

Spoken Digit Recognition

In this notebook, You will do Spoken Digit Recognition.

Input - speech signal, output - digit number

It contains

1. Reading the dataset. and Preprocess the data set. Detailed instructions are given below. You have to write the code in the same cell which contains the instruction.
2. Training the LSTM with RAW data
3. Converting to spectrogram and Training the LSTM network
4. Creating the augmented data and doing step 2 and 3 again.

Instructions:

1. Don't change any Grader Functions. Don't manipulate any Grader functions. If you manipulate any, it will be considered as plagiarised.
2. Please read the instructions on the code cells and markdown cells. We will explain what to write.
3. Please return outputs in the same format what we asked. Eg. Don't return List if we are asking for a numpy array.
4. Please read the external links that we are given so that you will learn the concept behind the code that you are writing.
5. We are giving instructions at each section if necessary, please follow them.

Every Grader function has to return True.

```
!git clone https://github.com/AllenDowney/ThinkDSP.git
import numpy as np
import pandas as pd
import librosa
import os
import glob
import matplotlib.pyplot as plt
import sys
import seaborn as sns
import pathlib
from collections import Counter
import IPython
sys.path.insert(0, 'ThinkDSP/code/')
import thinkdsp
```

```
from sklearn.model_selection import train_test_split
from prettytable import PrettyTable
from sklearn.utils import shuffle
import tensorflow as tf
from tensorflow.keras.preprocessing.sequence import pad_sequences
from tensorflow.keras.layers import Input, LSTM, Dense
from tensorflow.keras.models import Model
import tensorflow as tf
from sklearn.metrics import f1_score
%load_ext tensorboard
from tqdm import tqdm
tqdm.pandas()
```

##if you need any imports you can do that here.

Cloning into 'ThinkDSP'...
remote: Enumerating objects: 2469, done.ote: Total 2469 (delta 0),
reused 0 (delta 0), pack-reused 2469

We shared recordings.zip, please unzip those.

```
!gdown 17YGQheavMbM6aeHYjUcGssXfb7eQH0lz
!unzip recordings.zip
```

Downloading...

From: <https://drive.google.com/uc?id=17YGQheavMbM6aeHYjUcGssXfb7eQH0lz>

To: /content/recordings.zip

100% 9.28M/9.28M [00:00<00:00, 74.7MB/s]

Archive: recordings.zip

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  creating: recordings/
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  inflating: recordings/0_jackson_1.wav
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inflating: recordings/9_yweweler_21.wav
inflating: recordings/9_yweweler_22.wav
inflating: recordings/9_yweweler_23.wav
inflating: recordings/9_yweweler_24.wav
inflating: recordings/9_yweweler_25.wav
inflating: recordings/9_yweweler_26.wav

```
inflating: recordings/9_yweweler_27.wav
inflating: recordings/9_yweweler_28.wav
inflating: recordings/9_yweweler_29.wav
inflating: recordings/9_yweweler_3.wav
inflating: recordings/9_yweweler_30.wav
inflating: recordings/9_yweweler_31.wav
inflating: recordings/9_yweweler_32.wav
inflating: recordings/9_yweweler_33.wav
inflating: recordings/9_yweweler_34.wav
inflating: recordings/9_yweweler_35.wav
inflating: recordings/9_yweweler_36.wav
inflating: recordings/9_yweweler_37.wav
inflating: recordings/9_yweweler_38.wav
inflating: recordings/9_yweweler_39.wav
inflating: recordings/9_yweweler_4.wav
inflating: recordings/9_yweweler_40.wav
inflating: recordings/9_yweweler_41.wav
inflating: recordings/9_yweweler_42.wav
inflating: recordings/9_yweweler_43.wav
inflating: recordings/9_yweweler_44.wav
inflating: recordings/9_yweweler_45.wav
inflating: recordings/9_yweweler_46.wav
inflating: recordings/9_yweweler_47.wav
inflating: recordings/9_yweweler_48.wav
inflating: recordings/9_yweweler_49.wav
inflating: recordings/9_yweweler_5.wav
inflating: recordings/9_yweweler_6.wav
inflating: recordings/9_yweweler_7.wav
inflating: recordings/9_yweweler_8.wav
inflating: recordings/9_yweweler_9.wav
```

```
#read the all file names in the recordings folder given by us
#(if you get entire path, it is very useful in future)
#save those files names as list in "all_files"
data_dir = '/content/recordings'
data_dir = pathlib.Path(data_dir)
all_files = list(data_dir.glob('*'))
all_files = [str(i) for i in all_files]
```

Grader function 1

```
def grader_files():
    temp = len(all_files)==2000
    temp1 = all([x[-3:]=="wav" for x in all_files])
    temp = temp and temp1
    return temp
grader_files()
```

True

Create a dataframe(name=df_audio) with two columns(path, label).

You can get the label from the first letter of name.

Eg: 0_jackson_0 --> 0

0_jackson_43 --> 0

```
df_audio = pd.DataFrame()
df_audio['path'] = all_files
df_audio['label'] = [ele.split('_')
[0].replace('/content/recordings/', '') for ele in all_files]
```

```
df_audio.info()
```

```
<class 'pandas.core.frame.DataFrame'>
```

```
RangeIndex: 2000 entries, 0 to 1999
```

```
Data columns (total 2 columns):
```

```
#   Column  Non-Null Count  Dtype
---  -
0   path    2000 non-null         object
1   label    2000 non-null         object
```

```
dtypes: object(2)
```

```
memory usage: 31.4+ KB
```

```
df_audio.head()
```

	path	label
0	/content/recordings/8_theo_7.wav	8
1	/content/recordings/7_nicolas_12.wav	7
2	/content/recordings/8_nicolas_10.wav	8
3	/content/recordings/9_nicolas_45.wav	9
4	/content/recordings/4_theo_32.wav	4

Exploring the sound dataset

#It is a good programming practise to explore the dataset that you are dealing with. This dataset is unique in itself because it has sounds as input

#<https://colab.research.google.com/github/Tyler-Hilbert/AudioProcessingInPythonWorkshop/blob/master/AudioProcessingInPython.ipynb>

#visualize the data and write code to play 2-3 sound samples in the notebook for better understanding.

#please go through the following reference video

<https://www.youtube.com/watch?v=37zCgCdV468>

```
categories_dict = Counter(list(df_audio.label))
fig, ax = plt.subplots(figsize=(10,10))
plots = sns.barplot(y =list(categories_dict.keys()) , x =
list(categories_dict.values()),orient = 'h',palette = "husl")
print('*'*50)
print("Number of Categories :" , len(np.unique(list(df_audio.label))))
print('*'*50)
print()
for p in ax.patches:
```

```

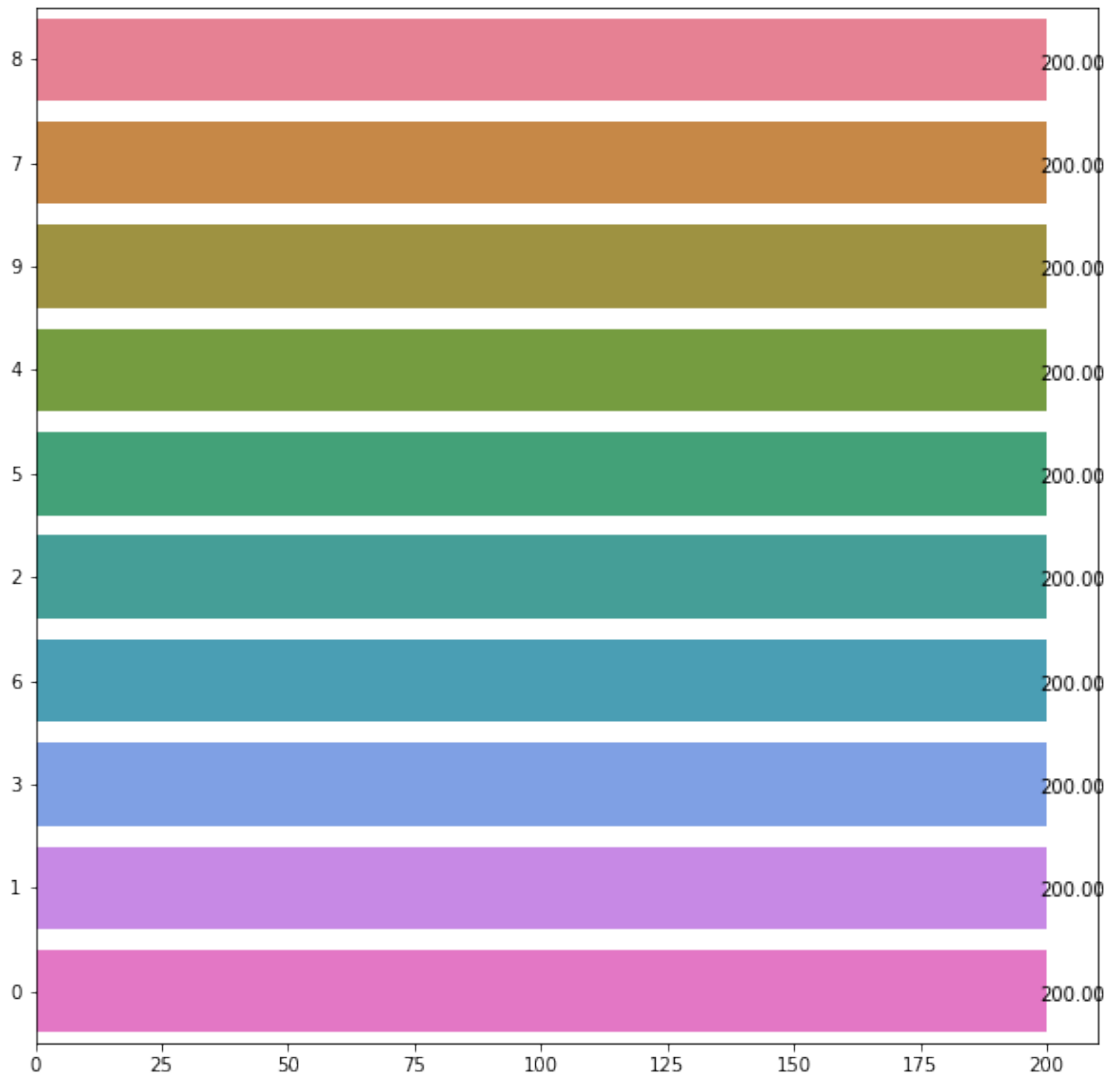
width = p.get_width()
plt.text(5+p.get_width(), p.get_y()+0.55*p.get_height(),
        '{:1.2f}'.format(width),
        ha='center', va='center')
plt.show()

```

```

*****
Number of Categories : 10
*****

```



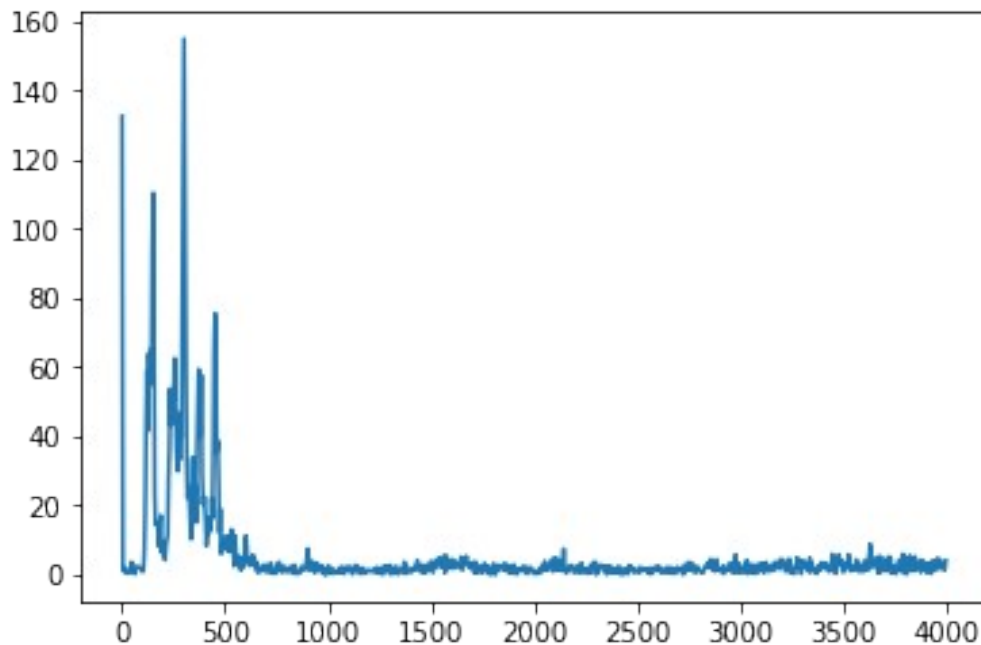
```

samples = df_audio.sample(n=1)
path = samples.path.values[0]
print('*'*30 + ' spectrum of number ' + str(samples.label.values[0]))
+ ' ' + '*'*30 )
print()
wave = thinkdsp.read_wave(path)
spectrum = wave.make_spectrum()

```

```
spectrum.plot()
plt.show()
print('*'* 30 + ' Listen to Audio for number ' +
str(samples.label.values[0]) + ' ' + '*'*30 )
print()
IPython.display.Audio(path)

***** spectrum of number 3
*****
```

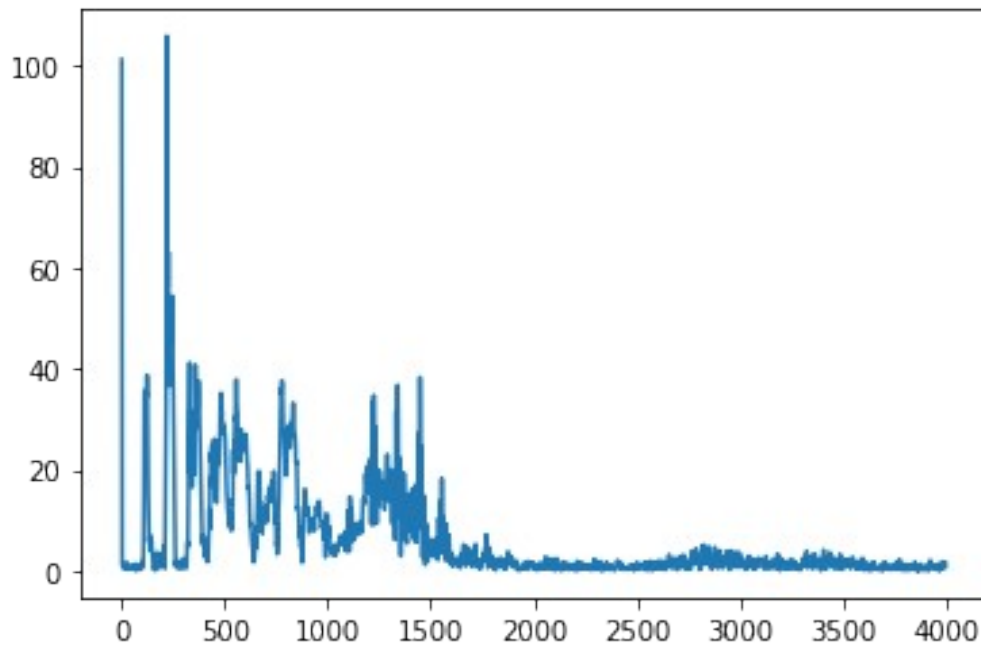


```
***** Listen to Audio for number 3
*****
```

<IPython.lib.display.Audio object>

```
samples = df_audio.sample(n=1)
path = samples.path.values[0]
print('*'* 30 + ' spectrum of number ' + str(samples.label.values[0])
+ ' ' + '*'*30 )
print()
wave = thinkdsp.read_wave(path)
spectrum = wave.make_spectrum()
spectrum.plot()
plt.show()
print('*'* 30 + ' Listen to Audio for number ' +
str(samples.label.values[0]) + ' ' + '*'*30 )
print()
IPython.display.Audio(path)
```

```
***** spectrum of number 9
*****
```

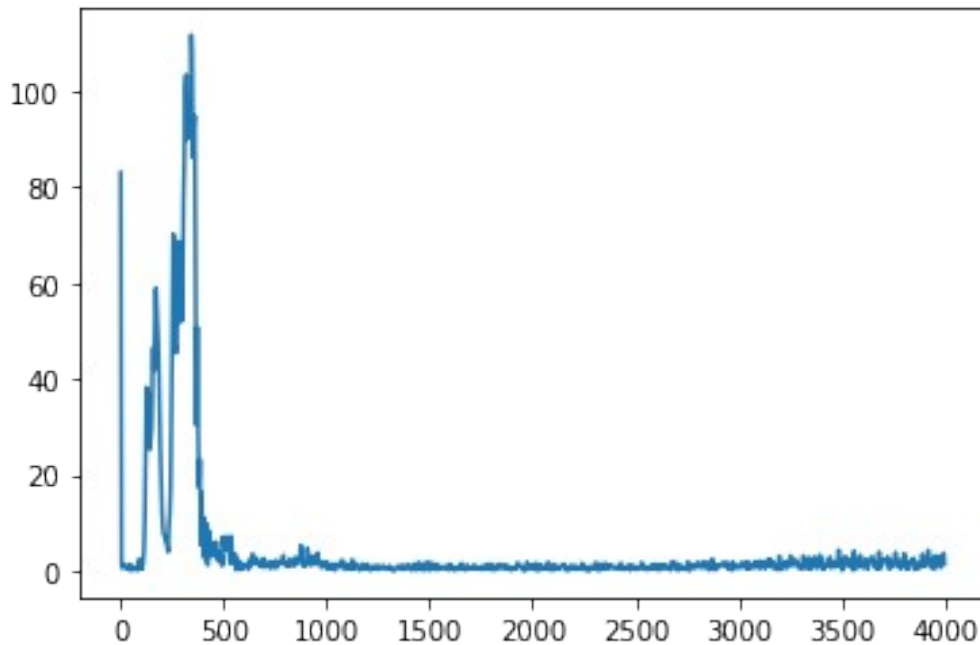


```
***** Listen to Audio for number 9
*****
```

```
<IPython.lib.display.Audio object>
```

```
samples = df_audio.sample(n=1)
path = samples.path.values[0]
print('*'* 30 + ' spectrum of number ' + str(samples.label.values[0])
+ ' ' + '*'*30 )
print()
wave = thinkdsp.read_wave(path)
spectrum = wave.make_spectrum()
spectrum.plot()
plt.show()
print('*'* 30 + ' Listen to Audio for number ' +
str(samples.label.values[0]) + ' ' + '*'*30 )
print()
IPython.display.Audio(path)
```

```
***** spectrum of number 2
*****
```



***** Listen to Audio for number 2

<IPython.lib.display.Audio object>

Creating dataframe

#Create a dataframe(name=df_audio) with two columns(path, label).
#You can get the label from the first letter of name.
#Eg: 0_jackson_0 --> 0
#0_jackson_43 --> 0

#info

df_audio.info()

<class 'pandas.core.frame.DataFrame'>

RangeIndex: 2000 entries, 0 to 1999

Data columns (total 2 columns):

#	Column	Non-Null Count	Dtype
0	path	2000 non-null	object
1	label	2000 non-null	object

dtypes: object(2)

memory usage: 31.4+ KB

Grader function 2

```
def grader_df():
    flag_shape = df_audio.shape==(2000,2)
    flag_columns = all(df_audio.columns==['path', 'label'])
    list_values = list(df_audio.label.value_counts())
```

```

        flag_label = len(list_values)==10
        flag_label2 = all([i==200 for i in list_values])
        final_flag = flag_shape and flag_columns and flag_label and
flag_label2
        return final_flag
grader_df()

True

from sklearn.utils import shuffle
df_audio = shuffle(df_audio, random_state=33)#don't change the random
state

#split the data into train and validation and save in X_train, X_test,
y_train, y_test
#use stratify sampling
#use random state of 45
#use test size of 30%
X_train, X_test, y_train, y_test = train_test_split(df_audio.path,
df_audio.label, test_size = 0.3, random_state = 45, stratify =
df_audio.label)

```

Grader function 3

```

def grader_split():
    flag_len = (len(X_train)==1400) and (len(X_test)==600) and
(len(y_train)==1400) and (len(y_test)==600)
    values_ytrain = list(y_train.value_counts())
    flag_ytrain = (len(values_ytrain)==10) and (all([i==140 for i in
values_ytrain]))
    values_ytest = list(y_test.value_counts())
    flag_ytest = (len(values_ytest)==10) and (all([i==60 for i in
values_ytest]))
    final_flag = flag_len and flag_ytrain and flag_ytest
    return final_flag
grader_split()

```

True

```

sample_rate = 22050
def load_wav(x, get_duration=True):
    '''This return the array values of audio with sampling rate of
22050 and Duration'''
    #loading the wav file with sampling rate of 22050
    samples, sample_rate = librosa.load(x, sr=22050)
    if get_duration:
        duration = librosa.get_duration(samples, sample_rate)
        return [samples, duration]
    else:
        return samples

```



```

#use load_wav function that was written above to get every wave.
#save it in X_train_processed and X_test_processed
# X_train_processed/X_test_processed should be dataframes with two
columns(raw_data, duration) with same index of X_train/y_train
samples_train, samples_test, durations_train, durations_test = [],[],
[],[]

for ele in tqdm(X_train.values):
    samples, duration = load_wav(ele)
    samples_train.append(samples)
    durations_train.append(duration)

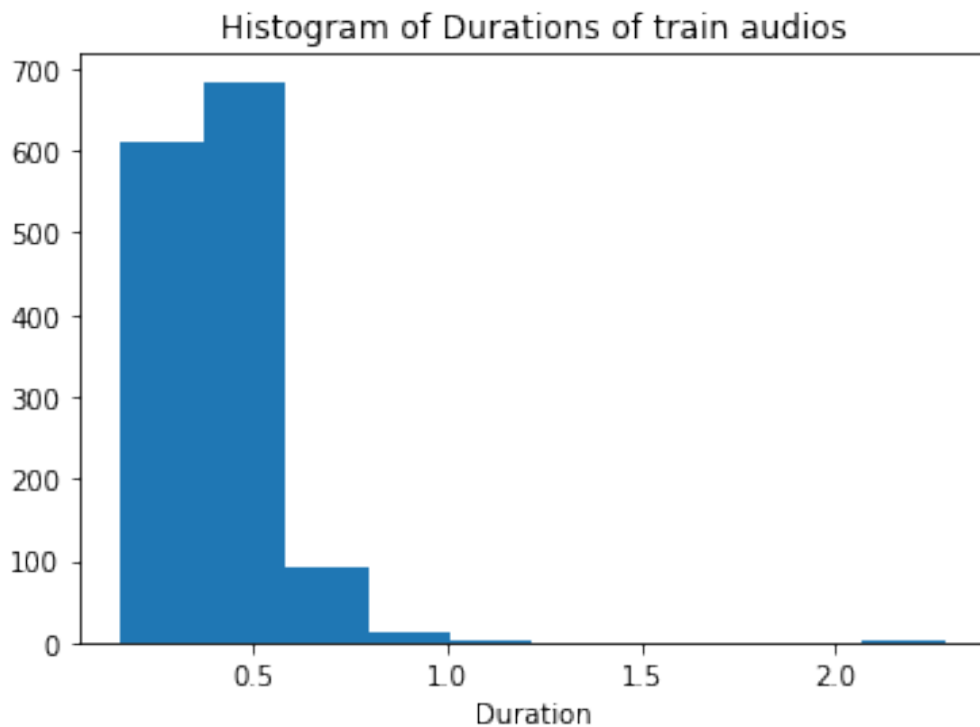
for ele in tqdm(X_test.values):
    samples, duration = load_wav(ele)
    samples_test.append(samples)
    durations_test.append(duration)

X_train_processed = pd.DataFrame({'raw_data' : samples_train,
'duration' : durations_train})
X_test_processed = pd.DataFrame({'raw_data' : samples_test, 'duration'
: durations_test})

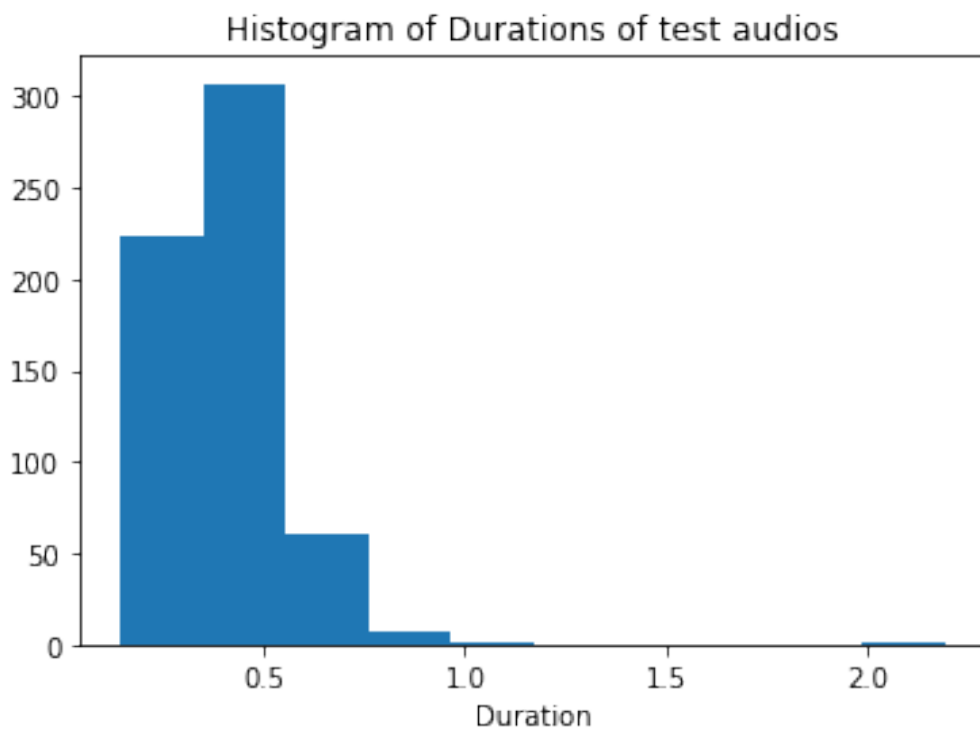
100%|██████████| 1400/1400 [00:13<00:00, 103.60it/s]
100%|██████████| 600/600 [00:05<00:00, 115.63it/s]

#plot the histogram of the duration for train
plt.hist(X_train_processed.duration)
plt.xlabel('Duration')
plt.title('Histogram of Durations of train audios')
plt.show()

```



```
#plot the histogram of the duration for test  
plt.hist(X_test_processed.duration)  
plt.xlabel('Duration')  
plt.title('Histogram of Durations of test audios')  
plt.show()
```



#print 0 to 100 percentile values with step size of 10 for train data duration.

```
for i in range(0,11,1):  
    print(f"{i*10}th percentile is  
{np.percentile(X_train_processed.duration.values, i*10)}")
```

```
0th percentile is 0.1564172335600907  
10th percentile is 0.25989569160997733  
20th percentile is 0.29872108843537415  
30th percentile is 0.33277097505668934  
40th percentile is 0.359718820861678  
50th percentile is 0.3898185941043084  
60th percentile is 0.4171156462585034  
70th percentile is 0.44616780045351473  
80th percentile is 0.48358276643990933  
90th percentile is 0.5447165532879821  
100th percentile is 2.282766439909297
```

##print 90 to 100 percentile values with step size of 1.

```
for i in range(0,11,1):  
    print(f"{i+90}th percentile is  
{np.percentile(X_train_processed.duration.values, i+90)}")
```

```
90th percentile is 0.5447165532879821  
91th percentile is 0.5635020408163269  
92th percentile is 0.5778757369614513  
93th percentile is 0.5933292517006804  
94th percentile is 0.610172335600907  
95th percentile is 0.6227800453514739  
96th percentile is 0.6430421768707484  
97th percentile is 0.66358231292517  
98th percentile is 0.6925750566893424  
99th percentile is 0.7906811791383219  
100th percentile is 2.282766439909297
```

Grader function 4

```
def grader_processed():  
    flag_columns = (all(X_train_processed.columns==['raw_data',  
'duration'])) and (all(X_test_processed.columns==['raw_data',  
'duration']))  
    flag_shape = (X_train_processed.shape ==(1400, 2)) and  
(X_test_processed.shape==(600,2))  
    return flag_columns and flag_shape  
grader_processed()
```

True

Based on our analysis 99 percentile values are less than 0.8sec so we will limit maximum length of X_train_processed and X_test_processed to 0.8 sec. It is similar to pad_sequence for a text dataset.

While loading the audio files, we are using sampling rate of 22050 so one sec will give array of length 22050. so, our maximum length is $0.8 * 22050 = 17640$ Pad with Zero if length of sequence is less than 17640 else Truncate the number.

Also create a masking vector for train and test.

masking vector value = 1 if it is real value, 0 if it is pad value. Masking vector data type must be bool.

max_length = 17640

as discussed above, Pad with Zero if length of sequence is less than 17640 else Truncate the number.

save in the X_train_pad_seq, X_test_pad_seq

also Create masking vector X_train_mask, X_test_mask

all the X_train_pad_seq, X_test_pad_seq, X_train_mask, X_test_mask will be numpy arrays mask vector dtype must be bool.

```
X_train_pad_seq = pad_sequences(X_train_processed.raw_data,
                                maxlen = max_length,
                                padding = 'post',
                                dtype = 'float32',
                                truncating = 'post')
```

```
X_test_pad_seq = pad_sequences(X_test_processed.raw_data,
                                maxlen = max_length,
                                padding = 'post',
                                dtype = 'float64',
                                truncating = 'post')
```

```
X_train_mask = X_train_pad_seq != 0
```

```
X_test_mask = X_test_pad_seq != 0
```

#X_train_pad_seq = np.expand_dims(X_train_pad_seq, -1)

#X_test_pad_seq = np.expand_dims(X_test_pad_seq, -1)

#y_train = y_train.values.astype('int')

#y_test = y_test.values.astype('int')

Grader function 5

```
def grader_padoutput():
    flag_padshape = (X_train_pad_seq.shape==(1400, 17640)) and
(X_test_pad_seq.shape==(600, 17640)) and (y_train.shape==(1400,))
    flag_maskshape = (X_train_mask.shape==(1400, 17640)) and
(X_test_mask.shape==(600, 17640)) and (y_test.shape==(600,))
    flag_dtype = (X_train_mask.dtype==bool) and
(X_test_mask.dtype==bool)
    return flag_padshape and flag_maskshape and flag_dtype
grader_padoutput()
```

True

```
result_dataset = pd.DataFrame(data = np.zeros((4,3)),index =
['model1', 'model2', 'model3', 'model4'], columns = ['Micro F1 Score',
'Loss', 'Accuracy'])
result_dataset
```

	Micro F1 Score	Loss	Accuracy
model1	0.0	0.0	0.0
model2	0.0	0.0	0.0
model3	0.0	0.0	0.0
model4	0.0	0.0	0.0

1. Giving Raw data directly.

Now we have

Train data: X_train_pad_seq, X_train_mask and y_train

Test data: X_test_pad_seq, X_test_mask and y_test

We will create a LSTM model which takes this input.

Task:

1. Create an LSTM network which takes "X_train_pad_seq" as input, "X_train_mask" as mask input. You can use any number of LSTM cells. Please read LSTM documentation(https://www.tensorflow.org/api_docs/python/tf/keras/layers/LSTM) in tensorflow to know more about mask and also https://www.tensorflow.org/guide/keras/masking_and_padding
2. Get the final output of the LSTM and give it to Dense layer of any size and then give it to Dense layer of size 10(because we have 10 outputs) and then compile with the sparse categorical cross entropy(because we are not converting it to one hot vectors). Also check the datatype of class labels(y_values) and make sure that you convert your class labels to integer datatype before fitting in the model.
3. While defining your model make sure that you pass both the input layer and mask input layer as input to lstm layer as follows
4. Use tensorboard to plot the graphs of loss and metric(use custom micro F1 score as metric) and histograms of gradients. You can write your code for computing F1 score using this link
5. make sure that it won't overfit.
6. You are free to include any regularization

```
X_train_pad_seq = np.expand_dims(X_train_pad_seq, -1)
X_test_pad_seq = np.expand_dims(X_test_pad_seq, -1)
```

```
y_train = y_train.values.astype('int')
y_test = y_test.values.astype('int')
```

Custom micro f1 score

```
class F1ScoreCB(tf.keras.callbacks.Callback):
    def __init__(self, train_data, test_data):
        super().__init__()
        self.train_data = train_data
        self.test_data = test_data
        self.history = {}
        self.history['val_f1_score'] = []

    def on_epoch_end(self, epochs, logs = {}):
        train_preds =
np.argmax(self.model.predict(self.train_data[0]), axis = -1)
        train_f1_score = f1_score(self.train_data[1], train_preds,
average='micro')
        train_f1_score = np.round(train_f1_score, 4)

        test_preds = np.argmax(self.model.predict(self.test_data[0]),
axis = -1)
        test_f1_score = f1_score(self.test_data[1], test_preds,
average='micro')
        test_f1_score = np.round(test_f1_score, 4)
        self.history['val_f1_score'].append(test_f1_score)

        print(f" - f1_score: {train_f1_score} - val_f1_score:
{test_f1_score}")

        writer1 = tf.summary.create_file_writer(logdir +
'./train_f1_score')
        writer2 = tf.summary.create_file_writer(logdir +
'./validation_f1_score')

        #writing to tensoboard
        with writer1.as_default():
            tf.summary.scalar('F1_Score', train_f1_score, step=epochs)
            writer1.flush()

        with writer2.as_default():
            tf.summary.scalar('F1_Score', test_f1_score, step=epochs)
            writer2.flush()

from tensorflow.keras.layers import Input, LSTM, Dense,Masking,Dropout
from tensorflow.keras.models import Model
import tensorflow as tf
#!/pip install keras-tuner
#import keras_tuner as kt
from tensorflow.keras.utils import plot_model
import datetime

## as discussed above, please write the architecture of the model.
## you will have two input layers in your model (data input layer and
```

```
mask input layer)
## make sure that you have defined the data type of masking layer as
bool
```

```
#creating the first model
```

```
tf.keras.backend.clear_session()
inp = Input(shape = (17640,1))
x_mask = Input(shape = (17640), dtype = 'bool')
x = LSTM(100,return_sequences = True)(inp, mask = x_mask)
x = LSTM(100)(x)
x = Dense(100, activation = 'relu', kernel_initializer = 'he_normal')(x)
out = Dense(10, activation = 'softmax', kernel_initializer =
'glorot_normal')(x)
```

```
model1 = Model(inputs = [inp, x_mask], outputs = out)
```

```
#printing the summary of model
```

```
model1.summary()
```

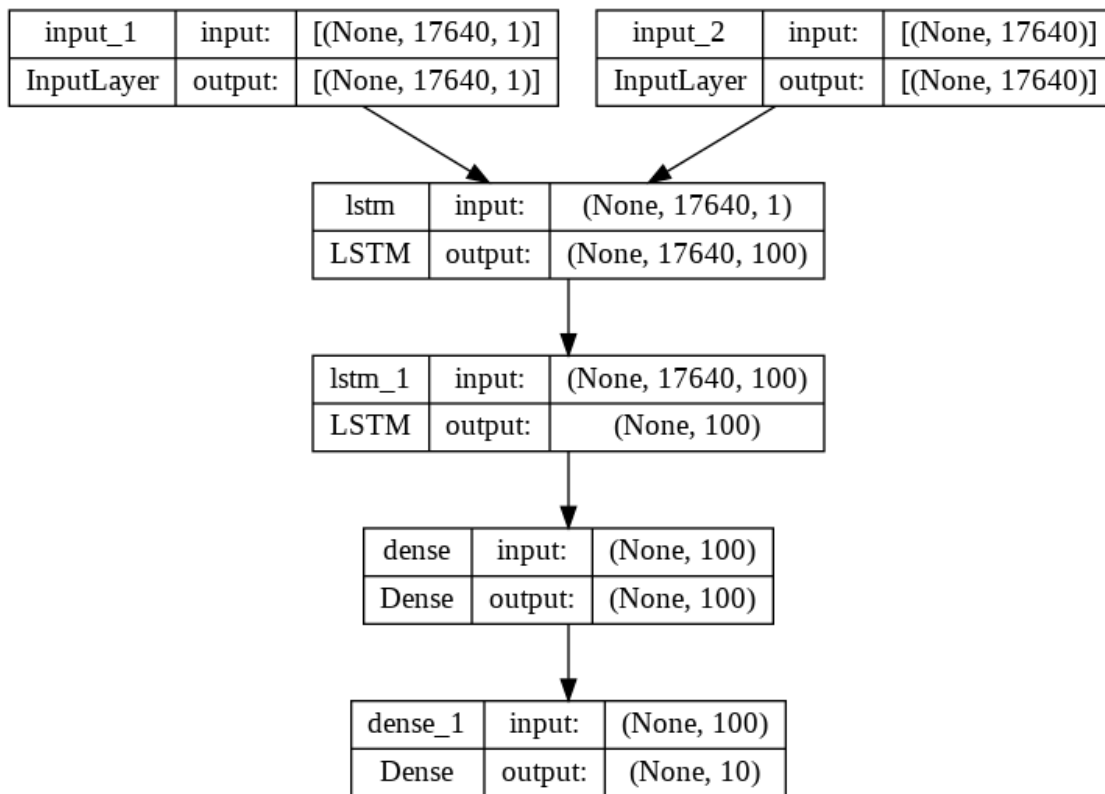
```
Model: "model"
```

Layer (type) Connected to	Output Shape	Param #
=====		
input_1 (InputLayer)	[(None, 17640, 1)]	0 []
input_2 (InputLayer)	[(None, 17640)]	0 []
lstm (LSTM) ['input_1[0][0]', 'input_2[0][0]']	(None, 17640, 100)	40800
lstm_1 (LSTM) ['lstm[0][0]']	(None, 100)	80400
dense (Dense) ['lstm_1[0][0]']	(None, 100)	10100
dense_1 (Dense)	(None, 10)	1010

```
['dense[0][0]']
```

```
=====
Total params: 132,310
Trainable params: 132,310
Non-trainable params: 0
=====
```

```
plot_model(model1, show_shapes = True)
```



```
!rm -rf ./logs/
logdir = os.path.join('logs', datetime.datetime.now().strftime('%Y%m
%d-%H%M%S'))

#train your model
model1.compile(optimizer = 'adam', loss =
'sparse_categorical_crossentropy', metrics = ['accuracy'])

model1_f1score = F1ScoreCB([X_train_pad_seq, X_train_mask], y_train),
([X_test_pad_seq, X_test_mask], y_test))
cb = [tf.keras.callbacks.TensorBoard(logdir, histogram_freq = 1,
write_graph = True), model1_f1score,
tf.keras.callbacks.EarlyStopping(monitor = 'val_loss', min_delta
```



```
= 0.1, patience = 5)]
```

```
model1_history = model1.fit([X_train_pad_seq, X_train_mask], y_train,  
validation_data = ([X_test_pad_seq, X_test_mask], y_test),  
batch_size = 32, epochs = 2, callbacks = cb)
```

```
Epoch 1/2
```

```
44/44 [=====] - 23s 467ms/step
```

```
19/19 [=====] - 10s 505ms/step
```

```
- f1_score: 0.1 - val_f1_score: 0.1
```

```
44/44 [=====] - 105s 2s/step - loss: 2.3048 -
```

```
accuracy: 0.0843 - val_loss: 2.3027 - val_accuracy: 0.1000
```

```
Epoch 2/2
```

```
44/44 [=====] - 21s 468ms/step
```

```
19/19 [=====] - 10s 506ms/step
```

```
- f1_score: 0.1 - val_f1_score: 0.1017
```

```
44/44 [=====] - 87s 2s/step - loss: 2.3039 -
```

```
accuracy: 0.0893 - val_loss: 2.3026 - val_accuracy: 0.1017
```

```
result_dataset['Micro F1 Score']
```

```
['model1']=max(model1_f1score.history['val_f1_score'])
```

```
result_dataset['Loss']['model1'] =
```

```
max(model1_history.history['val_loss'])
```

```
result_dataset['Accuracy']['model1']=
```

```
max(model1_history.history['val_accuracy'])
```

```
result_dataset
```

	Micro F1 Score	Loss	Accuracy
model1	0.1017	2.302677	0.101667
model2	0.0000	0.000000	0.000000
model3	0.0000	0.000000	0.000000
model4	0.0000	0.000000	0.000000

```
%tensorboard --logdir $logdir
```

Output hidden; open in <https://colab.research.google.com> to view.

2. Converting into spectrogram and giving spectrogram data as input

We can use librosa to convert raw data into spectrogram. A spectrogram shows the features in a two-dimensional representation with the intensity of a frequency at a point in time i.e we are converting Time domain to frequency domain. you can read more about this in <https://pnsn.org/spectrograms/what-is-a-spectrogram>

```
#reducing the dimensions back
```

```
X_train_pad_seq = np.squeeze(X_train_pad_seq, axis = -1)
```

```
X_test_pad_seq = np.squeeze(X_test_pad_seq, axis = -1)
```

```
def convert_to_spectrogram(raw_data):
```

```
    '''converting to spectrogram'''
```

```
    spectrum = librosa.feature.melspectrogram(y=raw_data,  
sr=sample_rate, n_mels=64)
```

```

logmel_spectrum = librosa.power_to_db(S=spectrum, ref=np.max)
return logmel_spectrum

##use convert_to_spectrogram and convert every raw sequence in
X_train_pad_seq and X_test_pad_seq.
## save those all in the X_train_spectrogram and X_test_spectrogram
( These two arrays must be numpy arrays)
X_train_spectrogram = []
for ele in X_train_pad_seq:
    logmel = convert_to_spectrogram(ele)
    X_train_spectrogram.append(logmel)
X_train_spectrogram = np.array(X_train_spectrogram)

X_test_spectrogram = []
for ele in X_test_pad_seq:
    logmel = convert_to_spectrogram(ele)
    X_test_spectrogram.append(logmel)
X_test_spectrogram = np.array(X_test_spectrogram)

X_train_spectrogram.shape

(1400, 64, 35)

```

Grader function 6

```

def grader_spectrogram():
    flag_shape = (X_train_spectrogram.shape==(1400,64, 35)) and
(X_test_spectrogram.shape == (600, 64, 35))
    return flag_shape
grader_spectrogram()

```

True

Now we have

Train data: X_train_spectrogram and y_train

Test data: X_test_spectrogram and y_test

We will create a LSTM model which takes this input.

Task:

1. Create an LSTM network which takes "X_train_spectrogram" as input and has to return output at every time step.
2. Average the output of every time step and give this to the Dense layer of any size. (ex: Output from LSTM will be (None, time_steps, features) average the output of every time step i.e, you should get (None,time_steps) and then pass to dense layer)
3. give the above output to Dense layer of size 10(output layer) and train the network with sparse categorical cross entropy.

4. Use tensorboard to plot the graphs of loss and metric(use custom micro F1 score as metric) and histograms of gradients. You can write your code for computing F1 score using this link
5. make sure that it won't overfit.
6. You are free to include any regularization

```
# write the architecture of the model
#print model.summary and make sure that it is following point 2
mentioned above
tf.keras.backend.clear_session()
inp = Input(shape = (64,35,))
x = LSTM(256, return_sequences = True)(inp)
x = tf.math.reduce_mean(x, axis = -1)
x = Dense(256, activation = 'relu', kernel_initializer = 'he_normal')(x)
x = Dropout(0.3)(x)
out = Dense(10, activation = 'softmax', kernel_initializer = 'glorot_normal')(x)

model2 = Model(inputs = inp, outputs = out)
#printing the model summary
model2.summary()
```

Model: "model"

Layer (type)	Output Shape	Param #
input_1 (InputLayer)	[(None, 64, 35)]	0
lstm (LSTM)	(None, 64, 256)	299008
tf.math.reduce_mean (TFOpLambda)	(None, 64)	0
dense (Dense)	(None, 256)	16640
dropout (Dropout)	(None, 256)	0
dense_1 (Dense)	(None, 10)	2570
Total params: 318,218		
Trainable params: 318,218		
Non-trainable params: 0		

```
plot_model(model2, show_shapes = True)
```

input_1	input:	[(None, 64, 35)]
InputLayer	output:	[(None, 64, 35)]



lstm	input:	(None, 64, 35)
LSTM	output:	(None, 64, 256)



tf.math.reduce_mean	input:	(None, 64, 256)
TFOpLambda	output:	(None, 64)



dense	input:	(None, 64)
Dense	output:	(None, 256)



dropout	input:	(None, 256)
Dropout	output:	(None, 256)



dense_1	input:	(None, 256)
Dense	output:	(None, 10)

```
#train your model
!rm -rf ./logs/
logdir = os.path.join('logs', datetime.datetime.now().strftime('%Y%m
%d-%H%M%S'))

model2_f1score = F1ScoreCB((X_train_spectrogram, y_train),
(X_test_spectrogram, y_test))
model2.compile(optimizer = 'adam', loss =
'sparse_categorical_crossentropy', metrics = ['accuracy'])
cb = [tf.keras.callbacks.TensorBoard(logdir, histogram_freq = 1,
write_graph = True), model2_f1score,
tf.keras.callbacks.EarlyStopping(monitor = 'val_loss', min_delta
= 0.05, patience = 3)]
```

```
model2_history = model2.fit(X_train_spectrogram, y_train,
validation_data = (X_test_spectrogram, y_test),
batch_size = 16, epochs = 15, callbacks = cb)
```

```
Epoch 1/15
1/88 [.....] - ETA: 2:28 - loss: 2.3108 -
accuracy: 0.1250
```

WARNING:tensorflow:Callback method `on_train_batch_end` is slow compared to the batch time (batch time: 0.0070s vs `on_train_batch_end` time: 0.0101s). Check your callbacks.

```
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.3057 - val_f1_score: 0.285
88/88 [=====] - 4s 22ms/step - loss: 2.2455 -
accuracy: 0.1900 - val_loss: 2.0789 - val_accuracy: 0.2850
```

```
Epoch 2/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.57 - val_f1_score: 0.5817
88/88 [=====] - 1s 11ms/step - loss: 1.8662 -
accuracy: 0.3764 - val_loss: 1.5783 - val_accuracy: 0.5817
```

```
Epoch 3/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.6214 - val_f1_score: 0.6117
88/88 [=====] - 1s 13ms/step - loss: 1.4879 -
accuracy: 0.5286 - val_loss: 1.2685 - val_accuracy: 0.6117
```

```
Epoch 4/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.6664 - val_f1_score: 0.64
88/88 [=====] - 1s 12ms/step - loss: 1.2324 -
accuracy: 0.6079 - val_loss: 1.1475 - val_accuracy: 0.6400
```

```
Epoch 5/15
44/44 [=====] - 0s 3ms/step
```

```
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7057 - val_f1_score: 0.72
88/88 [=====] - 1s 12ms/step - loss: 1.0828 -
accuracy: 0.6493 - val_loss: 0.9462 - val_accuracy: 0.7200
Epoch 6/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.6993 - val_f1_score: 0.7017
88/88 [=====] - 1s 12ms/step - loss: 0.9913 -
accuracy: 0.6700 - val_loss: 0.8712 - val_accuracy: 0.7017
Epoch 7/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7029 - val_f1_score: 0.695
88/88 [=====] - 1s 11ms/step - loss: 0.9469 -
accuracy: 0.6786 - val_loss: 0.9384 - val_accuracy: 0.6950
Epoch 8/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7486 - val_f1_score: 0.7417
88/88 [=====] - 1s 11ms/step - loss: 0.8752 -
accuracy: 0.7029 - val_loss: 0.8153 - val_accuracy: 0.7417
Epoch 9/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7664 - val_f1_score: 0.77
88/88 [=====] - 1s 12ms/step - loss: 0.8489 -
accuracy: 0.7121 - val_loss: 0.7653 - val_accuracy: 0.7700
Epoch 10/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 4ms/step
- f1_score: 0.7821 - val_f1_score: 0.795
88/88 [=====] - 1s 12ms/step - loss: 0.8032 -
accuracy: 0.7314 - val_loss: 0.6655 - val_accuracy: 0.7950
Epoch 11/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7786 - val_f1_score: 0.7717
88/88 [=====] - 1s 11ms/step - loss: 0.7678 -
accuracy: 0.7350 - val_loss: 0.6908 - val_accuracy: 0.7717
Epoch 12/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.7907 - val_f1_score: 0.7933
88/88 [=====] - 1s 12ms/step - loss: 0.7525 -
accuracy: 0.7471 - val_loss: 0.6437 - val_accuracy: 0.7933
Epoch 13/15
44/44 [=====] - 0s 3ms/step
19/19 [=====] - 0s 3ms/step
- f1_score: 0.785 - val_f1_score: 0.7933
```

```
88/88 [=====] - 1s 12ms/step - loss: 0.7228 -  
accuracy: 0.7571 - val_loss: 0.6090 - val_accuracy: 0.7933  
Epoch 14/15  
44/44 [=====] - 0s 3ms/step  
19/19 [=====] - 0s 3ms/step  
- f1_score: 0.8107 - val_f1_score: 0.8033  
88/88 [=====] - 1s 12ms/step - loss: 0.7153 -  
accuracy: 0.7586 - val_loss: 0.6148 - val_accuracy: 0.8033  
Epoch 15/15  
44/44 [=====] - 0s 3ms/step  
19/19 [=====] - 0s 3ms/step  
- f1_score: 0.8257 - val_f1_score: 0.82  
88/88 [=====] - 1s 12ms/step - loss: 0.6837 -  
accuracy: 0.7786 - val_loss: 0.5939 - val_accuracy: 0.8200
```

```
model2_history.history
```

```
{'loss': [2.2454817295074463,  
1.8662177324295044,  
1.48792564868927,  
1.2324451208114624,  
1.0828142166137695,  
0.9913450479507446,  
0.9468510150909424,  
0.8751721978187561,  
0.8489266633987427,  
0.803210973739624,  
0.7678343653678894,  
0.7525426149368286,  
0.722813606262207,  
0.7152576446533203,  
0.6836733222007751],  
'accuracy': [0.1899999976158142,  
0.3764285743236542,  
0.5285714268684387,  
0.6078571677207947,  
0.6492857336997986,  
0.6700000166893005,  
0.6785714030265808,  
0.7028571367263794,  
0.7121428847312927,  
0.7314285635948181,  
0.7350000143051147,  
0.7471428513526917,  
0.7571428418159485,  
0.758571445941925,  
0.7785714268684387],  
'val_loss': [2.078947067260742,  
1.5782654285430908,  
1.268479824066162,  
1.1475270986557007,
```

```

0.9462215900421143,
0.8712335228919983,
0.938387930393219,
0.8153355121612549,
0.7652550935745239,
0.6654719710350037,
0.6907837390899658,
0.6437439918518066,
0.6090192794799805,
0.6147552132606506,
0.5938963294029236],
'val_accuracy': [0.2849999964237213,
0.5816666483879089,
0.6116666793823242,
0.6399999856948853,
0.7200000286102295,
0.7016666531562805,
0.6949999928474426,
0.7416666746139526,
0.7699999809265137,
0.7950000166893005,
0.7716666460037231,
0.7933333516120911,
0.7933333516120911,
0.8033333420753479,
0.8199999928474426]]}

result_dataset['Micro F1 Score']
['model2']=max(model2_flscore.history['val_f1_score'])
result_dataset['Loss']['model2'] =
max(model2_history.history['val_loss'])
result_dataset['Accuracy']['model2']=
max(model2_history.history['val_accuracy'])
result_dataset

```

	Micro F1 Score	Loss	Accuracy
model1	0.1017	2.302677	0.101667
model2	0.8200	2.078947	0.820000
model3	0.0000	0.000000	0.000000
model4	0.0000	0.000000	0.000000

```
%tensorboard --logdir $logdir
```

Output hidden; open in <https://colab.research.google.com> to view.

3. Data augmentation with raw features

Till now we have done with 2000 samples only. It is very less data. We are giving the process of generating augmented data below.

There are two types of augmentation:

1. time stretching - Time stretching either increases or decreases the length of the file. For time stretching we move the file 30% faster or slower
2. pitch shifting - pitch shifting moves the frequencies higher or lower. For pitch shifting we shift up or down one half-step.

generating augmented data.

```
def generate_augmented_data(file_path):
    augmented_data = []
    samples = load_wav(file_path, get_duration=False)
    for time_value in [0.7, 1, 1.3]:
        for pitch_value in [-1, 0, 1]:
            time_stretch_data = librosa.effects.time_stretch(samples,
rate=time_value)
            final_data =
librosa.effects.pitch_shift(time_stretch_data, sr=sample_rate,
n_steps=pitch_value)
            augmented_data.append(final_data)
    return augmented_data
```

```
temp_path = df_audio.iloc[0].path
aug_temp = generate_augmented_data(temp_path)
```

```
len(aug_temp)
```

9

Follow the steps

1. Split data 'df_audio' into train and test (80-20 split)
2. We have 2000 data points(1600 train points, 400 test points)

```
X_train, X_test, y_train,
y_test=train_test_split(df_audio['path'],df_audio['label'],random_stat
e=45,test_size=0.2,stratify=df_audio['label'])
```

1. Do augmentation only on X_train,pass each point of X_train to generate_augmented_data function.After augmentation we will get 14400 train points. Make sure that you are augmenting the corresponding class labels (y_train) also.
2. Preprocess your X_test using load_wav function.
3. Convert the augmented_train_data and test_data to numpy arrays.
4. Perform padding and masking on augmented_train_data and test_data.
5. After padding define the model similar to model 1 and fit the data

Note - While fitting your model on the augmented data for model 3 you might face Resource exhaust error. One simple hack to avoid that is save the augmented_train_data,augment_y_train,test_data and y_test to Drive or into your local system. Then restart the runtime so that now you can train your model with full RAM capacity. Upload these files again in the new runtime session perform padding and masking and then fit your model.

```

train_aug_data = []
train_labels = []

for path, label in tqdm(zip(X_train.values, y_train.values)):
    aug_data = generate_augmented_data(path)
    train_aug_data.extend(aug_data)
    train_labels.extend(label*9)

X_train_processed = pd.DataFrame({'raw_data' : train_aug_data, 'label'
: train_labels})

```

```

test_data = []
for path in tqdm(X_test.values):
    test_data.append(load_wav(path, get_duration = False))

```

```

X_test_processed = pd.DataFrame({'raw_data' : test_data, 'label' :
y_test.values})

```

```

1600it [04:26, 6.01it/s]
100%|██████████| 400/400 [00:03<00:00, 119.22it/s]

```

#padding the sequences

```

X_train_pad_seq = pad_sequences(X_train_processed.raw_data, maxlen =
max_length,
                                dtype = 'float32', padding = 'post',
                                truncating = 'post')
X_test_pad_seq = pad_sequences(X_test_processed.raw_data, maxlen =
max_length,
                                dtype = 'float32', padding = 'post',
                                truncating = 'post')

```

```

y_train = X_train_processed.label.values.astype('int')
y_test = X_test_processed.label.values.astype('int')

```

```

X_train_mask = X_train_pad_seq != 0
X_test_mask = X_test_pad_seq != 0

```

```

X_train_pad_seq = np.expand_dims(X_train_pad_seq, -1)
X_test_pad_seq = np.expand_dims(X_test_pad_seq, -1)

```

lets define model 3

```

tf.keras.backend.clear_session()
inp = Input(shape = (17640,1))
inp_mask = Input(shape = (17640), dtype = 'bool')

x = LSTM(25)(inp, mask = inp_mask)
x = Dense(50, activation = 'relu', kernel_initializer = 'he_normal')
(x)
out = Dense(10, activation = 'softmax', kernel_initializer =
'glorot_normal')(x)

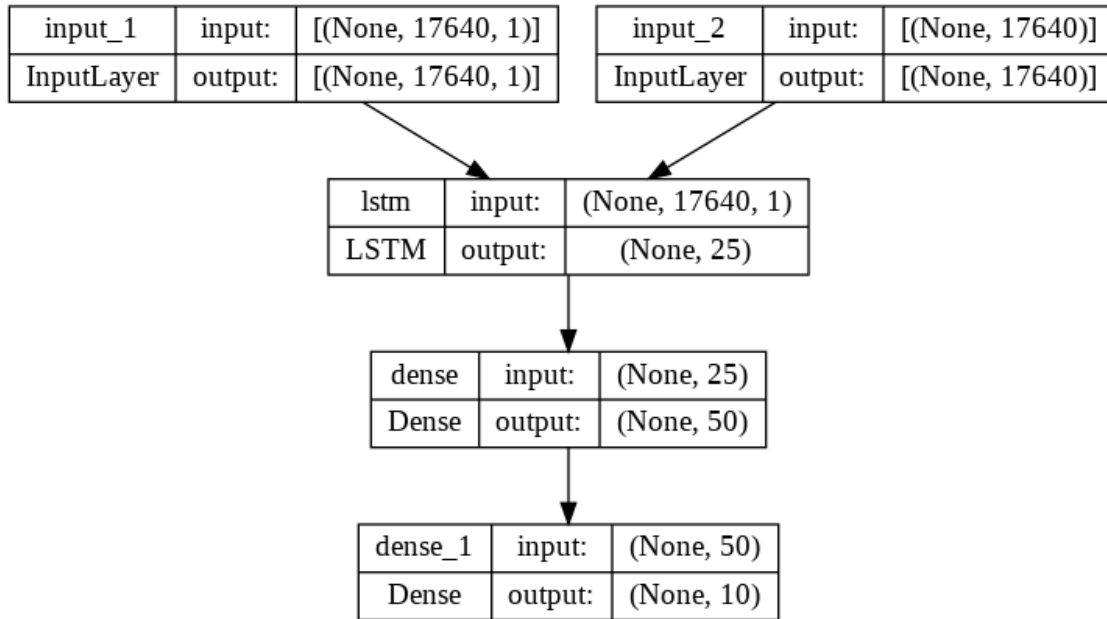
```

```
model3 = Model(inputs = [inp, inp_mask], outputs = out)
model3.summary()
```

Model: "model"

Layer (type) Connected to	Output Shape	Param #
=====		
input_1 (InputLayer)	[(None, 17640, 1)]	0
input_2 (InputLayer)	[(None, 17640)]	0
lstm (LSTM) ['input_1[0][0]', 'input_2[0][0]']	(None, 25)	2700
dense (Dense) ['lstm[0][0]']	(None, 50)	1300
dense_1 (Dense) ['dense[0][0]']	(None, 10)	510
=====		
Total params: 4,510		
Trainable params: 4,510		
Non-trainable params: 0		

```
plot_model(model3, show_shapes = True)
```



```
model3.compile(optimizer = 'adam',loss =
'sparse_categorical_crossentropy',metrics = ['accuracy'])
```

```
model3_f1_score = F1ScoreCB([X_train_pad_seq, X_train_mask],
y_train), ([X_test_pad_seq, X_test_mask], y_test))
cb = [tf.keras.callbacks.TensorBoard(logdir, histogram_freq=1,
write_graph = True),
tf.keras.callbacks.EarlyStopping(monitor = 'val_loss', min_delta
= 0.1, patience = 2),model3_f1_score]
```

```
model3_history = model3.fit([X_train_pad_seq, X_train_mask], y_train,
validation_data = ([X_test_pad_seq, X_test_mask], y_test),
epochs = 3, callbacks = cb, batch_size = 128)
```

```
Epoch 1/3
450/450 [=====] - 75s 165ms/step
13/13 [=====] - 3s 161ms/step
- f1_score: 0.0999 - val_f1_score: 0.1
113/113 [=====] - 139s 1s/step - loss: 2.3029
- accuracy: 0.0976 - val_loss: 2.3027 - val_accuracy: 0.1000
Epoch 2/3
450/450 [=====] - 75s 166ms/step
13/13 [=====] - 2s 162ms/step
- f1_score: 0.1044 - val_f1_score: 0.0975
113/113 [=====] - 132s 1s/step - loss: 2.3029
- accuracy: 0.0921 - val_loss: 2.3027 - val_accuracy: 0.0975
Epoch 3/3
450/450 [=====] - 75s 168ms/step
13/13 [=====] - 2s 178ms/step
- f1_score: 0.1069 - val_f1_score: 0.095
```

```
113/113 [=====] - 133s 1s/step - loss: 2.3027  
- accuracy: 0.0974 - val_loss: 2.3027 - val_accuracy: 0.0950
```

```
result_dataset['Micro F1 Score']  
['model3']=max(model3_f1_score.history['val_f1_score'])  
result_dataset['Loss']['model3'] =  
max(model3_history.history['val_loss'])  
result_dataset['Accuracy']['model3']=  
max(model3_history.history['val_accuracy'])  
result_dataset
```

	Micro F1 Score	Loss	Accuracy
model1	0.1017	2.302677	0.101667
model2	0.8200	2.078947	0.820000
model3	0.1000	2.302708	0.100000
model4	0.0000	0.000000	0.000000

```
%tensorboard --logdir $logdir
```

Output hidden; open in <https://colab.research.google.com> to view.

4. Data augmentation with spectrogram data

1. use `convert_to_spectrogram` and convert the padded data from train and test data to spectrogram data.
2. The shape of train data will be 14400 x 64 x 35 and shape of test_data will be 400 x 64 x 35
3. Define the model similar to model 2 and fit the data

```
X_train_pad_seq = np.squeeze(X_train_pad_seq, axis = -1)
```

```
X_test_pad_seq = np.squeeze(X_test_pad_seq, axis = -1)
```

```
##use convert_to_spectrogram and convert every raw sequence in  
X_train_pad_seq and X_test_pad_seq.
```

```
## save those all in the X_train_spectrogram and X_test_spectrogram  
( These two arrays must be numpy arrays)
```

```
X_train_spectrogram = []
```

```
for ele in tqdm(X_train_pad_seq):
```

```
    logmel = convert_to_spectrogram(ele)
```

```
    X_train_spectrogram.append(logmel)
```

```
X_train_spectrogram = np.array(X_train_spectrogram)
```

```
X_test_spectrogram = []
```

```
for ele in tqdm(X_test_pad_seq):
```

```
    logmel = convert_to_spectrogram(ele)
```

```
    X_test_spectrogram.append(logmel)
```

```
X_test_spectrogram = np.array(X_test_spectrogram)
```

```
100%|██████████| 14400/14400 [01:06<00:00, 216.62it/s]
```

```
100%|██████████| 400/400 [00:01<00:00, 219.14it/s]
```

Lets create model4

```
tf.keras.backend.clear_session()
inp = Input(shape = (64,35,))
x = LSTM(256, return_sequences = True)(inp)
x = tf.math.reduce_mean(x, axis = -1)
x = Dense(256, activation = 'relu', kernel_initializer = 'he_normal')(x)
out = Dense(10, activation = 'softmax', kernel_initializer = 'glorot_normal')(x)
```

```
model4 = Model(inputs = inp, outputs = out)
model4.summary()
```

Model: "model"

Layer (type)	Output Shape	Param #
input_1 (InputLayer)	[(None, 64, 35)]	0
lstm (LSTM)	(None, 64, 256)	299008
tf.math.reduce_mean (TFOpLambda)	(None, 64)	0
dense (Dense)	(None, 256)	16640
dense_1 (Dense)	(None, 10)	2570

```
=====  
Total params: 318,218  
Trainable params: 318,218  
Non-trainable params: 0  
=====
```

#train your model

```
!rm -rf ./logs/  
logdir = os.path.join('logs', datetime.datetime.now().strftime('%Y%m%d-%H%M%S'))  
  
model4.compile(optimizer = 'adam', loss = 'sparse_categorical_crossentropy', metrics = 'accuracy')  
model4_f1score = F1ScoreCB((X_train_spectrogram, y_train), (X_test_spectrogram, y_test))  
cb = [tf.keras.callbacks.TensorBoard(logdir, histogram_freq = 1, write_graph = True), model4_f1score, tf.keras.callbacks.EarlyStopping(monitor = 'val_loss', min_delta = 0.005, patience = 1)]
```

```
model4_history = model4.fit(X_train_spectrogram, y_train,
```

```
validation_data = (X_test_spectrogram, y_test),  
                  batch_size = 64, epochs = 15, callbacks = cb)
```

Epoch 1/15

```
6/225 [.....] - ETA: 2s - loss: 2.2876 -  
accuracy: 0.1745
```

WARNING:tensorflow:Callback method `on_train_batch_end` is slow compared to the batch time (batch time: 0.0052s vs `on_train_batch_end` time: 0.0129s). Check your callbacks.

```
450/450 [=====] - 2s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.7103 - val_f1_score: 0.7325  
225/225 [=====] - 6s 18ms/step - loss: 1.3728  
- accuracy: 0.5350 - val_loss: 0.7674 - val_accuracy: 0.7325
```

Epoch 2/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.8358 - val_f1_score: 0.87  
225/225 [=====] - 3s 13ms/step - loss: 0.6484  
- accuracy: 0.7820 - val_loss: 0.4462 - val_accuracy: 0.8700
```

Epoch 3/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.8626 - val_f1_score: 0.895  
225/225 [=====] - 3s 13ms/step - loss: 0.4805  
- accuracy: 0.8399 - val_loss: 0.3456 - val_accuracy: 0.8950
```

Epoch 4/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.8812 - val_f1_score: 0.905  
225/225 [=====] - 3s 13ms/step - loss: 0.4006  
- accuracy: 0.8680 - val_loss: 0.3114 - val_accuracy: 0.9050
```

Epoch 5/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.8905 - val_f1_score: 0.8975  
225/225 [=====] - 3s 13ms/step - loss: 0.3592  
- accuracy: 0.8844 - val_loss: 0.2913 - val_accuracy: 0.8975
```

Epoch 6/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 3ms/step  
- f1_score: 0.9043 - val_f1_score: 0.9125  
225/225 [=====] - 3s 15ms/step - loss: 0.3339  
- accuracy: 0.8944 - val_loss: 0.2664 - val_accuracy: 0.9125
```

Epoch 7/15

```
450/450 [=====] - 1s 3ms/step  
13/13 [=====] - 0s 4ms/step  
- f1_score: 0.915 - val_f1_score: 0.91  
225/225 [=====] - 3s 15ms/step - loss: 0.3088
```

```

- accuracy: 0.9037 - val_loss: 0.2582 - val_accuracy: 0.9100
Epoch 8/15
450/450 [=====] - 1s 3ms/step
13/13 [=====] - 0s 3ms/step
- f1_score: 0.9161 - val_f1_score: 0.93
225/225 [=====] - 4s 16ms/step - loss: 0.2860
- accuracy: 0.9107 - val_loss: 0.2324 - val_accuracy: 0.9300
Epoch 9/15
450/450 [=====] - 1s 3ms/step
13/13 [=====] - 0s 3ms/step
- f1_score: 0.9215 - val_f1_score: 0.935
225/225 [=====] - 3s 15ms/step - loss: 0.2778
- accuracy: 0.9126 - val_loss: 0.2273 - val_accuracy: 0.9350
Epoch 10/15
450/450 [=====] - 2s 4ms/step
13/13 [=====] - 0s 3ms/step
- f1_score: 0.9285 - val_f1_score: 0.94
225/225 [=====] - 4s 19ms/step - loss: 0.2608
- accuracy: 0.9179 - val_loss: 0.2124 - val_accuracy: 0.9400
Epoch 11/15
450/450 [=====] - 1s 3ms/step
13/13 [=====] - 0s 3ms/step
- f1_score: 0.9226 - val_f1_score: 0.9275
225/225 [=====] - 3s 15ms/step - loss: 0.2572
- accuracy: 0.9222 - val_loss: 0.2416 - val_accuracy: 0.9275

```

```

result_dataset['Micro F1 Score']
['model4']=max(model4_f1score.history['val_f1_score'])
result_dataset['Loss']['model4'] =
max(model4_history.history['val_loss'])
result_dataset['Accuracy']['model4']=
max(model4_history.history['val_accuracy'])
result_dataset

```

	Micro F1 Score	Loss	Accuracy
model1	0.1017	2.302677	0.101667
model2	0.8200	2.078947	0.820000
model3	0.1000	2.302708	0.100000
model4	0.9400	0.767448	0.940000

```

from tabulate import tabulate
print(tabulate(result_dataset,headers = 'keys', tablefmt = 'psql'))

```

	Micro F1 Score	Loss	Accuracy
model1	0.1017	2.30268	0.101667
model2	0.82	2.07895	0.82
model3	0.1	2.30271	0.1
model4	0.94	0.767448	0.94