Deep Learning for Pneumonia Detection from Chest X-Ray Images

Table of Contents

Table of Contents

- Import Module
  - Import the Libraries
  - Importing the Dataset (section_1_2)
- Data Visualization and Augmentation
  - Data Visualization
  - Data Augmentation (section_2_2)
- Build the Model - Main
- Evaluate the Model
  - Confusion Matrix & Classification Report
  - Plotting Loss and Accuracy
- Hyperparameter Tuning with SGD Optimizer - Model 2
- Hyperparameter Tuning with Network Depth - Model 3
- Inferences and Comments

Import Module

Import the Libraries

In [9]:

```
# importing the packages necessary for this assignment problem

import numpy as np
import pandas as pd
import math
import os
import timeit

from sklearn import preprocessing
from sklearn import metrics
from sklearn.metrics import roc_auc_score
from sklearn.metrics import roc_curve
from sklearn.model_selection import train_test_split

from sklearn.model_selection import RepeatedStratifiedKFold
from sklearn.model_selection import GridSearchCV

#for checking testing results
from sklearn.metrics import classification_report, confusion_matrix
import statsmodels.api as sm
from sklearn.metrics import accuracy_score

# Import visualization libraries
from matplotlib import pyplot as plt
plt.rc("font", size=14)
import matplotlib.cm as cm
from mpl_toolkits.mplot3d import Axes3D
from matplotlib.ticker import AutoLocator, MaxNLocator, LinearLocator, Multipl

import seaborn as sns
sns.set(style="white")
sns.set(style="whitegrid", color_codes=True)

# and we want to view the charts inline
%matplotlib inline

# Import deep learning libraries
import tensorflow as tf
print("TensorFlow version:", tf.__version__)

from tensorflow.keras.layers import Dense, Flatten, Conv2D
from tensorflow.keras import Model

from numpy import expand_dims
from keras.preprocessing.image import load_img
from keras.preprocessing.image import img_to_array
from keras.preprocessing.image import ImageDataGenerator
```

```
TensorFlow version: 2.8.2
```

Importing the Dataset

In [10]:

```
# Mount BITS Google Drive

from google.colab import drive
drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call
drive.mount("/content/drive", force_remount=True).
```

In [11]:
```
# All the train, test and val folders stored as keys in an array (arr)
arr = next(os.walk('drive/MyDrive/Colab Notebooks/chest_xray'))[1]
arr = arr[2:]

# Create a dictionary using the aforementioned keys to form a dataframe
d = {}
for i in arr:
  d[i] = next(os.walk('drive/MyDrive/Colab Notebooks/chest_xray/chest_xray/'+i

for i in arr:
    target = []
    images = []
    for j in d[i]:
        files = next(os.walk('drive/MyDrive/Colab Notebooks/chest_xray/chest_x
        images += files
        target += [j]*len(files)

    d[i] = pd.DataFrame({'images':np.array(images).flatten(),'target':np.array

# Appending absolute paths to the image url
for i in arr:
    d[i]['image_paths'] =  'drive/MyDrive/Colab Notebooks/chest_xray/chest_xra

train = d['train']
val = d['val']
test = d['test']

# Display the dataframe
train
```

Out[11]:

	images	target	image_paths
0	person549_bacteria_2303.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
1	person533_virus_1055.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
2	person491_bacteria_2081.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
3	person504_bacteria_2127.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
4	person548_bacteria_2297.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
...	...	...	...
5213	IM-0512-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5214	IM-0523-0001-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5215	IM-0524-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5216	IM-0531-0001-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5217	IM-0520-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...

5218 rows × 3 columns

In [12]:

```
# Shuffling the dataframe
train = train.sample(frac=1).reset_index()
train = train.drop(['index'],axis=1)
train
```

Out[12]:

	images	target	image_paths
0	person1814_bacteria_4669.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
1	person359_bacteria_1646.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
2	person420_bacteria_1847.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
3	IM-0555-0001.jpeg	NORMAL	drive/MyDrive/Colab Notebooks/chest_xray/chest...
4	person1122_virus_1847.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
...	...	...	...
5213	person294_virus_611.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5214	person827_bacteria_2738.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5215	person1433_virus_2447.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5216	person279_bacteria_1315.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...
5217	person448_bacteria_1933.jpeg	PNEUMONIA	drive/MyDrive/Colab Notebooks/chest_xray/chest...

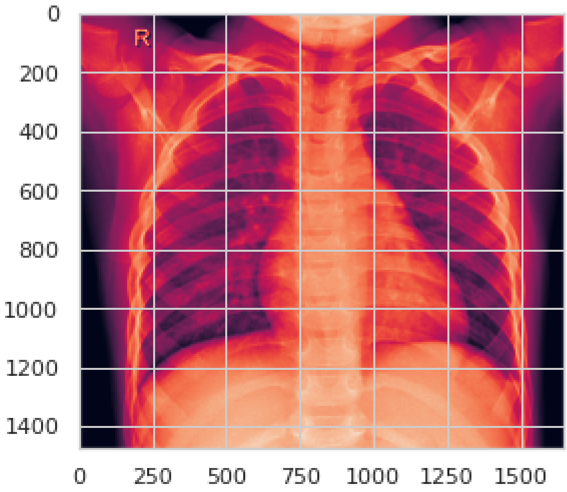
5218 rows × 3 columns

Data Visualization and Augmentation

Data Visualization

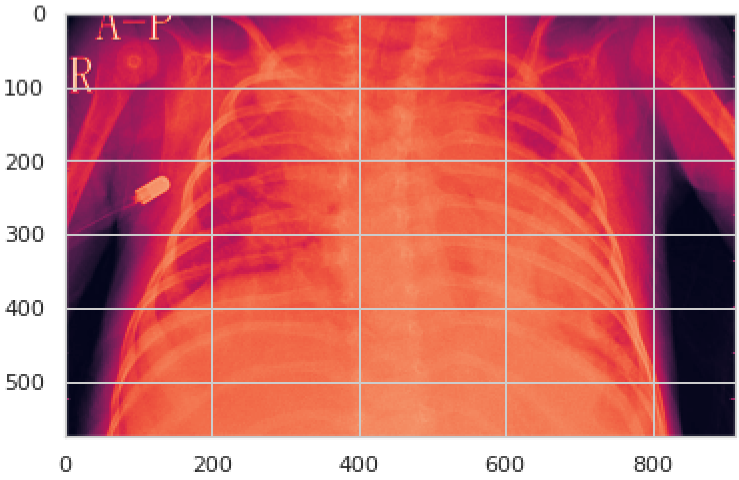
In [14]:
```
# Display Normal image
img_normal = plt.imread(train['image_paths'][3])
plt.imshow(img_normal)
print('target:' ,train['target'][3])
```

```
target: NORMAL
```



In [15]:
```
# Display Pneumonia image
img_pneumonia = plt.imread(train['image_paths'][0])
plt.imshow(img_pneumonia)

print('target:' ,train['target'][0])
```

```
target: PNEUMONIA
```



Data Augmentation

In [16]:

```
IMG_SIZE = 64
BATCH = 16
SEED = 42

train_datagen = tf.keras.preprocessing.image.ImageDataGenerator(rescale=1/255.
                                                                width_shift_ra

val_datagen = tf.keras.preprocessing.image.ImageDataGenerator(rescale=1/255.)

test_datagen = tf.keras.preprocessing.image.ImageDataGenerator(rescale=1/255.)
```

In [17]:

```
#directory=train_path, #dataframe contains the full paths

ds_train = train_datagen.flow_from_dataframe(train, x_col = 'image_paths', y_c
                                             class_mode = 'binary', batch_size

ds_val = val_datagen.flow_from_dataframe(val, x_col = 'image_paths', y_col = '
                                         class_mode = 'binary', batch_size = B

ds_test = test_datagen.flow_from_dataframe(test, x_col = 'image_paths', y_col
                                          class_mode = 'binary', batch_size =
```

```
Found 5216 validated image filenames belonging to 2 classes.
Found 16 validated image filenames belonging to 2 classes.
Found 624 validated image filenames belonging to 2 classes.
```

```
/usr/local/lib/python3.7/dist-packages/keras_preprocessing/image/dataframe_it
erator.py:282: UserWarning: Found 2 invalid image filename(s) in x_col="image
_paths". These filename(s) will be ignored.
  .format(n_invalid, x_col)
```

Build the Model - Main

In [37]:
```
model = tf.keras.Sequential()

# Input layer
model.add(tf.keras.layers.Conv2D(filters=16, kernel_size=3, activation='relu',
model.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 1
model.add(tf.keras.layers.Conv2D(filters=32, kernel_size=3, activation='relu')
model.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 2
model.add(tf.keras.layers.Conv2D(filters=64, kernel_size=3, activation='relu')
model.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 3
model.add(tf.keras.layers.Conv2D(filters=64, kernel_size=3, activation='relu')
model.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 4 - Flattening
model.add(tf.keras.layers.Flatten())
model.add(tf.keras.layers.Dense(units=128, activation='relu'))

# Output Layer
model.add(tf.keras.layers.Dense(units=1, activation='sigmoid'))

# Print Model Summary
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d (Conv2D)             (None, 62, 62, 16)        448       
                                                                 
 max_pooling2d (MaxPooling2D  (None, 31, 31, 16)       0         
 )                                                               
                                                                 
 conv2d_1 (Conv2D)           (None, 29, 29, 32)        4640      
                                                                 
 max_pooling2d_1 (MaxPooling  (None, 14, 14, 32)       0         
 2D)                                                             
                                                                 
 conv2d_2 (Conv2D)           (None, 12, 12, 64)        18496     
                                                                 
 max_pooling2d_2 (MaxPooling  (None, 6, 6, 64)         0         
 2D)                                                             
                                                                 
 conv2d_3 (Conv2D)           (None, 4, 4, 64)          36928     
                                                                 
 max_pooling2d_3 (MaxPooling  (None, 2, 2, 64)         0         
 2D)                                                             
                                                                 
 flatten (Flatten)           (None, 256)               0         
                                                                 
 dense (Dense)               (None, 128)               32896     
                                                                 
 dense_1 (Dense)             (None, 1)                 129       
                                                                 
=================================================================
Total params: 93,537
Trainable params: 93,537
Non-trainable params: 0
_________________________________________________________________
```

In [38]:

```
### CallBacks
count = 0

### Save the best model
saved_callbacks = tf.keras.callbacks.ModelCheckpoint('./saved_models/bestmodel
                                                     save_weights_only=False,

### Compile and Fit Model
model.compile(optimizer = tf.keras.optimizers.Adam(), loss = tf.keras.losses.B

history = model.fit(ds_train, validation_data = ds_val, epochs=12, verbose=2,
```

```
Epoch 1/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 1015s - loss: 0.4373 - accuracy: 0.8029 - val_loss: 0.5706 - val_ac
curacy: 0.7500 - 1015s/epoch - 3s/step
Epoch 2/12
326/326 - 86s - loss: 0.2020 - accuracy: 0.9191 - val_loss: 0.8160 - val_accu
racy: 0.6250 - 86s/epoch - 263ms/step
Epoch 3/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 88s - loss: 0.1723 - accuracy: 0.9369 - val_loss: 0.4881 - val_accu
racy: 0.8750 - 88s/epoch - 269ms/step
Epoch 4/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 89s - loss: 0.1452 - accuracy: 0.9429 - val_loss: 0.3954 - val_accu
racy: 0.8125 - 89s/epoch - 274ms/step
Epoch 5/12
326/326 - 86s - loss: 0.1386 - accuracy: 0.9440 - val_loss: 0.4305 - val_accu
racy: 0.8125 - 86s/epoch - 264ms/step
Epoch 6/12
326/326 - 88s - loss: 0.1180 - accuracy: 0.9572 - val_loss: 0.6775 - val_accu
racy: 0.6875 - 88s/epoch - 270ms/step
Epoch 7/12
326/326 - 88s - loss: 0.1259 - accuracy: 0.9519 - val_loss: 0.4522 - val_accu
racy: 0.7500 - 88s/epoch - 271ms/step
Epoch 8/12
326/326 - 89s - loss: 0.1132 - accuracy: 0.9578 - val_loss: 0.5081 - val_accu
racy: 0.6250 - 89s/epoch - 273ms/step
Epoch 9/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 89s - loss: 0.1025 - accuracy: 0.9611 - val_loss: 0.3894 - val_accu
racy: 0.8750 - 89s/epoch - 273ms/step
Epoch 10/12
326/326 - 87s - loss: 0.1160 - accuracy: 0.9559 - val_loss: 0.5935 - val_accu
racy: 0.6875 - 87s/epoch - 268ms/step
Epoch 11/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 89s - loss: 0.1115 - accuracy: 0.9590 - val_loss: 0.3646 - val_accu
racy: 0.8125 - 89s/epoch - 272ms/step
Epoch 12/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 88s - loss: 0.1022 - accuracy: 0.9615 - val_loss: 0.3255 - val_accu
racy: 0.9375 - 88s/epoch - 270ms/step
```

Evaluate the Model

In [39]:

```
model = tf.keras.models.load_model('./saved_models/bestmodel_'+str(count))
model.evaluate(ds_test)
```

```
39/39 [==============================] - 115s 3s/step - loss: 0.3108 - accura
cy: 0.8958
```

Out[39]:

```
[0.3108167052268982, 0.8958333134651184]
```

Confusion Matrix & Classification Report

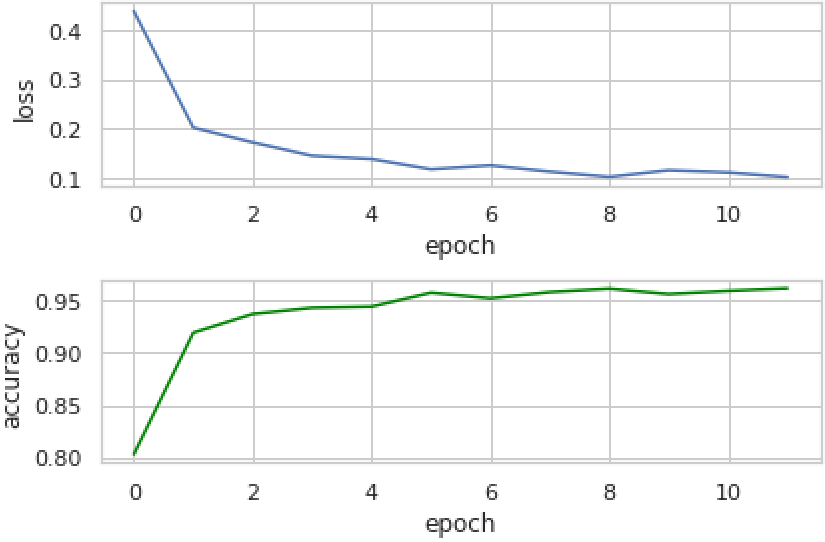
In [40]:

```
#Confusion Matrix and Classification Report
Y_pred = model.predict(ds_test, 39)
y_pred = np.argmax(Y_pred, axis=1)
print('Confusion Matrix')
print(confusion_matrix(ds_test.classes, y_pred))
print('Classification Report')
target_names = ['Normal', 'Pneumonia']
print(classification_report(ds_test.classes, y_pred, target_names=target_names
```

```
Confusion Matrix
[[234   0]
 [390   0]]
Classification Report
              precision    recall  f1-score   support

      Normal       0.38      1.00      0.55       234
   Pneumonia       0.00      0.00      0.00       390

    accuracy                           0.38       624
   macro avg       0.19      0.50      0.27       624
weighted avg       0.14      0.38      0.20       624


/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
```

Plotting Loss and Accuracy

```
In [41]: plt.subplot(2 ,1, 1)
         a = plt.plot(history.history['loss'])
         plt.ylabel('loss')
         plt.xlabel('epoch')

         plt.subplot(2, 1 ,2)
         b = plt.plot(history.history['accuracy'],color="green")
         plt.ylabel('accuracy')
         plt.xlabel('epoch')

         plt.tight_layout()
         plt.show()
```



Hyperparameter Tuning with SGD Optimizer - Model 2

In [42]:

```
model_2 = tf.keras.Sequential()

# Input layer
model_2.add(tf.keras.layers.Conv2D(filters=16, kernel_size=3, activation='relu
model_2.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 1
model_2.add(tf.keras.layers.Conv2D(filters=32, kernel_size=3, activation='relu
model_2.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 2
model_2.add(tf.keras.layers.Conv2D(filters=64, kernel_size=3, activation='relu
model_2.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 3
model_2.add(tf.keras.layers.Conv2D(filters=64, kernel_size=3, activation='relu
model_2.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 4 - Flattening
model_2.add(tf.keras.layers.Flatten())
model_2.add(tf.keras.layers.Dense(units=128, activation='relu'))

# Output Layer
model_2.add(tf.keras.layers.Dense(units=1, activation='sigmoid'))

# Print Model Summary
model_2.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_4 (Conv2D)           (None, 62, 62, 16)        448

 max_pooling2d_4 (MaxPooling  (None, 31, 31, 16)       0
 2D)

 conv2d_5 (Conv2D)           (None, 29, 29, 32)        4640

 max_pooling2d_5 (MaxPooling  (None, 14, 14, 32)       0
 2D)

 conv2d_6 (Conv2D)           (None, 12, 12, 64)        18496

 max_pooling2d_6 (MaxPooling  (None, 6, 6, 64)         0
 2D)

 conv2d_7 (Conv2D)           (None, 4, 4, 64)          36928

 max_pooling2d_7 (MaxPooling  (None, 2, 2, 64)         0
 2D)

 flatten_1 (Flatten)         (None, 256)               0

 dense_2 (Dense)             (None, 128)               32896

 dense_3 (Dense)             (None, 1)                 129

=================================================================
Total params: 93,537
Trainable params: 93,537
Non-trainable params: 0
_________________________________________________________________
```

In [43]:

```
### CallBacks
count = 0

### Save the best model
saved_callbacks = tf.keras.callbacks.ModelCheckpoint('./saved_models/bestmodel
                  save_weights_only=False, monitor='val_loss', save_best_only=

### Compile and Fit Model
model_2.compile(optimizer = tf.keras.optimizers.SGD(), loss = tf.keras.losses.

history_2 = model_2.fit(ds_train, validation_data = ds_val, epochs=12, verbose
```

```
Epoch 1/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 91s - loss: 0.5813 - accuracy: 0.7421 - val_loss: 0.7957 - val_accu
racy: 0.5000 - 91s/epoch - 280ms/step
Epoch 2/12
326/326 - 88s - loss: 0.5558 - accuracy: 0.7429 - val_loss: 0.7961 - val_accu
racy: 0.5000 - 88s/epoch - 270ms/step
Epoch 3/12
326/326 - 90s - loss: 0.5014 - accuracy: 0.7590 - val_loss: 0.8956 - val_accu
racy: 0.5625 - 90s/epoch - 276ms/step
Epoch 4/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 89s - loss: 0.4146 - accuracy: 0.8066 - val_loss: 0.5913 - val_accu
racy: 0.6875 - 89s/epoch - 274ms/step
Epoch 5/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 90s - loss: 0.3224 - accuracy: 0.8589 - val_loss: 0.4584 - val_accu
racy: 0.8125 - 90s/epoch - 276ms/step
Epoch 6/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 91s - loss: 0.2773 - accuracy: 0.8854 - val_loss: 0.3833 - val_accu
racy: 0.8125 - 91s/epoch - 279ms/step
Epoch 7/12
326/326 - 88s - loss: 0.2350 - accuracy: 0.9078 - val_loss: 0.4682 - val_accu
racy: 0.6875 - 88s/epoch - 271ms/step
Epoch 8/12
326/326 - 88s - loss: 0.2229 - accuracy: 0.9107 - val_loss: 0.5048 - val_accu
racy: 0.6250 - 88s/epoch - 271ms/step
Epoch 9/12
326/326 - 88s - loss: 0.2025 - accuracy: 0.9199 - val_loss: 0.5802 - val_accu
racy: 0.6875 - 88s/epoch - 270ms/step
Epoch 10/12
326/326 - 89s - loss: 0.1981 - accuracy: 0.9202 - val_loss: 0.3999 - val_accu
racy: 0.7500 - 89s/epoch - 272ms/step
Epoch 11/12
326/326 - 88s - loss: 0.1812 - accuracy: 0.9321 - val_loss: 0.5754 - val_accu
racy: 0.6875 - 88s/epoch - 270ms/step
Epoch 12/12
326/326 - 88s - loss: 0.1819 - accuracy: 0.9296 - val_loss: 0.8051 - val_accu
racy: 0.6875 - 88s/epoch - 269ms/step
```

In [44]:

```
model_2 = tf.keras.models.load_model('./saved_models/bestmodel_'+str(count))
model_2.evaluate(ds_test)
```

```
39/39 [==============================] - 8s 211ms/step - loss: 0.3778 - accur
acy: 0.8157
```

Out[44]:

```
[0.3778236210346222, 0.8157051205635071]
```

In [45]:

```
#Confusion Matrix and Classification Report
Y_pred_2 = model_2.predict_generator(ds_test, 40)
y_pred_2 = np.argmax(Y_pred_2, axis=1)
print('Confusion Matrix')
print(confusion_matrix(ds_test.classes, y_pred_2))
print('Classification Report')
target_names = ['Normal', 'Pneumonia']
print(classification_report(ds_test.classes, y_pred_2, target_names=target_nam
```

```
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:2: UserWarning:
`Model.predict_generator` is deprecated and will be removed in a future versi
on. Please use `Model.predict`, which supports generators.


WARNING:tensorflow:Your input ran out of data; interrupting training. Make su
re that your dataset or generator can generate at least `steps_per_epoch * ep
ochs` batches (in this case, 40 batches). You may need to use the repeat() fu
nction when building your dataset.
Confusion Matrix
[[234   0]
 [390   0]]
Classification Report
              precision    recall  f1-score   support

      Normal       0.38      1.00      0.55       234
   Pneumonia       0.00      0.00      0.00       390

    accuracy                           0.38       624
   macro avg       0.19      0.50      0.27       624
weighted avg       0.14      0.38      0.20       624


/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
```

Hyperparameter Tuning with Network Depth - Model 3

In [46]:

```
model_3 = tf.keras.Sequential()

# Input layer
model_3.add(tf.keras.layers.Conv2D(filters=16, kernel_size=3, activation='relu
model_3.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 1
model_3.add(tf.keras.layers.Conv2D(filters=32, kernel_size=3, activation='relu
model_3.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 2
model_3.add(tf.keras.layers.Conv2D(filters=64, kernel_size=3, activation='relu
model_3.add(tf.keras.layers.MaxPool2D(pool_size=2, strides=2))

# Hidden Layer 3 - Flattening
model_3.add(tf.keras.layers.Flatten())
model_3.add(tf.keras.layers.Dense(units=128, activation='relu'))

# Output Layer
model_3.add(tf.keras.layers.Dense(units=1, activation='sigmoid'))

# Print Model Summary
model_3.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_8 (Conv2D)           (None, 62, 62, 16)        448

 max_pooling2d_8 (MaxPooling  (None, 31, 31, 16)       0
 2D)

 conv2d_9 (Conv2D)           (None, 29, 29, 32)        4640

 max_pooling2d_9 (MaxPooling  (None, 14, 14, 32)       0
 2D)

 conv2d_10 (Conv2D)          (None, 12, 12, 64)        18496

 max_pooling2d_10 (MaxPoolin  (None, 6, 6, 64)         0
 g2D)

 flatten_2 (Flatten)         (None, 2304)              0

 dense_4 (Dense)             (None, 128)               295040

 dense_5 (Dense)             (None, 1)                 129

=================================================================
Total params: 318,753
Trainable params: 318,753
Non-trainable params: 0
_________________________________________________________________
```

In [47]:

```
### CallBacks
count = 0

### Save the best model
saved_callbacks = tf.keras.callbacks.ModelCheckpoint('./saved_models/bestmodel
                  save_weights_only=False, monitor='val_loss', save_best_only=

### Compile and Fit Model
model_3.compile(optimizer = tf.keras.optimizers.Adam(), loss = tf.keras.losses

history_3 = model_3.fit(ds_train, validation_data = ds_val, epochs=12, verbose
```

```
Epoch 1/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 91s - loss: 0.4191 - accuracy: 0.8129 - val_loss: 0.3850 - val_accu
racy: 0.8125 - 91s/epoch - 280ms/step
Epoch 2/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 88s - loss: 0.2493 - accuracy: 0.8984 - val_loss: 0.3273 - val_accu
racy: 0.8125 - 88s/epoch - 270ms/step
Epoch 3/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 88s - loss: 0.1883 - accuracy: 0.9287 - val_loss: 0.3138 - val_accu
racy: 0.8750 - 88s/epoch - 271ms/step
Epoch 4/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 88s - loss: 0.1780 - accuracy: 0.9302 - val_loss: 0.2996 - val_accu
racy: 0.9375 - 88s/epoch - 271ms/step
Epoch 5/12
326/326 - 89s - loss: 0.1569 - accuracy: 0.9396 - val_loss: 0.3946 - val_accu
racy: 0.8750 - 89s/epoch - 273ms/step
Epoch 6/12
326/326 - 88s - loss: 0.1425 - accuracy: 0.9484 - val_loss: 0.3055 - val_accu
racy: 0.9375 - 88s/epoch - 269ms/step
Epoch 7/12
326/326 - 88s - loss: 0.1343 - accuracy: 0.9473 - val_loss: 0.3967 - val_accu
racy: 0.8125 - 88s/epoch - 269ms/step
Epoch 8/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 91s - loss: 0.1349 - accuracy: 0.9479 - val_loss: 0.2722 - val_accu
racy: 0.8125 - 91s/epoch - 280ms/step
Epoch 9/12
326/326 - 89s - loss: 0.1247 - accuracy: 0.9503 - val_loss: 0.3647 - val_accu
racy: 0.8125 - 89s/epoch - 274ms/step
Epoch 10/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 91s - loss: 0.1099 - accuracy: 0.9551 - val_loss: 0.2673 - val_accu
racy: 0.8750 - 91s/epoch - 280ms/step
Epoch 11/12
INFO:tensorflow:Assets written to: ./saved_models/bestmodel_0/assets
326/326 - 90s - loss: 0.1291 - accuracy: 0.9519 - val_loss: 0.2562 - val_accu
racy: 0.9375 - 90s/epoch - 276ms/step
Epoch 12/12
326/326 - 90s - loss: 0.1182 - accuracy: 0.9549 - val_loss: 0.3900 - val_accu
racy: 0.8750 - 90s/epoch - 277ms/step
```

In [48]:

```
model_3 = tf.keras.models.load_model('./saved_models/bestmodel_'+str(count))
model_3.evaluate(ds_test)
```

```
39/39 [==============================] - 9s 217ms/step - loss: 0.4252 - accur
acy: 0.8670
```

Out[48]:

```
[0.4252314567565918, 0.8669871687889099]
```

In [50]:

```
#Confusion Matrix and Classification Report
Y_pred_3 = model_3.predict_generator(ds_test, 40)
y_pred_3 = np.argmax(Y_pred_3, axis=1)
print('Confusion Matrix')
print(confusion_matrix(ds_test.classes, y_pred_3))
print('Classification Report')
target_names = ['Normal', 'Pneumonia']
print(classification_report(ds_test.classes, y_pred_3, target_names=target_nam
```

```
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:2: UserWarning:
`Model.predict_generator` is deprecated and will be removed in a future versi
on. Please use `Model.predict`, which supports generators.


WARNING:tensorflow:Your input ran out of data; interrupting training. Make su
re that your dataset or generator can generate at least `steps_per_epoch * ep
ochs` batches (in this case, 40 batches). You may need to use the repeat() fu
nction when building your dataset.
Confusion Matrix
[[234   0]
 [390   0]]
Classification Report
              precision    recall  f1-score   support

      Normal       0.38      1.00      0.55       234
   Pneumonia       0.00      0.00      0.00       390

    accuracy                           0.38       624
   macro avg       0.19      0.50      0.27       624
weighted avg       0.14      0.38      0.20       624


/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
/usr/local/lib/python3.7/dist-packages/sklearn/metrics/_classification.py:131
8: UndefinedMetricWarning: Precision and F-score are ill-defined and being se
t to 0.0 in labels with no predicted samples. Use `zero_division` parameter t
o control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
```

Inferences and Comments

Explanations

- The results of the Adam optimizer are generally better than every other optimization algorithms, have faster computation time, and require fewer parameters for tuning. Because of all that, Adam is recommended as the default optimizer for most of the applications.

- The main model that used Adam optimizer and 4 hidden layers gave ~90% accuracy whereas the other 2 models gave a lower accuracy. The model that used SGD and 4 hidden layers gave ~82% accuracy. The model that used Adam optimizer and 3 hidden layers gave ~87% accuracy.