sequence x_t . Traditionally, we depict this nature in the following image:



In the 1990's the vanishing gradient problem emerged as a major obstacle to RNN performance. The gradient expresses the change in all weights with respect to the change in error. Thus, not knowing the gradient does not allow us to adjust the weights in a direction that will reduce the error. If we can't do this then the network will not learn. If any quantity is multiplied by a slightly larger quantity in a repeated fashion, the quantity can become very large. This is also true for the reverse case. If we multiply a quantity repeatedly by a quantity less than one, the quantity will become infinitesimal. If this is hard to see, imagine that you are a gambler. You keep betting 1 dollar, but win 97 cents on that dollar every bet. You will soon see that this is not sustainable and you will go bankrupt very soon. The layers and timesteps in an RNN relate to each other through multiplication so the derivatives are susceptible to explosion or vanishing. For instance, let us look at multiple applications of the sigmoid in a repeated fashion:



The sigmoid activation function is a popular activation in RNN's. We see here that the slope of the data becomes negligible and hence undetectable, thus vanishing.

RNN's were a great achievement. They were able to learn on sequential data where feed forward networks failed, but do suffer from the vanishing gradient problem.

History of the LSTM

In 1991, Dr. Jürgen Schmidhuber and his former PhD student Sepp Hochreiter proposed a feedback network to overcome the vanishing and exploding gradient problem found with RNNs. In 1997, Schmidhuber and Hochreiter published the paper [Long Short-Term Memory](#). In this paper they review Hochreiter's 1991 analysis of the problem of insufficient decaying error backflow in recurrent backpropagation. They combatted this problem by introducing the Long Short-Term Memory (LSTM). In the 90's, computing was still expensive and computing resources were not advanced, so LSTMs were not widely adopted. Fast forward 10 years and services like Amazon AWS and Microsoft Azure offered inexpensive computing which brought massive attention to LSTMs.

What are LSTMs?

Long Short-Term Memory networks are a type of recurrent neural network, which overcome the vanishing gradient problem found in a regular RNN. They typical LSTM has 3 main gates and a

cell unit:

- **Input Gate:** The input gate controls how much of the newly computed state for the current input that you want to let through.
- **Forget Gate:** The forget gate defines how much of the previous state you want to let through.
- **Output Gate:** The output gate defines how much of the interant state you want to expose to the external network.

Mathematically, we can define these gates as equations as follows:

$$i_t = g(W_{x_i}x_t + W_{h_i}h_{t-1} + b_i)$$

$$f_t = g(W_{x_f}x_t + W_{h_f}h_{t-1} + b_f)$$

$$o_t = g(W_{x_o}x_t + W_{h_o}h_{t-1} + b_o)$$

Above, i_t is the input gate, f_t is the forget gate, o_t is the output gate, g is a sigmoid activation function, W represents a particular weight, and b is a bias.

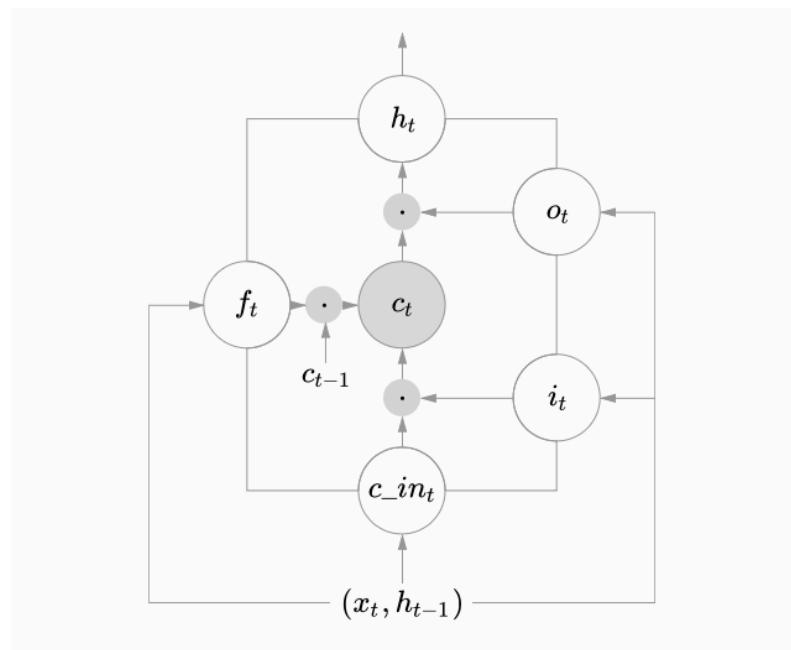
The cell unit can be transformed as:

$$c_{in_t} = \tanh (W_{xc}x_t + W_{hc}h_{t-1} + b_{c_{in}})$$

where $h_t = o_t \cdot \tanh (c_t)$. The state can then be updated as:

$$c_t = f_t \cdot c_{t-1} + i_t \cdot c_{in_t}$$

We can depict all of these equations graphically as:



The gating allows the cell to keep pieces of information for prolonged periods of time while protecting the gradient inside the cell during training. This ensures that the gradient does not explode or vanish from multiple activations being processed.

Applications:

- Image Captioning - Oriol Vinyas, Alexander Toshev, Samy Bengio, and Dumitru Erhan published [Show and Tell: A Neural Image Caption Generator](#). This paper uses an LSTM to automatically describe the content of an image.
- Hand Writing Generation - In 2014, Alex Graves published [Generating Sequences With Recurrent Neural Networks](#). In this paper an LSTM model was used to generate handwriting from text. The handwriting was shown to be realistic cursive in a wide variety of styles.
- Stock Market Prediction - Tal Perry published the article [Deep Learning the Stock Market](#). Here he used an LSTM to predict market prices.
- Movie Reviews - Jason Brownley published [Sequence Classification with LSTM Recurrent Neural Networks in Python with Keras](#) where he uses an LSTM to classify IMDB movie sentiment.
- Image Generation - In 2015, the Google DeepMind team published [DRAW: A Recurrent Neural Network For Image Generation](#). This paper introduces the Deep Recurrent Attentive Writer, DRAW, which generates MNIST digits. DRAW was build with an LSTM layer.
- Reddit Comment Generator - Braulio Chavez published [Reddit Comment Generator](#) where he used LSTM cells to generate comments on Reddit.

Improving Performance of LSTMs:

To improve the performance of LSTMs we can attempt to do some of the following:

- Adding Regularization - Use l1, l2, or dropout layers.
- Bias - Adding a bias of 1 in every neuron in an LSTM layer has been noted to improve

performance, drastically in some cases.

- Activation - Use softsign activation function over tanh. Also try softsign over softmax.
- Optimizers - RMSProp and AdaGrad are good choices for optimizers.
- Learning Rate - This parameter is very important, a well tuned learning rate can drastically improve performance.
- Data - Normalizing data can help. Also more data is always better because it helps combat overfitting.

Building our own LSTM:

Now that we have some background on LSTMs, let us build an LSTM for language detection. Hit the button below to jump to the next tutorial where we construct this LSTM using python, tensorflow, and keras.

Let's Build an LSTM

References

- Images:
 - Image 1 - <http://coderoncode.com/machine-learning/2017/03/26/neural-networks-without-a-phd-part2.html>
 - Image 2 - <http://colah.github.io/posts/2015-08-Understanding-LSTMs/>
 - Image 3 - <http://colah.github.io/posts/2015-08-Understanding-LSTMs/>
 - Image 4 - <https://deeplearning4j.org/lstm.html>
 - Image 5 - <https://apaszke.github.io/lstm-explained.html>
- Content:
 - <http://www.deeplearningbook.org/contents/rnn.html>
 - <http://www.wildml.com/2015/10/recurrent-neural-network-tutorial-part-4-implementing-a-gru-lstm-rnn-with-python-and-theano/>
 - <https://deeplearning4j.org/lstm.html>
 - <http://colah.github.io/posts/2015-08-Understanding-LSTMs/>

- https://en.wikipedia.org/wiki/Long_short-term_memory
- <https://www.quora.com/What-are-the-various-applications-where-LSTM-networks-have-been-successfully-used>

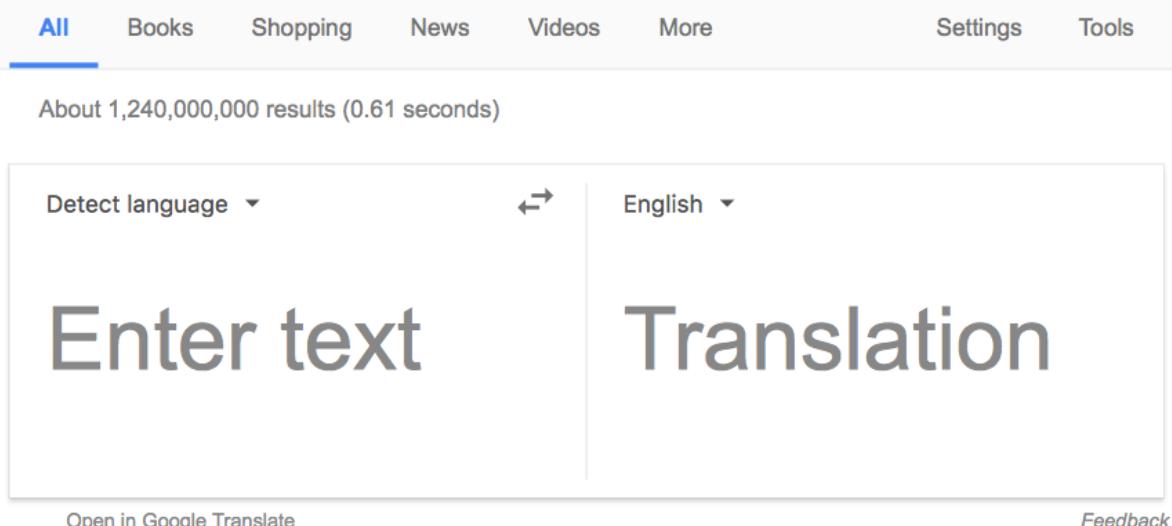
Long Short-Term Memory

Part 2: Building an LSTM for Language Detection

By: Adam Lieberman, Ravish Chawla, & Garrett Mallory

Introduction

If you are a frequent user of Google, you have probably seen this box before:



This is Google Translate. When you start typing in a sentence to translate, it automatically picks up the current language you are typing in. Let's test it out:

About 1,240,000,000 results (0.61 seconds)

The image shows a screenshot of the Google Translate interface. At the top, there are tabs for 'French - detected' and 'English'. Between them are icons for microphone, speaker, and a double-headed arrow. Below the input field 'bonjour' is a small icon of a downward arrow followed by the text '8 more translations'. At the bottom left is a link 'Open in Google Translate' and at the bottom right is a link 'Feedback'.

We see that we have typed in "bonjour", which means hello in french, and that google has automatically detected that our word is french. Here, Google uses recurrent neural networks to detect the current language and then translate it into the user's language of choice.

Language detection can be accomplished through Long Short-Term Memory. Let us take on the task of language detection using two datasets: a dataset consisting of english sentences and a dataset consisting of french sentences.

Environment Setup

Below we have a description of each library we will use. Please click the links under installation and documentation to install and learn more about each library.

- **Programming Language:**

- Python 3 - Python is a general-purpose interpreted, interactive, object-oriented, and high-level programming language. We will be using version 3.x. This can be obtained from the official Python website or through the Anaconda distribution, which contains python 3 and many useful scientific computing libraries.
 - Python Installation: [Python Installation](#) or [Anaconda Installation](#)
 - Pip Installation: [Pip Installation](#)

- **Libraries:**

- TensorFlow - TensorFlow is an open-source software for machine intelligence. It is

currently a very popular choice for developing deep learning models.

- Installation: [TensorFlow Installation](#)
- Documentation: [TensorFlow Documentation](#)

- Numpy - Numpy is a package for scientific computing that contains many useful operations for a multi-dimensional data structure called an ndarray (np array).
 - Installation: [Numpy Installation](#)
 - Documentation: [Numpy Documentation](#)
- Matplotlib - Matplotlib, from the creators of numpy, is a plotting library that allows for custom charts like scatter plots, bar charts, line graphs, etc.
 - Installation: [Matplotlib Installation](#)
 - Documentation: [Matplotlib Documentation](#)
- Seaborn - Seaborn is an alternate plotting library that allows for easy construction of plots such as heatmaps.
 - Installation: [Matplotlib Installation](#)
 - Documentation: [Matplotlib Documentation](#)
- Scipy - Scipy, from the creators of numpy, is an alternate library for mathematics, science, and engineering.
 - Installation: [Scipy Installation](#)
 - Documentation: [Scipy Documentation](#)
- Sklearn - Sklearn has efficient tools for data mining, analysis, and machine learning.
 - Installation: [Sklearn Installation](#)
 - Documentation: [Sklearn Documentation](#)
- Random - Random allows us to create pseudo-random number generators for various distributions.
 - Installation: Installed with Python
 - Documentation: [Random Documentation](#)

Data

We will be detecting language between English and French. For this task, we will use the datasets found [here](#). At this link there will be eng.txt and frn.txt. Both datasets contain sentences, in their

respective language, from the Universal Declaration of Human Rights.

Imports

We start by importing the following libraries:

```
from __future__ import print_function;
import sys;
import random;
from random import randint

import numpy as np;

from keras.models import Sequential;
from keras.layers import Dense, Activation;
from keras.layers import LSTM;
from keras.optimizers import RMSprop;
from keras.utils.data_utils import get_file;
from keras.models import load_model;

from sklearn.cross_validation import train_test_split;
from sklearn.metrics import *;
from sklearn.externals import joblib;

import matplotlib.pyplot as plt;
from IPython.display import clear_output
from keras.callbacks import ModelCheckpoint, Callback

import subprocess;
import h5py;
```

Loading Data

Now that we have our English and French data, we need to load it. To do so we can open the filepath of the data and then use .read() to read it in. Additionally, we lower case the alphabet in the respective datafiles. Additionally, we will print the length of our English and French corpus so that we can see how much data we are dealing with. We do so as follows:

```
english_text = open('data/eng.txt').read().lower()
french_text = open('data/frn.txt').read().lower()
```

```
print('English corpus length:', len(english_text))
print('French corpus length:', len(french_text))

>>>
English corpus length: 10746
French corpus length: 12009
```

We see that our English corpus has length 10746 and our French corpus has length 12009.

Character Set and Dictionary

Now that we have our English and French text loaded in we will need to obtain the character map for both datasets. To do so we can first create a set of the characters and then iterate over each character to create a dictionary where the keys are the characters and the values are integers from 0 to len(characters). Additionally, we create an inverse dictionary where the keys and values are flipped. The purpose of creating these dictionaries are to map the features to the feature indices in our upcoming design matrix. We do so as follows:

```
english_chars = sorted(list(set(english_text)))
french_chars = sorted(list(set(french_text)))

english_char_map = dict((c, i) for i, c in enumerate(english_chars))
french_char_map = dict((c, i) for i, c in enumerate(french_chars))

english_char_map_inverse = dict((i, c) for i, c in enumerate(english_chars))
french_char_map_inverse = dict((i, c) for i, c in enumerate(french_chars))
```

Sentence Creation

We now create sentences from both the English and French text, with a rolling window of 40 characters. These will serve as our features. To do so we set a maxlen of 40 and a step size of 3. We create an empty list for the sentences and an empty list for the next characters. We then iterate over the length of the text minus the maxlen with a step size of 3 and append the text of the current character to 40 characters from that character. We also append the next character (character $i + 40$) to the next characters list. After doing so we will obtain an $[x, 40]$ matrix where each row will have length alphabet-size. We will additionally print the number of English and French sentences that we construct. We do so as follows:

```

maxlen = 40
step = 3

english_sentences = []
english_next_chars = []
for i in range(0, len(english_text) - maxlen, step):
    english_sentences.append(english_text[i: i + maxlen])
    english_next_chars.append(english_text[i + maxlen])

french_sentences = []
french_next_chars = []
for i in range(0, len(french_text) - maxlen, step):
    french_sentences.append(french_text[i: i + maxlen])
    french_next_chars.append(french_text[i + maxlen])

print('nb English sequences:', len(english_sentences))
print('nb French sequences:', len(french_sentences))

>>>
nb English sequences: 3569
nb French sequences: 3990

```

We see that we have created 3569 English sentences and 3990 French sentences.

Design Matrix Creation:

We can now vectorize the matrices we created above. Here, we create a feature matrix x , which is full of zeros and has size $\text{len}(\text{sentences}), \text{maxlength}$, character length. We will then let this matrix be of dtype boolean. We create a labels matrix y , full of zeros with size $\text{len}(\text{sentences})$, character length. This matrix is also of dtype boolean. We then iterate over the sentences and look at the t, char in the sentence. We set $x[i, t, \text{char_map}[\text{char}]] = 1$ in the inner loop and set $y[i, \text{char_map}[\text{next_chars}[i]]] = 1$. This will give us our vectorized features. We do so as follows:

```

char_len = max(len(english_chars), len(french_chars));

english_x = np.zeros((len(english_sentences), maxlen, char_len), dtype=np.bool)
english_y = np.zeros((len(english_sentences), char_len), dtype=np.bool)
for i, sentence in enumerate(english_sentences):
    for t, char in enumerate(sentence):
        english_x[i, t, english_char_map[char]] = 1
    english_y[i, english_char_map[english_next_chars[i]]] = 1

```

```
franch_x = np.zeros((len(french_sentences), maxlen, char_len), dtype=np.bool)
franch_y = np.zeros((len(french_sentences), char_len), dtype=np.bool)
for i, sentence in enumerate(french_sentences):
    for t, char in enumerate(sentence):
        franch_x[i, t, french_char_map[char]] = 1
        franch_y[i, french_char_map[french_next_chars[i]]] = 1
```

Train/Test Split:

Now that we have our English and French features with their corresponding labels, we can use sklearn's train_test_split function to obtain a split of 80% training data and 20% testing data. Here, we will set a random_state = 1024. We do so as follows:

```
english_train_x, english_test_x, english_train_y, english_test_y = train_test_sp
french_train_x, french_test_x, french_train_y, french_test_y = train_test_split(
```

Now that we have our training and testing data, let us look at the shapes of the matrices.

```
print('English Shapes');
print(english_train_x.shape);
print(english_train_y.shape);
print(english_test_x.shape);
print(english_test_y.shape);
print()
print('French Shapes');
print(french_train_x.shape);
print(french_train_y.shape);
print(french_test_x.shape);
print(french_test_y.shape);
```

```
>>>
English Shapes
(2855, 40, 43)
(2855, 43)
(714, 40, 43)
(714, 43)
```

```
French Shapes
(3192, 40, 43)
(3192, 43)
(798, 40, 43)
(798, 43)
```

Above, we see that both languages have [x, 40, 43] values for training, even though French has 41 total alphabet characters. We see this because we pad the smaller language with 2 extra columns of all 0s, in order to make sure that our neural network can train properly on the same input shape.

Generating Test Data:

The test split above was our holdout data. For the English and French holdout sets we will generate a new set of test data by randomly selecting 100 5-character substrings from each respective dataset. Here, we will end up with 200 strings, which will be our test features for evaluation. Our labels for the corresponding test data will have a 1 for English and a 0 for French. We will have 100 1's in the test labels and 100 0's. To create this test data we will create a function called random_generate(), which takes in our test data and a key. We start by creating two empty lists called labels, which will hold our labels, and feats, which will hold our features. We have a conditional that checks if the key is "english" or "french". If the key is english then the labels vector will contain 100 1's. If it is french than the labels vector will contain 100 0's. We now iterate over range(100) and generate a random number between 0 and the length of the test data passed in. This will represent a random index to pull from inside the test data. We then generate another random integer between 0 and the length of the data in the index minus 5. This will represent a starting character. We can then extract this character plus the next 4 characters to obtain our random 5 character substring. We append this into the features variable. We will call this process for the English data and the French data and then combine the lists of the features and the lists of the labels and make each one a numpy array. We do so as follows:

```
def random_generate(test_x, key):
    labels = []
    feats = []
    if key == "english":
        labels = [1 for i in range(100)]
    elif key == 'french':
        labels = [0 for i in range(100)]
    else:
        return feats, labels;

    for i in range(100):
        r1 = randint(0, len(test_x) - 1)
        ind = test_x[r1]

        r2 = randint(0, len(ind) - 5)
```

```

    sub_string = ind[r2:r2+5]

    feats.append(sub_string)

return feats,labels

english_sample, english_labels = random_generate(english_test_x, 'english')
french_sample, french_labels = random_generate(french_test_x, 'french')

test_data = np.array(english_sample + french_sample)
test_labels = np.array(english_labels + french_labels)

```

LSTM Model Creation:

Now that we have our training and test data, we can create our Long Short-Term Memory Model. To do so we will construct a function called build_model. This will set up a Sequential model with an LSTM layer that has 256 neurons followed by a dense layer that has shape number of characters (43) and a softmax activation function. Here we will use an RMSprop optimizer, with a learning rate of 0.01, and a loss function of categorical_crossentropy. We create our function as follows:

```

def build_model(chars):
    print('Build model...')
    model = Sequential()
    model.add(LSTM(256, input_shape=(None, char_len)))
    model.add(Dense(char_len))
    model.add(Activation('softmax'))

    optimizer = RMSprop(lr=0.01)
    model.compile(loss='categorical_crossentropy', optimizer=optimizer, metrics=)
    return model

```

Prediction & Log Likelihood:

For each test string, we need to compute the log likelihood of that string for each model. To do so we will create a function called predict_on_sample which takes in a model and a test value. Here, we will iterate over each character, obtain the vector associated with it along with the previous START characters, and obtain the prediction score for it on the next character. Finally,

we sum up the logs of these values and return it. We create this function as follows:

```
def predict_on_sample(model, test_val):
    start = np.zeros((1, 1, char_len), dtype=bool)
    start_prob = model.predict(start)

    next_vec = start.copy()[0][0]
    probs = []

    probs.append(start_prob[0], np.argwhere(test_val[0])[0][0]))

    for idx, vec in enumerate(test_val):
        next_vec = np.append(next_vec, vec).reshape(1, idx+2, char_len)
        next_prob = model.predict(next_vec)

        probs.append(next_prob[0], np.argwhere(test_val[idx])[0][0]))

    return np.sum(np.log(probs))
```

ROC

Using the above function, we can predict the results on each test string. We can then create a function called predict_results(). We pass in the string along with both the English model and the French model, obtain the predicted probabilities, and compute the Generalized Likelihood Ratio Test (GLRT). The ratio gives us a vector of probability scores, in which we set all values ≥ 1 to 1, and otherwise 0. We can then obtain the false positive rate and true positive rate from the roc_curve function in the sklearn library and then use those to get the roc_auc from the auc function in sklearn. We create the function as follows:

```
def predict_results(english_model, french_model):
    english_preds = np.array([predict_on_sample(english_model, x) for x in test_x])
    french_preds = np.array([predict_on_sample(french_model, x) for x in test_x])
    ratio_probs = english_preds - french_preds

    fpr, tpr, _ = roc_curve(test_labels, ratio_probs);
    roc_auc = auc(fpr, tpr)

    print(roc_auc)

    return roc_auc, fpr, tpr
```

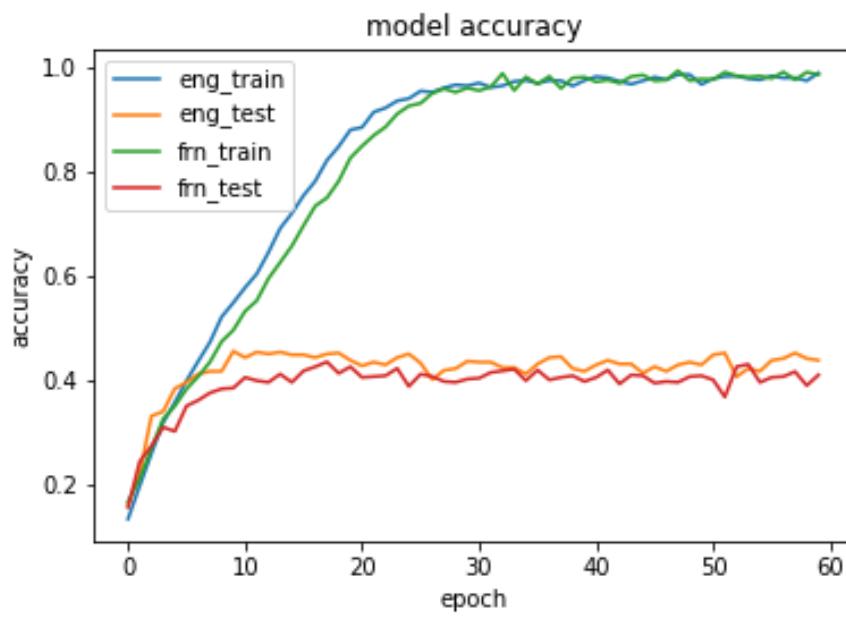
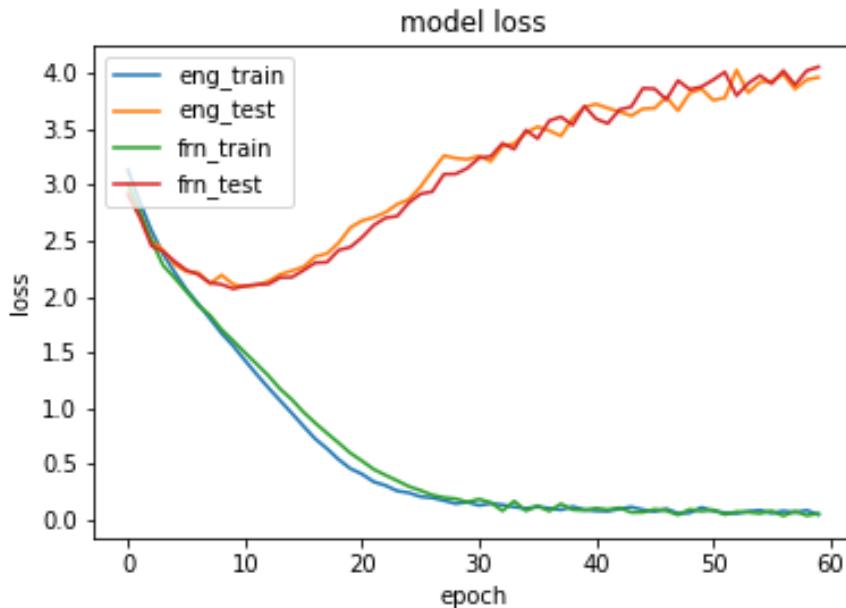
Now that we have the ROC, we can create a function called `plot_roc_auc_curve` to plot our ROC curve, which takes in the false positive rate, the true positive rate, the `roc_auc`, and a title. We create this function as follows:

```
def plot_roc_auc_curve(fpr, tpr, roc_auc, title):
    plt.figure()
    lw = 2
    plt.plot(fpr, tpr, color='darkorange',
              lw=lw, label='ROC curve (area = %0.2f)' % roc_auc)
    plt.plot([0, 1], [0, 1], color='navy', lw=lw, linestyle='--')
    plt.xlim([0.0, 1.0])
    plt.ylim([0.0, 1.05])
    plt.xlabel('False Positive Rate')
    plt.ylabel('True Positive Rate')
    plt.title('Receiver operating characteristic for ' + title)
    plt.legend(loc="lower right")
    plt.show()
```

Hyperparameter Tuning:

Above we have set up a functions to create our model LSTM model, obtain the predictions, compute the log likelihood, and compute the ROC. We have not instantiated the model yet as we do not know the optimal hyperparameters. Let us now perform a hyperparameter search. Previously, we wrote a function called `train_and_predict()`. We cycle though a set range of epochs and evaluate the model quality as the iterations increase. We then take the best performing model. Other hyperparameters tuned are the learning rate, decay rate, batch sizes used in training, and size of the LSTM layer. Some of these we tuned manually rather than create a automated function for it. Finally, we found that the best performance is given by `epochs=8, learning_rate=0.01, decay=0.0, layer_size=256`.

Below we display graphs showing the loss vs. epochs and accuracy vs. epochs for learning rate 0.01 as a demonstration of our parameter selection process.



Building English & French LSTM Models

Let us create our English and French LSTM models with 5 epochs, a step size of 5, and an optimal batch size of 2512:

```
models_1 = train_and_predict(5, 5, 2512)

>>>
Build model...
Build model...
Epoch 1/5
2855/2855 [=====] - 3s - loss: 3.7206 - acc: 0.0221
Epoch 2/5
```

```
2855/2855 [=====] - 2s - loss: 5.3884 - acc: 0.1426
Epoch 3/5
2855/2855 [=====] - 2s - loss: 4.2558 - acc: 0.0676
Epoch 4/5
2855/2855 [=====] - 2s - loss: 3.5550 - acc: 0.1625
Epoch 5/5
2855/2855 [=====] - 2s - loss: 3.4811 - acc: 0.0550
Epoch 1/5
3192/3192 [=====] - 3s - loss: 3.8357 - acc: 0.0711
Epoch 2/5
3192/3192 [=====] - 2s - loss: 3.4972 - acc: 0.0655
Epoch 3/5
3192/3192 [=====] - 2s - loss: 4.1910 - acc: 0.1103
Epoch 4/5
3192/3192 [=====] - 2s - loss: 3.0199 - acc: 0.0840
Epoch 5/5
3192/3192 [=====] - 2s - loss: 2.9137 - acc: 0.1732
0.7948
```

We see that this configuration has given us an ROC of 0.7948.

Let us now create our LSTM models with 12 epochs, a step size of 3 epochs, and a batch size of 2512:

```
models_2 = train_and_predict(12, 3, 2512)

>>>
Build model...
Build model...
Epoch 1/3
2855/2855 [=====] - 3s - loss: 3.8244 - acc: 0.0319
Epoch 2/3
2855/2855 [=====] - 2s - loss: 3.8091 - acc: 0.0501
Epoch 3/3
2855/2855 [=====] - 2s - loss: 4.0902 - acc: 0.0630
Epoch 1/3
3192/3192 [=====] - 4s - loss: 3.6929 - acc: 0.0592
Epoch 2/3
3192/3192 [=====] - 2s - loss: 4.6424 - acc: 0.1419
Epoch 3/3
3192/3192 [=====] - 2s - loss: 4.5772 - acc: 0.0617
0.8456
Epoch 1/3
2855/2855 [=====] - 2s - loss: 3.1018 - acc: 0.1625
Epoch 2/3
2855/2855 [=====] - 2s - loss: 3.0159 - acc: 0.1541
Epoch 3/3
2855/2855 [=====] - 2s - loss: 3.0308 - acc: 0.1625
```

```
Epoch 1/3
3192/3192 [=====] - 2s - loss: 3.7905 - acc: 0.1604
Epoch 2/3
3192/3192 [=====] - 2s - loss: 3.7677 - acc: 0.1554
Epoch 3/3
3192/3192 [=====] - 2s - loss: 3.7589 - acc: 0.1560
0.8479
Epoch 1/3
2855/2855 [=====] - 2s - loss: 3.0133 - acc: 0.1625
Epoch 2/3
2855/2855 [=====] - 2s - loss: 2.9974 - acc: 0.1604
Epoch 3/3
2855/2855 [=====] - 2s - loss: 2.9674 - acc: 0.1625
Epoch 1/3
3192/3192 [=====] - 2s - loss: 3.6747 - acc: 0.1538
Epoch 2/3
3192/3192 [=====] - 2s - loss: 3.7156 - acc: 0.1441
Epoch 3/3
3192/3192 [=====] - 2s - loss: 3.7864 - acc: 0.1444
0.865
Epoch 1/3
2855/2855 [=====] - 2s - loss: 2.9449 - acc: 0.1653
Epoch 2/3
2855/2855 [=====] - 2s - loss: 2.9600 - acc: 0.1520
Epoch 3/3
2855/2855 [=====] - 2s - loss: 3.0080 - acc: 0.1891
Epoch 1/3
3192/3192 [=====] - 2s - loss: 3.7089 - acc: 0.1598
Epoch 2/3
3192/3192 [=====] - 2s - loss: 3.6826 - acc: 0.1526
Epoch 3/3
3192/3192 [=====] - 2s - loss: 3.7564 - acc: 0.1507
0.8629
```

Here, we see that our ROC is now 0.8629, which is much better than that of the model that used 5 epochs.

We note that there is a lot of variability in model performance. We noticed that our ROC varied from 0.65 to 0.95. Thus, we have re run our above model generation code multiple times and have saved the best performing model. Below we save these best performing models:

```
models_1[3][0].save('model_current_e.h5')
models_1[3][1].save('model_current_f.h5')
```

We can now load the best performing models:

```
model_1 = load_model('model_current_e.h5')
model_2 = load_model('model_current_f.h5')
```

Model Performance:

We can now call our functions to obtain the ROC, false positive rate, true positive rate. We call our function with our models as follows:

```
roc, fpr, tpr = predict_results(model_1, model_2)

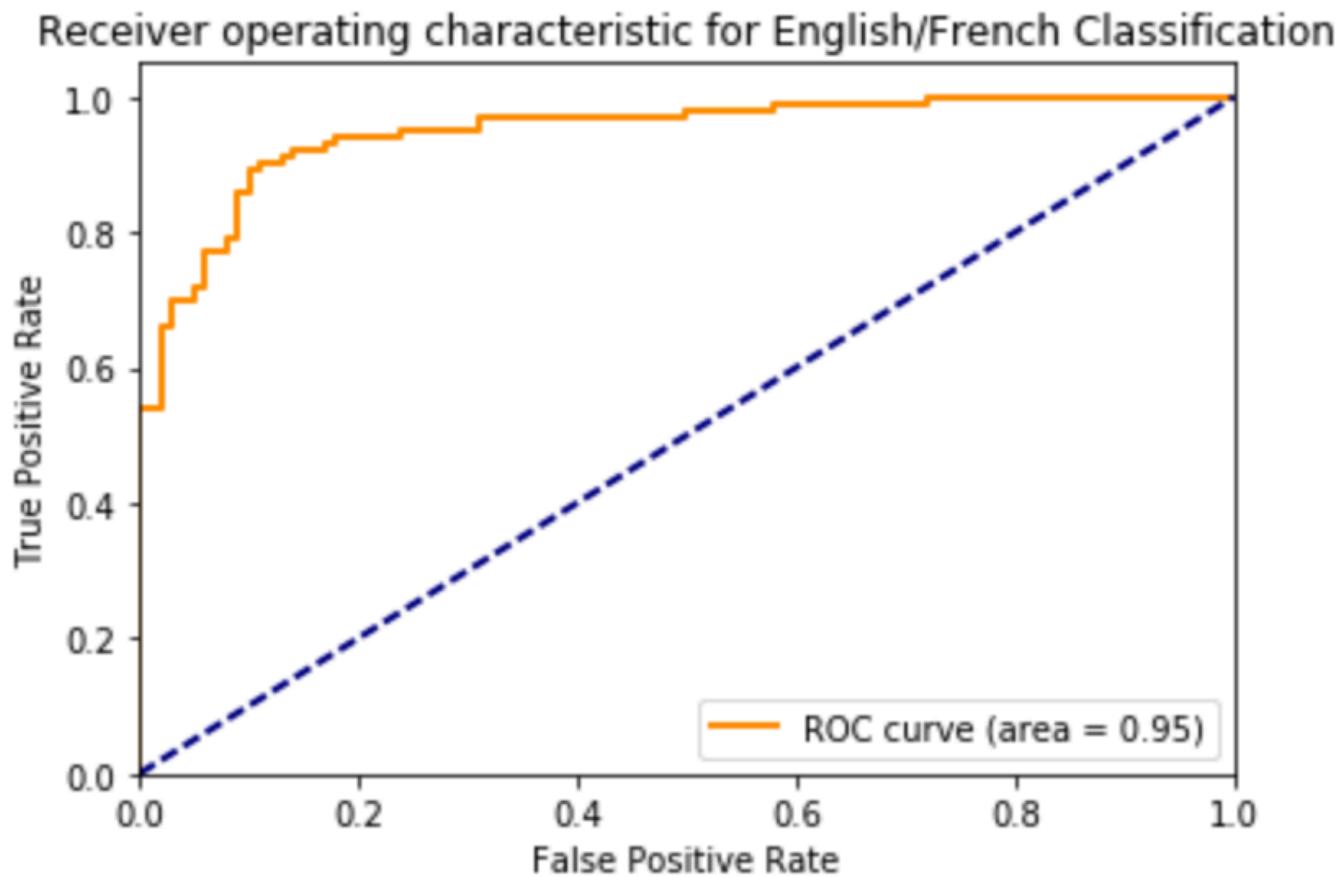
>>>
0.9476
```

Here we see that we have achieved a great ROC of 0.9476.

Let us now plot our ROC curve:

```
plot_roc_auc_curve(fpr, tpr, roc, 'English/French Classification')
```

```
>>>
```



We see that the above ROC curve looks great.

Questions

- **Is this model good?** We believe that our model is good. Our model was able to produce an ROC of 0.9476, where a 1.0 is the highest possible ROC score. To achieve this ROC, we tuned our parameters and trained our Neural Network on the best set of parameters we found. The measure of accuracy is also dependent on the test examples we use for evaluation. While training and testing our model, we saw that there were some examples which were more difficult to distinguish between languages than others. Using a sample from those test examples yielded worse ROC, around 0.65, but some examples gave us above 0.95 ROC. Despite the variability in these results, the lower limit of our ROC is still very high, which shows that our model performs well.
- **What are 3 Alternatives to language detection with their pros and cons?**
 1. **Naive Bayes Classification** - Textblob is a popular python module for processing text data using natural language processing. In particular, they have a language detector that is built using a Naive Bayes Classifier, which can pass in a feature extractor as a parameter. Information on how to build this language detector can be found [here](#). In this example, a feature extractor that uses the last letter of a given word is used. This seems very simple, but achieved an accuracy of 0.7 on the test set. They had found that words that do not end with the letter "o" tend to be English. The pros of this approach is that the naive bayes classifier works very well with high dimensions and is computationally inexpensive. This would allow us to create a custom feature extractor that has very high dimensionality but still runs in a reasonable amount of time. The cons of their approach is that the feature here is weak. Using only the last letter of each word does not seem to build a great feature. There are many words that end with the same letter in across multiple languages so this might not work well for languages that are fairly similar. Additionally, a con with regards to a naive bayes classifier is that it relies on an independence assumption. If this assumption is not met the classifier will perform badly.
 2. **N-Grams** - Mark Galea implemented Language Detection using N-Grams in [this post](#). An N-gram is an N-character slice of a longer string. He notes that words that appear

in the English language are clearly different than words that appear in the French language and that the set of N-grams will be different for each language. Further he notes that if a language detector is used on small fragments of text then there is less susceptibility to noise which makes the language detector more resilient. Galea uses the following preprocessing steps in his N-Gram language detector:

- Remove extra spaces
- Discard digits and punctuation except apostrophes
- Tokenize
- Generate train/test split
- Scan down each token generating all possible N-grams for $N = 1 - 5$
- Create a hash table

He then takes the top 300 N-Grams. He then uses the out of place measure to determine how far out of place an N-gram is in the English language profile versus the other language profiles. The language that has the smallest difference is the language he chooses. A pro to this method is that human words, in their respective language, have structure. For instance, it is very common for the letter 'u' to follow the letter 'q', but this is not the case in Arabic. N-grams capture this structure. Thus we will find that certain combinations of letters are more likely in some languages than others. A con to using N-Grams is that in general the number of n-grams for words is m^n where m is the number of letters in the alphabet. This can become computationally expensive if we have a large alphabet. Additionally, N-grams do not capture non-local dependencies, for instance in the sentence "The boy (who was here yesterday) went home". Also there needs to be a large amount of data to estimate large $n > 3$ values, which adds to their sparsity.

3. **Logistic Regression** - Language detection using Logistic Regression has also been implemented by Bugro [here](#). This approach takes advantage of language roots, such as prefixes and suffixes, and creates features based on them. These features are then used to train a Logistic Regression model that gives high accuracy on the problem of classification. There are a few advantages of this. One is that it takes advantage of parts of a word that contribute more to a model than those that don't. For instance, verbs in the english language usually end in 'ing', 'ed', and other tenses, but french verbs have 'ais' and 'ent'. By training on specifically these types of features, we can increase the accuracy of the model. However, this advantage is offset by using a Logistic model as the primary classifier. It is difficult to justify the linearity of this problem, and logistic regression relies on the linear separability of a problem. To overcome this significant disadvantage, we can use kernels and regularization. Kernels can be applied to a logistic regression classifier to fit a non-linear classifiable

dataset. Regularization, on the other hand, can be used to reduce the variance of our classifier, at the cost of introducing more bias. This is actually one of the main problems with our Neural Network model. Its high variance is evident in the results that range from 65% to 95% ROC, which a Logistic Regression model trained on word roots should be able to overcome.

- **What are 5 ways in which we could improve our model?**

1. **More Data** - Having more training and testing data is always better, especially when we are using deep learning. We had 3569 total English sentences to work with and 3990 French sentences to work with. This is not a huge dataset. Having more data from each dataset would allow us to better train our model to better represent the actual population of the data. If we had more text that looked like English or French our model would be able to better understand the English features compared to the French features. However, more data would increase the computational expense for our model. This task already had some expense to it and adding multiple times the amount of data would drastically increase the runtime. We believe that having more data would drop our ROC slightly as we would better be able to represent the English and French populations, but our computational expense would be much higher.
2. **Alternate Layers** - Our model had an LSTM layer and a dense layer. Here, we did not explore the possibility of adding alternate layers such as a dropout layer. A dropout layer is a powerful regularization technique. Here, neurons that are randomly selected are ignored during training. This allows our network to be less sensitive to the specific weights of neurons. Thus, our network is capable of better generalization and is less likely to overfit the training data. Less overfitting is definitely a pro. Adding and experimenting with different layers can help improve performance, but a con is that this would add computational expense to our program in terms of runtime and in human labor as we would have to find the optimal hyperparameters for the layers. Also, this is not guaranteed to help in terms of performance. It may very well be that our network performs worse with a dropout layer or a different layer structure. We believe that adding a dropout layer would prevent overfitting and that experimenting with layers could boost performance in terms of accuracy, precision, recall, and AUC.
3. **Different Optimizer** - In our model we used an RMSprop optimizer with a learning rate of 0.01. We did not try alternate optimization techniques such as SGD, Adagrad, Adadelta, Adam , etc. With regards to Long Short-Term Memory, Adam and Adadelta usually are a fine choice. We tuned the learning rate for the RMSprop, but did not

experiment with these alternate optimizers. Potentially, we could have achieved better performance or converged more quickly than with our choice of optimizer. However, it is not guaranteed that a different optimizer would drastically improve the performance. Also, it might take longer to converge than our choice of optimizer. Additionally, running experiments with these would take additional time. We do not think that the optimizer choice would make a huge difference in performance, but we do think that some optimizers are better suited for tasks than others. Thus, we think that we could converge faster using an optimizer such as Adam. This would allow us to run less epochs and decrease our computational expense.

4. **Bias** - Adding a bias of 1 has been shown to help improve the performance and prevent overfitting especially in regards to LSTM models. When we created our LSTM in keras we did not set `use_bias = True`. Having this bias vector could have lead to less overfitting in our model. A con would be that our ROC could potentially drop and our model would not look as good as it does. We think that adding bias is a great idea, which would help prevent our model from overfitting, but would drop our ROC. In this case this is fine because we want user querys to be as accurate as possible. Using a bias could potentially achieve this.
5. **More Epochs** - We used a maximum of 12 epochs when we trained our model. Using a GPU allows for more training in a smaller time frame. Instead of running 12 epochs we could have run 100. Running this experiment and obtaining shorter run time is definitely a positive, but a con would be that the model converges after a few iterations and there is no gained performance by using the GPU to run more epochs. We think that we could run more epochs, but we would have no change in efficacy. We saw that there was convergence across 8-10 epochs as the derivative of the loss started became somewhat constant from iteration to iteration. However, GPUs allow for much faster training.

Extra Credit:

In extension to our previously developed language detection model for English vs French, we will now explore a 10-way language comparison of both traditional western languages as well as non-Latin based languages. The languages we are utilizing are as follows:

- English
- French

- Dutch
- German
- Italian
- Latin
- Portugese
- Japanese
- Russian
- Spanish

We will create LSTM models for each language and tune the set of optimal hyperparameters found in the English-French LSTM comparison in the previous notebook. There, we evaluated learning rate, decay, batch size, LSTM layer size, and number of epochs. In order to train our 10 models efficiently we spun up a Microsoft Azure NC12 which has 12 cores, 120 GiB ram, and 2 K80 GPUs. This will allow us to run over 2000 epochs in less than two hours. After doing so we will examine the ROC for pairs of language models and be able to determine which pairs of languages our model was able to distinguish best and which languages our models were not able to distinguish.

Imports

We import the following libraries:

```
from __future__ import print_function;
import re;
import sys;
import random;
import unicodedata;
from random import randint;

import numpy as np;
import seaborn as sns;

from keras.models import Sequential;
from keras.layers import Dense, Activation;
from keras.layers import LSTM;
from keras.optimizers import RMSprop;
from keras.utils.data_utils import get_file;
from sklearn.cross_validation import train_test_split;
from sklearn.metrics import.*;
from sklearn.externals import joblib;

import matplotlib.pyplot as plt;
```

```
from IPython.display import clear_output
from keras.callbacks import ModelCheckpoint, Callback

import subprocess;
import h5py;
```

Notifications:

Since we will be running many epochs across many different languages we have set up a slack channel to push notifications when functions finish running. This will help monitor the status of our program. We create a function called notify_slack which takes in a text to be sent to our channel. We create it as follows:

```
def notify_slack(text):
    text = 'WebSearch: ' + text;
    subprocess.Popen('''curl -X POST --data-urlencode "payload={'channel' : '#ra'}}
```

Data Cleaning:

Our data might originally be messy and contain accents that are not held within English alphanumeric characters. Thus, we will create a function called strip_accents which takes in a string to remove these characters to avoid giving certain models an unfair advantage. Inside this function we use the unicodedata.normalize function on our given strings with an appropriate code. We do so as follows:

```
def strip_accents(s):
    return ''.join(c for c in unicodedata.normalize('NFD', s)
                  if unicodedata.category(c) != 'Mn')
```

Loading Data:

In order to use languages with a non-Latin script, we first need to transliterate them into traditional English. We've used [this link](#) to Romanize Russian and [this link](#) to Romanize Japanese. Additionally, we stripped out these non-translated characters: 及, 受, 胞, 認. We can now load our

language datasets. Here we first create a list of all our language txt files. Additionally, we create a list with their respective names. We'll keep languages in this order for all of our datasets for simplicity. We strip accents, lower case each character and add it to an overall list of languages.

```
languages = ['data/eng.txt',
             'data/frn.txt',
             'languages/dut.txt',
             'languages/ger.txt',
             'languages/itn.txt',
             'languages/ltn.txt',
             'languages/por.txt',
             'languages/romanized_jap.txt',
             'languages/romanized_rus.txt',
             'languages/spn.txt']

language_names = ['English',
                  'French',
                  'Dutch',
                  'German',
                  'Italian',
                  'Latin',
                  'Portuguese',
                  'Japanese',
                  'Russian',
                  'Spanish']

all_text = []
for file in languages:
    text = open(file).read().lower()
    all_text.append(strip_accents(text))

for text in all_text:
    print(text[0:20])

>>>
universal declaratio
declaration universe
universele verklarin
resolution 217 a (ii
il 10 dicembre 1948,
declarationem homini
declaracao universal
'sekai jinken sengen
vseobsaja deklaracij
declaracion universa
```

Character Set & Dictionary

We now need to obtain a set of all of the characters in our language, a dictionary that maps each character to an integer, and a dictionary that maps integers to the characters. To do so we can iterate over all of our languages text in all_data and create a set of the characters in the text for each language. We can then append this into all_chars. In all_char_map we can create a dictionary with the keys as the elements in the sorted set and the values as integers from 0 to len(sorted_characters). We can then append this dictionary into the list all_char_map. We then swap the keys and values in the all_char_map dictionary and append this into all_char_map_inverse. We do so as follows:

```
all_chars = []
all_char_map = []
all_char_map_inverse = []
for idx, lang in enumerate(all_text):
    all_chars.append(sorted(list(set(lang))))
    all_char_map.append(dict((c, i) for i, c in enumerate(sorted(list(set(lang)))))
    all_char_map_inverse.append(dict((i, c) for i, c in enumerate(sorted(list(set(lang))))))

    print (language_names[idx])
    print ("\tCorpus length:", len(lang))
    print ("\tCharacter Count", len(all_chars[idx]))
    print ()
```

>>>
English
Corpus length: 10746
Character Count 43

French
Corpus length: 12009
Character Count 41

Dutch
Corpus length: 12887
Character Count 42

German
Corpus length: 12078
Character Count 45

Italian
Corpus length: 12768
Character Count 39

Latin

Corpus length: 10065

Character Count 32

Portugese

Corpus length: 11459

Character Count 42

Japanese

Corpus length: 11551

Character Count 38

Russian

Corpus length: 12240

Character Count 43

Spanish

Corpus length: 12078

Character Count 42

We can now create our sentences like we previously did for our English and French models:

```
maxlen = 40
step = 3

all_sentences = []
all_next_chars = []

for idx, lang in enumerate(all_text):
    sentences = []
    next_chars = []
    for i in range(0, len(lang) - maxlen, step):
        sentences.append(lang[i: i + maxlen])
        next_chars.append(lang[i + maxlen])

    all_sentences.append(sentences)
    all_next_chars.append(next_chars)

print (language_names[idx])
print ("\tSentences:", len(sentences))
print ()
```

>>>

English

Sentences: 3569

French

Sentences: 3990

Dutch

Sentences: 4283

German

Sentences: 4013

Italian

Sentences: 4243

Latin

Sentences: 3342

Portuguese

Sentences: 3807

Japanese

Sentences: 3837

Russian

Sentences: 4067

Spanish

Sentences: 4013

Design Matrix Creation

We will now vectorize the above matrices by creating a design matrix. This will result in an [x, 40, max-alphabet-length] shape matrix for each language. We do so like we did for the English and French models:

```
char_len = max([len(x) for x in all_chars])

all_x = []
all_y = []

for idx, lang in enumerate(all_text):
    x = np.zeros((len(all_sentences[idx]), maxlen, char_len), dtype=np.bool)
    y = np.zeros((len(all_sentences[idx]), char_len), dtype=np.bool)

    for i, sentence in enumerate(all_sentences[idx]):
        for t, char in enumerate(sentence):
            x[i, t, all_char_map[idx][char]] = 1
            y[i, all_char_map[idx][all_next_chars[idx][i]]] = 1
```

```
all_x.append(x)
all_y.append(y)
```

Train/Test Split:

We now use sklearn's train_test_split function to create an 80% training set and 20% testing set for our data.

```
all_train_x = []
all_test_x = []
all_train_y = []
all_test_y = []

for idx, lang in enumerate(all_text):
    train_x, test_x, train_y, test_y = train_test_split(all_x[idx], all_y[idx],
    all_train_x.append(train_x)
    all_test_x.append(test_x)
    all_train_y.append(train_y)
    all_test_y.append(test_y)
```

Generate Testing Data:

Having obtained the test split, we need to obtain a smaller sample of 100 strings of 5 length characters each. We do this by using a Random number generator to select a random string each time, append it to our features array, along with the label associated with it. In order to compare two languages, we had to make changes to the language generation method. We take two random seeds to create random generators. We seed them in such a way to ensure that the language in the first pair has the same text for each language it is compared to and similarly for the second pair. This also ensures that when we compare English to English, we use two different test samples. For example, the same English text will be compared to all other languages. Then when we compare all other languages to English we still use the same English text sample. This ensures the maximum variability in our language detection scheme.

```
def random_generate(test_x_1, test_x_2, seed_1, seed_2):
    both_labels = []
    both_feats = []

    rands = [random.Random(), random.Random()]
```

```

rands[0].seed(seed_1)
rands[1].seed(sys.maxsize - seed_2)

key = 1
for test_x in [test_x_1, test_x_2]:
    labels = []
    feats = []
    for i in range(100):
        r1 = rands[key].randint(0, len(test_x) - 1)

        ind = test_x[r1]
        r2 = rands[key].randint(0, len(ind) - 5)

        sub_string = ind[r2:r2+5]

        feats.append(sub_string)
        labels.append(key)

    both_labels.append(labels)
    both_feats.append(feats)
    key = key^1

return both_feats, both_labels

```

With out above function we can now call it for all pairs of languages and append them into a samples and labels list:

```

all_samples_1 = []
all_labels_1 = []

all_samples_2 = []
all_labels_2 = []

for idx, test_x in enumerate(all_test_x):
    for idx2, test_x2 in enumerate(all_test_x):

        [[feats_1, feats_2], [labels_1, labels_2]] = random_generate(test_x, test_x2)
        all_samples_1.append(feats_1)
        all_labels_1.append(labels_1)

        all_samples_2.append(feats_2)
        all_labels_2.append(labels_2)

```

LSTM Model Creation:

Now that we have obtained our data for training and testing, we will build a LSTM model. To do this, we will create a function that will build a Sequential LSTM model. The parameters for the model below have been tuned after testing multiple configurations with over 60 epochs each. We settled on using 256 Neurons on the LSTM layer, with a RMSProp optimizer using 0.01 Learning rate. We will show our results on how we obtained these values later.

```
def build_model(chars):
    print('Build model...')
    model = Sequential()
    model.add(LSTM(256, input_shape=(None, char_len)))
    model.add(Dense(char_len))
    model.add(Activation('softmax'))

    optimizer = RMSprop(lr=0.01)
    model.compile(loss='categorical_crossentropy', optimizer=optimizer, metrics=
    return model
```

Prediction & Log Likelihood:

To do a prediction on our data, we will use a log of probabilities over each character in a string. We will iterate over each character, obtain the vector associated with it along with the previous START characters, and obtain the prediction score for it on the next character. Finally, we sum up the logs of these values and return it.

```
def predict_on_sample(model, test_val):
    start = np.zeros((1, 1, char_len), dtype=bool);
    start_prob = model.predict(start);

    next_vec = start.copy()[0][0];
    probs = [];

    probs.append(start_prob[0,np.argmax(test_val[0])[0][0]]);

    for idx, vec in enumerate(test_val):
        next_vec = np.append(next_vec, vec).reshape(1, idx+2, char_len)
        next_prob = model.predict(next_vec);

        probs.append(next_prob[0, np.argmax(test_val[idx])[0][0]]);
```

```
return np.sum(np.log(probs));
```

Using the above function, we can predict the results on each test string. To do this, we pass in the string along with both the English model and the French model, obtain the probabilities, and compute the GLRT. The ratio gives us a vector of probability scores, in which we set all values ≥ 1 to 1, and otherwise 0. The ROC score can then be computed on these values.

ROC

We can use the same function `predict_results` that we built in Part 1 to obtain the ROC score, false positive rate, and true positive rate. We do so as follows:

```
def predict_results(model_1, model_2, lang_idx_1, lang_idx_2):  
  
    test_data = np.array(all_samples_1[lang_idx_1] + all_samples_2[lang_idx_2]);  
    test_labels = np.array(all_labels_1[lang_idx_1] + all_labels_2[lang_idx_2]);  
  
    preds_1 = np.array([predict_on_sample(model_1, x) for x in test_data]);  
    preds_2 = np.array([predict_on_sample(model_2, x) for x in test_data]);  
  
    ratio_probs = preds_1 - preds_2;  
  
    fpr, tpr, _ = roc_curve(test_labels, ratio_probs);  
    roc_auc = roc_auc_score(test_labels, ratio_probs);  
  
    return roc_auc, fpr, tpr;
```

Hyperparameter Tuning:

We use the same hyperparameters as we did in the first section. Here we did an entense search which gave us an ROC of ~ 0.95 for our English and French models. For more details on this please read the above hyperparameter tuning section.

Building Models:

We create a function called `train_and_predict` to build two models for each respective language, fit the training data, predict the results, and obtain the roc. The function is as follows:

```

def train_and_predict(lang_idx_1, lang_idx_2, total_epochs, batch_size=2048):
    model_1 = build_model(all_chars[lang_idx_1])
    model_2 = build_model(all_chars[lang_idx_2]);

    epochs_ran = 0;

    history_1 = model_1.fit(all_train_x[lang_idx_1], all_train_y[lang_idx_1],
                           batch_size=batch_size, epochs=total_epochs, shuffle=True)
    history_2 = model_2.fit(all_train_x[lang_idx_2], all_train_y[lang_idx_2],
                           batch_size=batch_size, epochs=total_epochs, shuffle=True)

    roc, _, _ = predict_results(model_1, model_2, lang_idx_1, lang_idx_2);

    return roc, history_1, history_2, model_1, model_2;

```

We can now run each of our 100 models for comparisons between every language. We then save them to a 5-tuple of outputs which we represent as a variable called `all_models`.

```

all_models = []
for idx, lang in enumerate(all_text):
    model_results = []
    for idx_2, lang2 in enumerate(all_text):
        result = train_and_predict(lang_idx_1=idx, lang_idx_2=idx_2, total_epochs=10)
        model_results.append(result)
        print ("Finished: %s -> %s with ROC=%f" % (language_names[idx], language_names[idx_2], result['roc']))
    all_models.append(model_results)
    notify_slack("Finished all models for " + language_names[idx])

```

Model Evaluation:

Next, we extract the loss and the ROC of each language combination. We've printed the ROCs below so they can be read easily and then create a heat map to give a graphical representation of how languages compare to each other.

```

all_roc = dict()
all_roc_list = []

all_fpr = dict()
all_tpr = dict()
all_loss = []

```

```
for idx_1 in range(len(all_models)):
    language_roc = []
    language_loss = []

    for idx_2 in range(len(all_models[idx_1])):
        roc, history_1, history_2, model_1, model_2 = all_models[idx_1][idx_2]
        roc_auc, fpr, tpr = predict_results(model_1, model_2, idx_1, idx_2)

        index = idx_1*len(all_models) + idx_2
        all_roc[index] = roc_auc
        all_fpr[index] = fpr
        all_tpr[index] = tpr

        language_roc.append(roc_auc)
        language_loss.append(history_2.history["loss"][-1])

        print ("%s - %s ROC: %f" % (language_names[idx_1], language_names[idx_2]))
    print()

all_roc_list.append(language_roc)
all_loss.append(language_loss)
```

>>>

```
English - English ROC: 0.477350
English - French ROC: 0.802600
English - Dutch ROC: 0.755800
English - German ROC: 0.908600
English - Italian ROC: 0.810800
English - Latin ROC: 0.998000
English - Portugese ROC: 0.762200
English - Japanese ROC: 0.867500
English - Russian ROC: 0.749200
English - Spanish ROC: 0.882100
```

```
French - English ROC: 0.539400
French - French ROC: 0.591300
French - Dutch ROC: 0.540000
French - German ROC: 0.821700
French - Italian ROC: 0.730300
French - Latin ROC: 0.876100
French - Portugese ROC: 0.700300
French - Japanese ROC: 0.619500
French - Russian ROC: 0.839700
French - Spanish ROC: 0.249700
```

```
Dutch - English ROC: 0.569900
Dutch - French ROC: 0.427800
Dutch - Dutch ROC: 0.403100
Dutch - German ROC: 0.872900
Dutch - Italian ROC: 0.673000
```

Dutch – Latin ROC: **0.993700**
Dutch – Portugese ROC: **0.280700**
Dutch – Japanese ROC: **0.954800**
Dutch – Russian ROC: **0.862400**
Dutch – Spanish ROC: **0.532500**

German – English ROC: **0.419550**
German – French ROC: **0.589200**
German – Dutch ROC: **0.562500**
German – German ROC: **0.275900**
German – Italian ROC: **0.791100**
German – Latin ROC: **0.960000**
German – Portugese ROC: **0.656000**
German – Japanese ROC: **0.888800**
German – Russian ROC: **0.731600**
German – Spanish ROC: **0.634300**

Italian – English ROC: **0.523200**
Italian – French ROC: **0.764300**
Italian – Dutch ROC: **0.718100**
Italian – German ROC: **0.851100**
Italian – Italian ROC: **0.710600**
Italian – Latin ROC: **0.921500**
Italian – Portugese ROC: **0.729000**
Italian – Japanese ROC: **0.496600**
Italian – Russian ROC: **0.859700**
Italian – Spanish ROC: **0.719200**

Latin – English ROC: **0.459950**
Latin – French ROC: **0.774300**
Latin – Dutch ROC: **0.474000**
Latin – German ROC: **0.582900**
Latin – Italian ROC: **0.620700**
Latin – Latin ROC: **0.122300**
Latin – Portugese ROC: **0.759200**
Latin – Japanese ROC: **0.889800**
Latin – Russian ROC: **0.722400**
Latin – Spanish ROC: **0.687900**

Portugese – English ROC: **0.465650**
Portugese – French ROC: **0.181500**
Portugese – Dutch ROC: **0.440800**
Portugese – German ROC: **0.883500**
Portugese – Italian ROC: **0.704400**
Portugese – Latin ROC: **0.940300**
Portugese – Portugese ROC: **0.765300**
Portugese – Japanese ROC: **0.581000**
Portugese – Russian ROC: **0.762200**
Portugese – Spanish ROC: **0.781800**

```
Japanese - English ROC: 0.509550
Japanese - French ROC: 0.491700
Japanese - Dutch ROC: 0.558000
Japanese - German ROC: 0.684700
Japanese - Italian ROC: 0.440500
Japanese - Latin ROC: 0.860400
Japanese - Portugese ROC: 0.719100
Japanese - Japanese ROC: 0.185900
Japanese - Russian ROC: 0.558600
Japanese - Spanish ROC: 0.587150
```

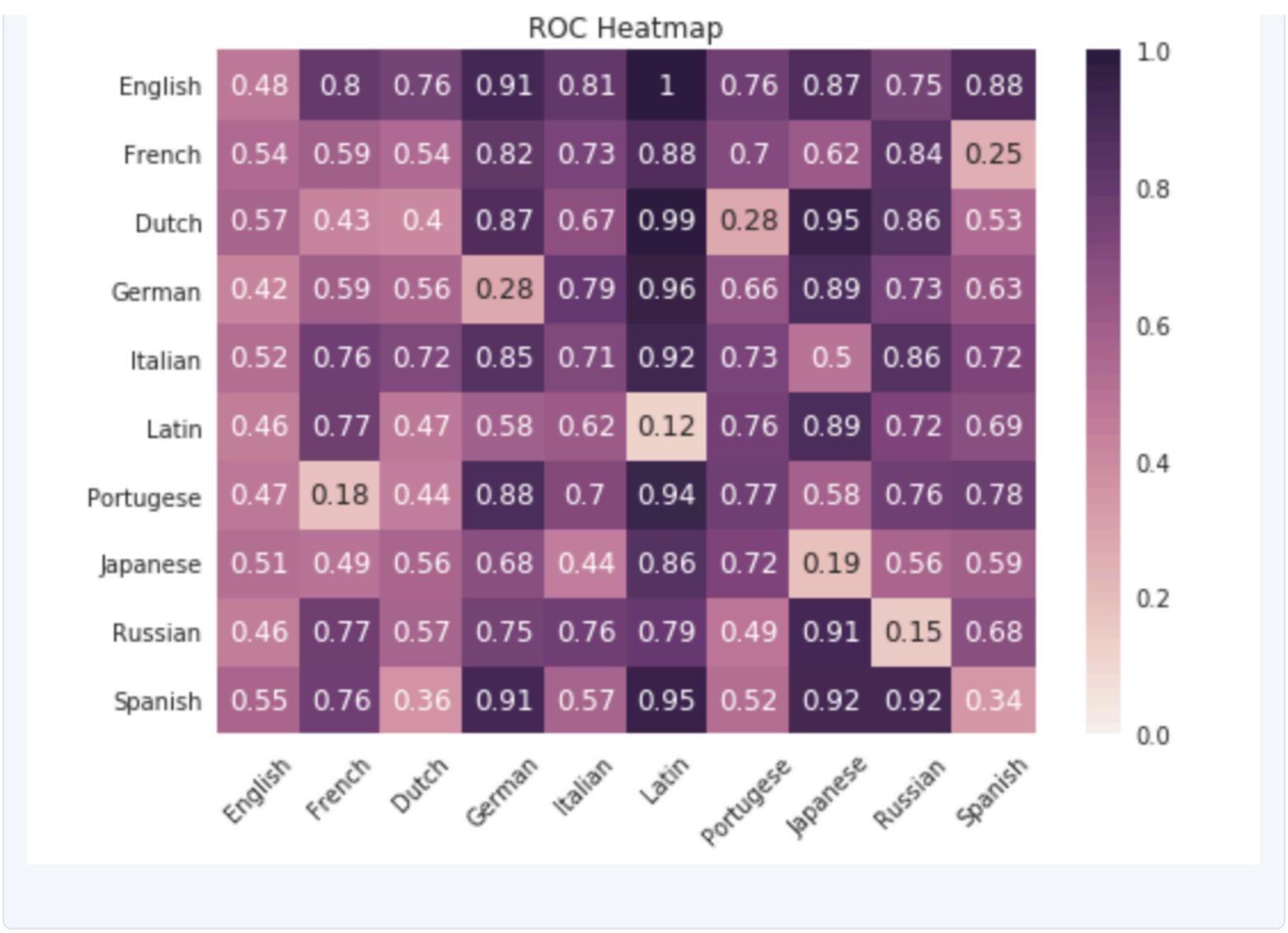
```
Russian - English ROC: 0.456500
Russian - French ROC: 0.767000
Russian - Dutch ROC: 0.567500
Russian - German ROC: 0.753800
Russian - Italian ROC: 0.762700
Russian - Latin ROC: 0.789500
Russian - Portugese ROC: 0.485850
Russian - Japanese ROC: 0.912000
Russian - Russian ROC: 0.153200
Russian - Spanish ROC: 0.682300
```

```
Spanish - English ROC: 0.553750
Spanish - French ROC: 0.764800
Spanish - Dutch ROC: 0.361900
Spanish - German ROC: 0.912800
Spanish - Italian ROC: 0.567100
Spanish - Latin ROC: 0.953900
Spanish - Portugese ROC: 0.519700
Spanish - Japanese ROC: 0.917700
Spanish - Russian ROC: 0.917300
Spanish - Spanish ROC: 0.342050
```

To see these easier we can create a heatmap to display the ROC's for each language. We do so as follows:

```
sns.set()
ax = sns.heatmap(all_roc_list, vmin=0, vmax=1, annot=True, yticklabels=language_
plt.xticks(rotation=45)
plt.title("ROC Heatmap")
sns.plt.show()

>>>
```



We can also generate an ROC curve to plot multiple ROC curves on the same graph. This will allow us to visualize all ROC's together:

```

def plot_roc_auc(fpr_, tpr_, roc_, title, num_plot):
    plt.figure(figsize=(10,12))

    language_pairs = []
    for lang in language_names:
        for lang2 in language_names:
            language_pairs.append(lang[0:3]+"-"+lang2[0:3])

    lw=1.15
    for i in range(num_plot):
        plt.plot(fpr_[i], tpr_[i], lw=lw,
                 label='{0} (area = {1:0.2f})'
                 .format(language_pairs[i], roc_[i]))

    plt.plot([0, 1], [0, 1], 'k--', lw=lw)
    plt.xlim([0.0, 1.0])
    plt.ylim([0.0, 1.05])

```

```
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title("ROC AUC Curve for " + title)
# plt.legend(loc=9, bbox_to_anchor=(0.5, -0.1))
plt.legend(bbox_to_anchor=(1.05, 1), loc=2, borderaxespad=0.)

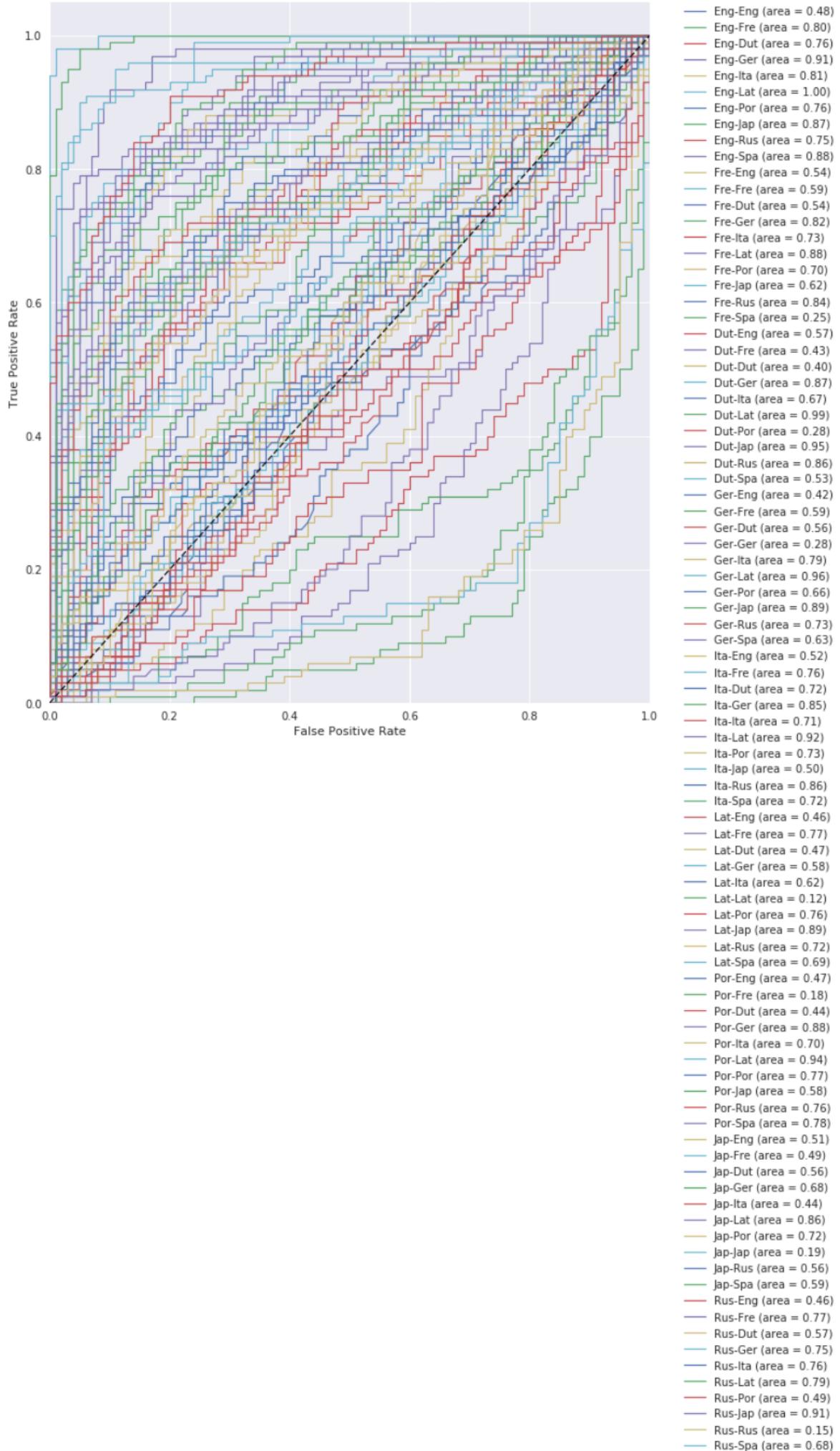
plt.show()
```

Let us now call this function:

```
plot_roc_auc(all_fpr, all_tpr, all_roc, "all Languages", len(all_fpr))
```

```
>>>
```

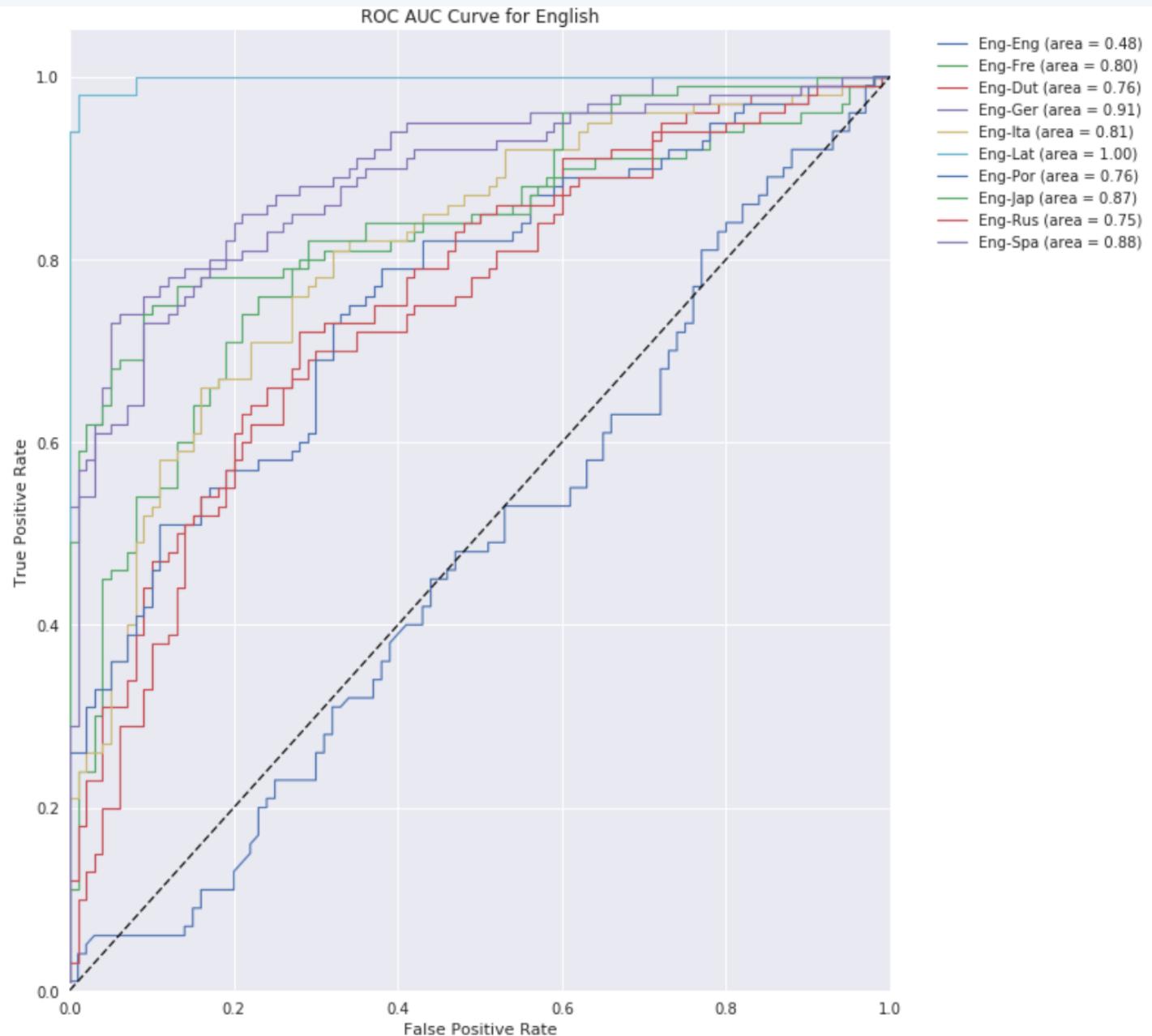
ROC AUC Curve for all Languages



Because of the large number of lines in the plot, it is hard to discern what the different ROCs are, but we can see a good range of values such as those that are above the line, near the middle, and those on the other side. Let's plot the curves for only English to see a more cleaner plot.

```
plot_roc_auc(all_fpr, all_tpr, all_roc, "English", 10)
```

```
>>>
```



The plot shows that the only line that is around the line is the English-to-English curve, which makes sense because a well trained Neural Network will be unable to distinguish between two samples of the same language.

Results & Analysis

The ROC heatmap is a really interesting way to represent the interplay between languages. We can see clear trends in display. First, Latin consistently is the most easily differentiable of the languages with several high values and a max ROC of 0.96 in its comparison to English. This shows us that the model did a great job of distinguishing between Latin and other languages.

Interestingly, Russian and Japanese are not very well distinguishable. This is very likely due to the Romanization process of the languages. The Romanized forms of these languages did not develop on their own but are artificially created. As a result, they are probably somewhat tame and constrained over a "true" language like Spanish or French.

Another aspect of the matrix is that we should expect the diagonal of the map to be around 0.50 as we cannot easily distinguish between two random samples of a single language. We see this trend as expected, minus a few outliers like Italian. This variability is caused by the random sampling used. Throughout the project, we consistently found that there was a huge amount of variability in performance based on pure-luck. It seems as though one of the sample sets is very "Italian" while the other is not particularly remarkable. As a result, the models can more easily classify the samples. The ROC plots are self explanatory. For English, we see strong performance on all languages excluding the English-English comparison.

Code

To obtain the code please refer to this [GitHub repository](#).

References:

- <https://keras.io/getting-started/sequential-model-guide/>
- https://github.com/fchollet/keras/blob/master/examples/lstm_text_generation.py

