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Phase4 Project

X-Ray Diagnostics: Pediatric Pneumonia

This notebook will develop a model to classify pediatric chest x-rays with convolutional neural networks.

Importing Downloaded Data

Importing Necessary Python Libraries

In [1]:
```
import os, shutil
```

1. Splitting Original Directories into Train/Test/Validation Directories
2. Loading Directory Paths & Contents into Variables

In [2]:
```
# Loading Directory Paths into Variables
original_normal = 'ORIGINAL_DATA/NORMAL'
original_pneumonia = 'ORIGINAL_DATA/PNEUMONIA'

new_dir = 'data/'

train_folder = os.path.join(new_dir, 'train')
train_normal = os.path.join(train_folder, 'normal')
train_pneumonia = os.path.join(train_folder, 'pneumonia')

test_folder = os.path.join(new_dir, 'test')
test_normal = os.path.join(test_folder, 'normal')
test_pneumonia = os.path.join(test_folder, 'pneumonia')

val_folder = os.path.join(new_dir, 'validation')
val_normal = os.path.join(val_folder, 'normal')
val_pneumonia = os.path.join(val_folder, 'pneumonia')

# Creating Split Directories
os.mkdir(new_dir)

os.mkdir(test_folder)
os.mkdir(test_normal)
os.mkdir(test_pneumonia)

os.mkdir(train_folder)
os.mkdir(train_normal)
os.mkdir(train_pneumonia)

os.mkdir(val_folder)
os.mkdir(val_normal)
os.mkdir(val_pneumonia)
```

In [3]:
```
# Exploring Raw Source Data

# Number of Images in NORMAL Directory
imgs_normal = [file for file in os.listdir(
    original_normal) if file.endswith('.jpeg')]
print(len(imgs_normal), 'images in NORMAL directory')

# NUmber of Images in PNEUMONIA Directory
imgs_pneumonia = [file for file in os.listdir(
```

```
    original_pneumonia) if file.endswith('.jpeg')]
print(len(imgs_pneumonia), 'images in PNEUMONIA directory')
```

```
1583 images in NORMAL directory
4273 images in PNEUMONIA directory
```

In [4]:
```
# Copying Raw Data into Split Directories

# train normal
imgs = imgs_normal[:1200]
for img in imgs:
    origin = os.path.join(original_normal, img)
    destination = os.path.join(train_normal, img)
    shutil.copyfile(origin, destination)

# test normal
imgs = imgs_normal[1200:1383]
for img in imgs:
    origin = os.path.join(original_normal, img)
    destination = os.path.join(test_normal, img)
    shutil.copyfile(origin, destination)

# validation normal
imgs = imgs_normal[1383:]
for img in imgs:
    origin = os.path.join(original_normal, img)
    destination = os.path.join(val_normal, img)
    shutil.copyfile(origin, destination)

# train pneumonia
imgs = imgs_pneumonia[:3900]
for img in imgs:
    origin = os.path.join(original_pneumonia, img)
    destination = os.path.join(train_pneumonia, img)
    shutil.copyfile(origin, destination)

# test pneumonia
imgs = imgs_pneumonia[3900:4073]
for img in imgs:
    origin = os.path.join(original_pneumonia, img)
    destination = os.path.join(test_pneumonia, img)
    shutil.copyfile(origin, destination)

# validation pneumonia
imgs = imgs_pneumonia[4073:]
for img in imgs:
    origin = os.path.join(original_pneumonia, img)
    destination = os.path.join(val_pneumonia, img)
    shutil.copyfile(origin, destination)
```

In [5]:
```
## CELL INTENDED TO RE-ESTABLISH VARIABLES ##
## FROM DEAD/RESTARTED KERNELS ##

# Loading Directory Paths into Variables
train_folder = 'data/train'
train_normal = 'data/train/normal'
train_pneumonia = 'data/train/pneumonia'

test_folder = 'data/test'
test_normal = 'data/test/normal'
test_pneumonia = 'data/test/pneumonia'

val_folder = 'data/validation'
val_normal = 'data/validation/normal'
val_pneumonia = 'data/validation/pneumonia'
```

Verifying Data in Split Directories

In [6]:
```
# Number of Images in Each Directory

a1 = len(os.listdir(train_normal))
a2 = len(os.listdir(train_pneumonia))
a = a1 + a2
b1 = len(os.listdir(test_normal))
b2 = len(os.listdir(test_pneumonia))
b = b1 + b2
c1 = len(os.listdir(val_normal))
c2 = len(os.listdir(val_pneumonia))
c = c1 + c2

print(a, 'images in train directory')
print(b, 'images in test directory')
print(c, 'images in validation directory')
```

```
5100 images in train directory
356 images in test directory
400 images in validation directory
```

Preprocessing Data

Importing Necessary Python Libraries

In [7]:
```
import scipy
import numpy as np
from PIL import Image
from scipy import ndimage
from keras.preprocessing.image import (
    ImageDataGenerator, array_to_img,
    img_to_array, load_img)

np.random.seed(123)
```

Preprocess Part A

In [8]:
```
# flow_from_directory Variables
targetimagesize_ = (150, 150)
trainbatchsize_ = a
testbatchsize_ = b
valbatchsize_ = c

# Reshape Data in train Directory
train_generator = ImageDataGenerator(
    rescale=1./255).flow_from_directory(
    train_folder,
    target_size = targetimagesize_,
    batch_size = trainbatchsize_)

# Reshape Data in test Directory
test_generator = ImageDataGenerator(
    rescale=1./255).flow_from_directory(
    test_folder,
    target_size = targetimagesize_,
    batch_size = testbatchsize_)

# Reshape Data in validation Directory
val_generator = ImageDataGenerator(
    rescale=1./255).flow_from_directory(
    val_folder,
    target_size = targetimagesize_,
    batch_size = valbatchsize_)
```

```
Found 5100 images belonging to 2 classes.
Found 356 images belonging to 2 classes.
Found 400 images belonging to 2 classes.
```

In [9]:

```
# Load Dataset into Variables
train_images, train_labels = next(train_generator)
test_images, test_labels = next(test_generator)
val_images, val_labels = next(val_generator)
```

In [10]:

```
# Exploring Final Datasets
m_train = train_images.shape[0]
m_test = test_images.shape[0]
m_val = val_images.shape[0]

print ("Number of training samples: " + str(m_train))
print ("Number of testing samples: " + str(m_test))
print ("Number of validation samples: " + str(m_val))
print ("train_images shape: " + str(train_images.shape))
print ("train_labels shape: " + str(train_labels.shape))
print ("test_images shape: " + str(test_images.shape))
print ("test_labels shape: " + str(test_labels.shape))
print ("val_images shape: " + str(val_images.shape))
print ("val_labels shape: " + str(val_labels.shape))
```

```
Number of training samples: 5100
Number of testing samples: 356
Number of validation samples: 400
train_images shape: (5100, 150, 150, 3)
train_labels shape: (5100, 2)
test_images shape: (356, 150, 150, 3)
test_labels shape: (356, 2)
val_images shape: (400, 150, 150, 3)
val_labels shape: (400, 2)
```

Preprocess Part B

In [11]:

```
# Reshaping into 2-D Array

train_img = train_images.reshape(train_images.shape[0], -1)
test_img = test_images.reshape(test_images.shape[0], -1)
val_img = val_images.reshape(val_images.shape[0], -1)

print(train_img.shape)
print(test_img.shape)
print(val_img.shape)
```

```
(5100, 67500)
(356, 67500)
(400, 67500)
```

In [12]:

```
# Loading y Variables as 2-D Array

train_y = np.reshape(train_labels[:,0], (trainbatchsize_,1))
test_y = np.reshape(test_labels[:,0], (testbatchsize_,1))
val_y = np.reshape(val_labels[:,0], (valbatchsize_,1))

input_shape_ = train_img.shape[1]
```

Modeling

Importing Necessary Python Libraries

In [13]:

```
# Importing Python Libraries to Fit Models
from keras.models import Sequential
from keras.layers import (
```

```
    Conv2D, Dense, Flatten, MaxPooling2D)
from keras import optimizers

# Importing Python Libraries for Analysis
import datetime
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.metrics import (
    classification_report, roc_curve, auc,
    confusion_matrix)

%matplotlib inline
np.random.seed(123)
```

Baseline Model

In [14]:
```
# Building the Model

def Build_Baseline():
    model = Sequential()
    model.add(Dense(20, activation='relu',
                           input_shape=(input_shape_,)))
    model.add(Dense(7, activation='relu'))
    model.add(Dense(5, activation='relu'))
    model.add(Dense(1, activation='sigmoid'))

    # Compile model
    model.compile(optimizer='sgd',
                  loss='binary_crossentropy',
                  metrics=['acc'])
    return model
```

In [15]:
```
# Timer Start
start = datetime.datetime.now()
```

In [16]:
```
base = Build_Baseline()
basehist = base.fit(train_img,
                    train_y,
                    epochs=50,
                    batch_size=32,
                    validation_data=(val_img, val_y))
```

```
Epoch 1/50
160/160 [==============================] - 2s 11ms/step - loss: 0.4558 - acc: 0.7996 - val_loss:
0.5014 - val_acc: 0.7825
Epoch 2/50
160/160 [==============================] - 1s 9ms/step - loss: 0.3256 - acc: 0.8669 - val_loss: 1.
3702 - val_acc: 0.5200
Epoch 3/50
160/160 [==============================] - 1s 8ms/step - loss: 0.2586 - acc: 0.8941 - val_loss: 0.
2888 - val_acc: 0.8700
Epoch 4/50
160/160 [==============================] - 1s 8ms/step - loss: 0.2307 - acc: 0.9039 - val_loss: 0.
8482 - val_acc: 0.6125
Epoch 5/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1877 - acc: 0.9286 - val_loss: 0.
4494 - val_acc: 0.8100
Epoch 6/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1951 - acc: 0.9224 - val_loss: 0.
5184 - val_acc: 0.7875
Epoch 7/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1822 - acc: 0.9273 - val_loss: 0.
5070 - val_acc: 0.8000
Epoch 8/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1746 - acc: 0.9335 - val_loss: 0.
2193 - val_acc: 0.9025
```

```
Epoch 9/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1794 - acc: 0.9280 - val_loss: 0.
4827 - val_acc: 0.7850
Epoch 10/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1758 - acc: 0.9329 - val_loss: 0.
3105 - val_acc: 0.8750
Epoch 11/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1617 - acc: 0.9375 - val_loss: 0.
4740 - val_acc: 0.7925
Epoch 12/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1738 - acc: 0.9357 - val_loss: 0.
3565 - val_acc: 0.8500
Epoch 13/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1520 - acc: 0.9427 - val_loss: 0.
4667 - val_acc: 0.8000
Epoch 14/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1501 - acc: 0.9406 - val_loss: 0.
3021 - val_acc: 0.8775
Epoch 15/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1422 - acc: 0.9451 - val_loss: 0.
3877 - val_acc: 0.8475
Epoch 16/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1423 - acc: 0.9455 - val_loss: 0.
2056 - val_acc: 0.9125
Epoch 17/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1525 - acc: 0.9396 - val_loss: 0.
2109 - val_acc: 0.9075
Epoch 18/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1332 - acc: 0.9520 - val_loss: 0.
4235 - val_acc: 0.8200
Epoch 19/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1444 - acc: 0.9469 - val_loss: 0.
2334 - val_acc: 0.9075
Epoch 20/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1354 - acc: 0.9469 - val_loss: 0.
2266 - val_acc: 0.9050
Epoch 21/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1335 - acc: 0.9478 - val_loss: 0.
2035 - val_acc: 0.9300
Epoch 22/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1369 - acc: 0.9480 - val_loss: 0.
2167 - val_acc: 0.9150
Epoch 23/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1274 - acc: 0.9502 - val_loss: 0.
2256 - val_acc: 0.9125
Epoch 24/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1318 - acc: 0.9492 - val_loss: 0.
2837 - val_acc: 0.8850
Epoch 25/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1326 - acc: 0.9500 - val_loss: 0.
2191 - val_acc: 0.9025
Epoch 26/50
160/160 [==============================] - 1s 9ms/step - loss: 0.1297 - acc: 0.9504 - val_loss: 0.
2172 - val_acc: 0.9125
Epoch 27/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1255 - acc: 0.9514 - val_loss: 0.
2213 - val_acc: 0.9125
Epoch 28/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1239 - acc: 0.9551 - val_loss: 0.
2329 - val_acc: 0.8950
Epoch 29/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1253 - acc: 0.9522 - val_loss: 0.
2848 - val_acc: 0.8900
Epoch 30/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1234 - acc: 0.9522 - val_loss: 0.
2428 - val_acc: 0.9000
Epoch 31/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1237 - acc: 0.9529 - val_loss: 0.
5362 - val_acc: 0.7850
Epoch 32/50
```

```
160/160 [==============================] - 1s 8ms/step - loss: 0.1182 - acc: 0.9576 - val_loss: 0.
3199 - val_acc: 0.8875
Epoch 33/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1201 - acc: 0.9563 - val_loss: 0.
1935 - val_acc: 0.9325
Epoch 34/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1194 - acc: 0.9537 - val_loss: 0.
3693 - val_acc: 0.8375
Epoch 35/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1149 - acc: 0.9573 - val_loss: 0.
2020 - val_acc: 0.9200
Epoch 36/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1112 - acc: 0.9588 - val_loss: 0.
2087 - val_acc: 0.9200
Epoch 37/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1088 - acc: 0.9598 - val_loss: 0.
1816 - val_acc: 0.9300
Epoch 38/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1086 - acc: 0.9582 - val_loss: 0.
7579 - val_acc: 0.7475
Epoch 39/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1131 - acc: 0.9582 - val_loss: 0.
4557 - val_acc: 0.8125
Epoch 40/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1145 - acc: 0.9580 - val_loss: 0.
1809 - val_acc: 0.9325
Epoch 41/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1062 - acc: 0.9625 - val_loss: 0.
4450 - val_acc: 0.8275
Epoch 42/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1147 - acc: 0.9571 - val_loss: 0.
2581 - val_acc: 0.8925
Epoch 43/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1114 - acc: 0.9600 - val_loss: 0.
2369 - val_acc: 0.9125
Epoch 44/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1061 - acc: 0.9588 - val_loss: 0.
1993 - val_acc: 0.9200
Epoch 45/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1086 - acc: 0.9590 - val_loss: 0.
2287 - val_acc: 0.9025
Epoch 46/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1016 - acc: 0.9612 - val_loss: 0.
2337 - val_acc: 0.9025
Epoch 47/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1011 - acc: 0.9653 - val_loss: 0.
1786 - val_acc: 0.9350
Epoch 48/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1037 - acc: 0.9610 - val_loss: 0.
3447 - val_acc: 0.8575
Epoch 49/50
160/160 [==============================] - 1s 8ms/step - loss: 0.0976 - acc: 0.9643 - val_loss: 0.
1913 - val_acc: 0.9275
Epoch 50/50
160/160 [==============================] - 1s 8ms/step - loss: 0.1044 - acc: 0.9610 - val_loss: 0.
2143 - val_acc: 0.9100
```

In [17]:

```
# Timer End
end = datetime.datetime.now()
elapsed = end - start
print('Training Elapsed Time: {}'.format(elapsed))
```

```
Training Elapsed Time: 0:01:09.876972
```

Baseline Model Analysis

In [124…

```
# Loading Variables for Analysis

results_train = base.evaluate(train_img, train_y)
```

```python
results_test = base.evaluate(test_img, test_y)

pred_y = base.predict(test_img).ravel()

fpr_, tpr_, thresholds_ = roc_curve(test_y, pred_y)
auc_ = auc(fpr_, tpr_)
```

```
160/160 [==============================] - 1s 4ms/step - loss: 0.1165 - acc: 0.9537
12/12 [==============================] - 0s 2ms/step - loss: 0.2521 - acc: 0.9045
```

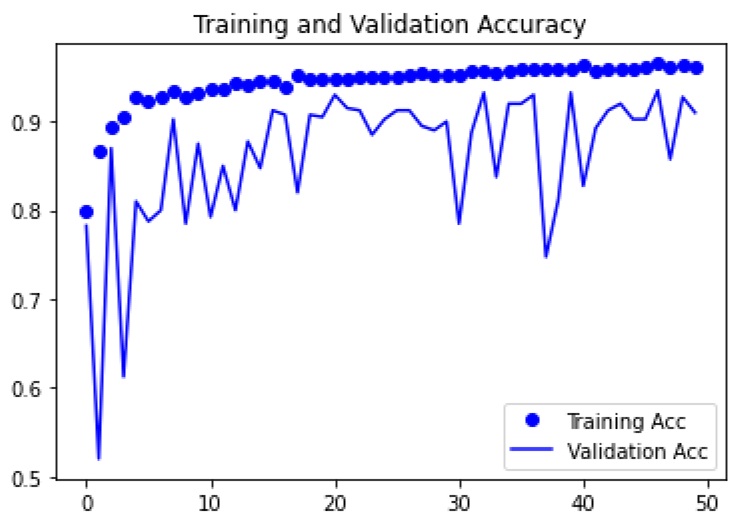
In [125…

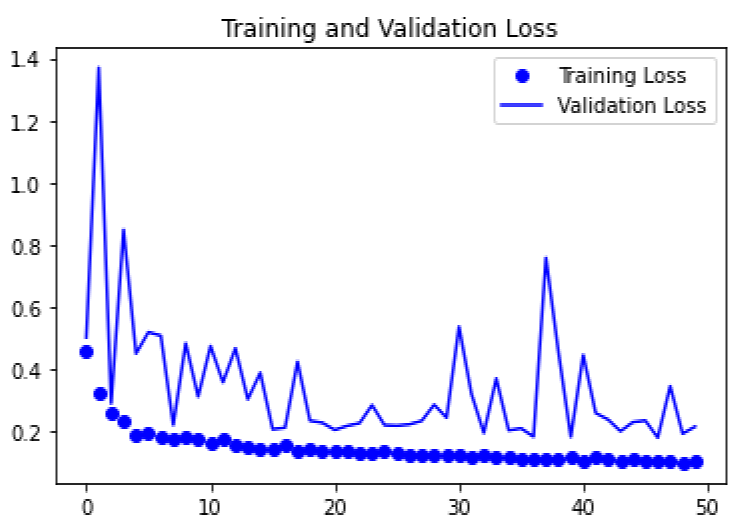
```python
# Evaluation Results
print ('Train Results:', results_train)
print ('Test Results:', results_test)
```

```
Train Results: [0.11654186993837357, 0.9537255167961121]
Test Results: [0.25213193893432617, 0.9044944047927856]
```

In [126…

```python
acc = basehist.history['acc']
val_acc = basehist.history['val_acc']
loss = basehist.history['loss']
val_loss = basehist.history['val_loss']
epochs = range(len(acc))
plt.plot(epochs, acc, 'bo', label='Training Acc')
plt.plot(epochs, val_acc, 'b', label='Validation Acc')
plt.title('Training and Validation Accuracy')
plt.legend()
plt.figure()
plt.plot(epochs, loss, 'bo', label='Training Loss')
plt.plot(epochs, val_loss, 'b', label='Validation Loss')
plt.title('Training and Validation Loss')
plt.legend()
plt.show()
```



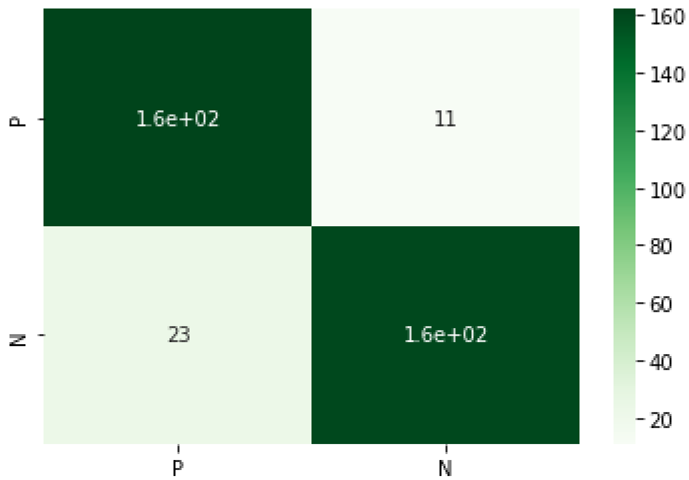


In [127…

```
pred_y = (base.predict(test_img).ravel() > 0.5).astype(int)
```

In [128…

```
# Confusion Matrix
cm = confusion_matrix(test_y, pred_y)
f = sns.heatmap(cm, annot=True, cmap='Greens',
                xticklabels='PN', yticklabels='PN')
plt.show()

# Classification Report
print(classification_report(test_y, pred_y))
```




```
              precision    recall  f1-score   support

         0.0       0.88      0.94      0.91       173
         1.0       0.94      0.87      0.90       183

    accuracy                           0.90       356
   macro avg       0.91      0.91      0.90       356
weighted avg       0.91      0.90      0.90       356
```

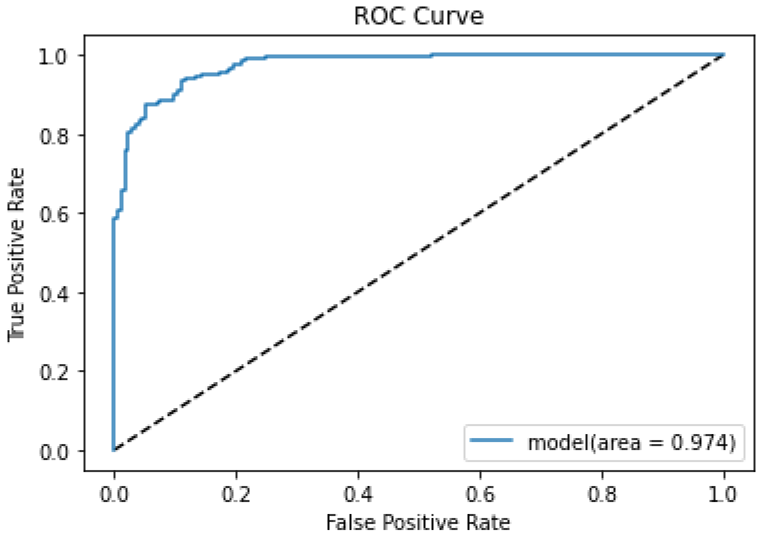
In [129…

```
print('False Normal Rate:', (11/b2)*100)
```

```
False Normal Rate: 6.358381502890173
```

In [130…

```
plt.figure(1)
plt.plot([0, 1], [0, 1], 'k--')
plt.plot(fpr_, tpr_,
         label='model(area = {:.3f})'.format(auc_))
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('ROC Curve')
plt.legend(loc='best')
plt.show()
```

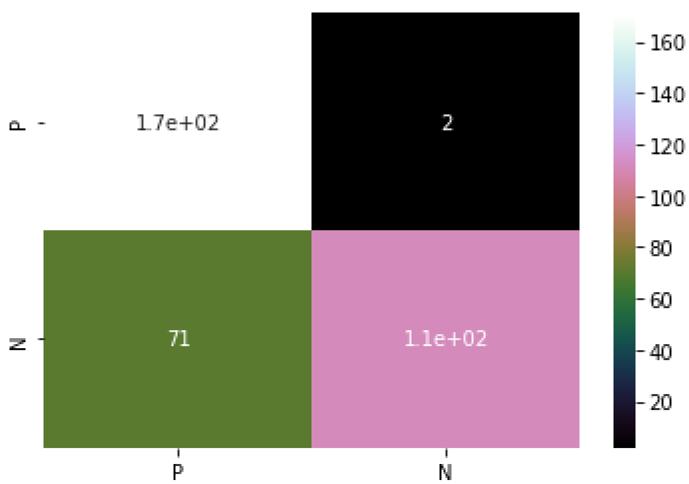


In [131…
```
auc_
```

Out[131… 0.9736567800625414

In [134…
```
pred_y = (base.predict(test_img).ravel() > 0.95).astype(int)
```

In [135…
```
# Confusion Matrix
cm = confusion_matrix(test_y, pred_y)
f = sns.heatmap(cm, annot=True, cmap='cubehelix',
                xticklabels='PN', yticklabels='PN')
plt.show()

# Classification Report
print(classification_report(test_y, pred_y))
```




```
              precision    recall  f1-score   support

         0.0       0.71      0.99      0.82       173
         1.0       0.98      0.61      0.75       183

    accuracy                           0.79       356
   macro avg       0.84      0.80      0.79       356
weighted avg       0.85      0.79      0.79       356
```

In [136…
```
print('False Normal Rate:', (2/b2)*100)
```

False Normal Rate: 1.1560693641618496

In [59]:
```
base.save('XRAY_Baseline_Model.h5')
```

CNN Model

In [26]:
```
# Building the Model

def Build_CNN():
    model = Sequential()

    model.add(Conv2D(32, (3, 3), activation='relu',
                     input_shape=(150 ,150,  3)))
    model.add(MaxPooling2D((2, 2)))
    model.add(Conv2D(32, (4, 4), activation='relu'))
    model.add(MaxPooling2D((2, 2)))
    model.add(Conv2D(64, (3, 3), activation='relu'))
    model.add(MaxPooling2D((2, 2)))

    model.add(Flatten())
    model.add(Dense(64, activation='relu'))
    model.add(Dense(1, activation='sigmoid'))

    # Compile model
    model.compile(optimizer='sgd',
                  loss='binary_crossentropy',
                  metrics=['acc'])
    return model
```

In [27]:
```
# Timer Start
start = datetime.datetime.now()
```

In [29]:
```
cnn = Build_CNN()
history = cnn.fit(train_images,
                    train_y,
                    epochs=50,
                    batch_size=32,
                    validation_data=(val_images, val_y))
```

```
Epoch 1/50
160/160 [==============================] - 73s 458ms/step - loss: 0.5162 - acc: 0.7727 - val_loss:
0.5916 - val_acc: 0.6425
Epoch 2/50
160/160 [==============================] - 74s 460ms/step - loss: 0.3747 - acc: 0.8406 - val_loss:
0.3607 - val_acc: 0.8500
Epoch 3/50
160/160 [==============================] - 74s 461ms/step - loss: 0.2678 - acc: 0.8957 - val_loss:
0.3012 - val_acc: 0.8650
Epoch 4/50
160/160 [==============================] - 74s 463ms/step - loss: 0.2082 - acc: 0.9196 - val_loss:
0.2674 - val_acc: 0.8825
Epoch 5/50
160/160 [==============================] - 74s 461ms/step - loss: 0.1899 - acc: 0.9259 - val_loss:
0.7132 - val_acc: 0.6750
Epoch 6/50
160/160 [==============================] - 75s 470ms/step - loss: 0.1676 - acc: 0.9357 - val_loss:
0.2129 - val_acc: 0.9150
Epoch 7/50
160/160 [==============================] - 74s 460ms/step - loss: 0.1559 - acc: 0.9443 - val_loss:
0.1949 - val_acc: 0.9175
Epoch 8/50
160/160 [==============================] - 74s 461ms/step - loss: 0.1457 - acc: 0.9461 - val_loss:
0.3333 - val_acc: 0.8625
Epoch 9/50
160/160 [==============================] - 72s 453ms/step - loss: 0.1410 - acc: 0.9484 - val_loss:
0.1715 - val_acc: 0.9325
Epoch 10/50
160/160 [==============================] - 80s 497ms/step - loss: 0.1327 - acc: 0.9522 - val_loss:
0.1695 - val_acc: 0.9450
Epoch 11/50
160/160 [==============================] - 74s 461ms/step - loss: 0.1261 - acc: 0.9531 - val_loss:
```

```
0.1835 - val_acc: 0.9250
Epoch 12/50
160/160 [==============================] - 74s 463ms/step - loss: 0.1187 - acc: 0.9567 - val_loss:
0.2253 - val_acc: 0.9175
Epoch 13/50
160/160 [==============================] - 76s 474ms/step - loss: 0.1135 - acc: 0.9584 - val_loss:
0.1566 - val_acc: 0.9375
Epoch 14/50
160/160 [==============================] - 74s 461ms/step - loss: 0.1089 - acc: 0.9608 - val_loss:
0.2095 - val_acc: 0.9175
Epoch 15/50
160/160 [==============================] - 71s 446ms/step - loss: 0.1048 - acc: 0.9602 - val_loss:
0.1643 - val_acc: 0.9450
Epoch 16/50
160/160 [==============================] - 65s 408ms/step - loss: 0.0979 - acc: 0.9629 - val_loss:
0.2025 - val_acc: 0.9225
Epoch 17/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0998 - acc: 0.9641 - val_loss:
0.1763 - val_acc: 0.9425
Epoch 18/50
160/160 [==============================] - 65s 407ms/step - loss: 0.0932 - acc: 0.9651 - val_loss:
0.1336 - val_acc: 0.9525
Epoch 19/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0901 - acc: 0.9667 - val_loss:
0.1328 - val_acc: 0.9625
Epoch 20/50
160/160 [==============================] - 65s 406ms/step - loss: 0.0888 - acc: 0.9667 - val_loss:
0.1662 - val_acc: 0.9400
Epoch 21/50
160/160 [==============================] - 65s 404ms/step - loss: 0.0851 - acc: 0.9676 - val_loss:
0.1287 - val_acc: 0.9600
Epoch 22/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0830 - acc: 0.9682 - val_loss:
0.1561 - val_acc: 0.9550
Epoch 23/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0755 - acc: 0.9716 - val_loss:
0.1499 - val_acc: 0.9475
Epoch 24/50
160/160 [==============================] - 65s 404ms/step - loss: 0.0771 - acc: 0.9727 - val_loss:
0.1307 - val_acc: 0.9625
Epoch 25/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0729 - acc: 0.9731 - val_loss:
0.1397 - val_acc: 0.9550
Epoch 26/50
160/160 [==============================] - 65s 407ms/step - loss: 0.0702 - acc: 0.9741 - val_loss:
0.1732 - val_acc: 0.9350
Epoch 27/50
160/160 [==============================] - 65s 404ms/step - loss: 0.0676 - acc: 0.9751 - val_loss:
0.1148 - val_acc: 0.9625
Epoch 28/50
160/160 [==============================] - 65s 408ms/step - loss: 0.0647 - acc: 0.9755 - val_loss:
0.2118 - val_acc: 0.9200
Epoch 29/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0646 - acc: 0.9765 - val_loss:
0.1289 - val_acc: 0.9550
Epoch 30/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0633 - acc: 0.9739 - val_loss:
0.1178 - val_acc: 0.9700
Epoch 31/50
160/160 [==============================] - 65s 406ms/step - loss: 0.0566 - acc: 0.9796 - val_loss:
0.1282 - val_acc: 0.9575
Epoch 32/50
160/160 [==============================] - 66s 410ms/step - loss: 0.0558 - acc: 0.9806 - val_loss:
0.1449 - val_acc: 0.9600
Epoch 33/50
160/160 [==============================] - 65s 405ms/step - loss: 0.0520 - acc: 0.9814 - val_loss:
0.1240 - val_acc: 0.9650
Epoch 34/50
160/160 [==============================] - 65s 406ms/step - loss: 0.0531 - acc: 0.9802 - val_loss:
0.3962 - val_acc: 0.8800
```

```
Epoch 35/50
160/160 [==============================] - 72s 451ms/step - loss: 0.0531 - acc: 0.9820 - val_loss:
0.1303 - val_acc: 0.9575
Epoch 36/50
160/160 [==============================] - 1269s 8s/step - loss: 0.0469 - acc: 0.9837 - val_loss:
0.1437 - val_acc: 0.9550
Epoch 37/50
160/160 [==============================] - 60s 375ms/step - loss: 0.0503 - acc: 0.9818 - val_loss:
0.1247 - val_acc: 0.9550
Epoch 38/50
160/160 [==============================] - 59s 366ms/step - loss: 0.0441 - acc: 0.9837 - val_loss:
0.1289 - val_acc: 0.9550
Epoch 39/50
160/160 [==============================] - 58s 364ms/step - loss: 0.0469 - acc: 0.9827 - val_loss:
0.1221 - val_acc: 0.9575
Epoch 40/50
160/160 [==============================] - 59s 369ms/step - loss: 0.0425 - acc: 0.9863 - val_loss:
0.2873 - val_acc: 0.9000
Epoch 41/50
160/160 [==============================] - 62s 385ms/step - loss: 0.0404 - acc: 0.9857 - val_loss:
0.1403 - val_acc: 0.9475
Epoch 42/50
160/160 [==============================] - 61s 383ms/step - loss: 0.0398 - acc: 0.9857 - val_loss:
0.1375 - val_acc: 0.9575
Epoch 43/50
160/160 [==============================] - 59s 372ms/step - loss: 0.0384 - acc: 0.9855 - val_loss:
0.1390 - val_acc: 0.9550
Epoch 44/50
160/160 [==============================] - 63s 392ms/step - loss: 0.0353 - acc: 0.9884 - val_loss:
0.1328 - val_acc: 0.9625
Epoch 45/50
160/160 [==============================] - 66s 413ms/step - loss: 0.0392 - acc: 0.9863 - val_loss:
0.1209 - val_acc: 0.9600
Epoch 46/50
160/160 [==============================] - 65s 406ms/step - loss: 0.0323 - acc: 0.9900 - val_loss:
0.1782 - val_acc: 0.9500
Epoch 47/50
160/160 [==============================] - 66s 410ms/step - loss: 0.0421 - acc: 0.9849 - val_loss:
0.2284 - val_acc: 0.9350
Epoch 48/50
160/160 [==============================] - 67s 417ms/step - loss: 0.0304 - acc: 0.9888 - val_loss:
0.1670 - val_acc: 0.9550
Epoch 49/50
160/160 [==============================] - 66s 413ms/step - loss: 0.0295 - acc: 0.9890 - val_loss:
0.1363 - val_acc: 0.9650
Epoch 50/50
160/160 [==============================] - 66s 413ms/step - loss: 0.0254 - acc: 0.9910 - val_loss:
0.1306 - val_acc: 0.9575
```

In [30]:

```
# Timer End
end = datetime.datetime.now()
elapsed = end - start
print('Training Elapsed Time: {}'.format(elapsed))
```

```
Training Elapsed Time: 1:26:36.105971
```

CNN Model Analysis

In [137…

```
# Loading Variables for Analysis

results_train = cnn.evaluate(train_images, train_y)
results_test = cnn.evaluate(test_images, test_y)

pred_y = cnn.predict(test_images).ravel()

fpr_, tpr_, thresholds_ = roc_curve(test_y, pred_y)
auc_ = auc(fpr_, tpr_)
```

```
160/160 [==============================] - 10s 65ms/step - loss: 0.0190 - acc: 0.9951
```

```
12/12 [==============================] - 1s 54ms/step - loss: 0.1540 - acc: 0.9466
```

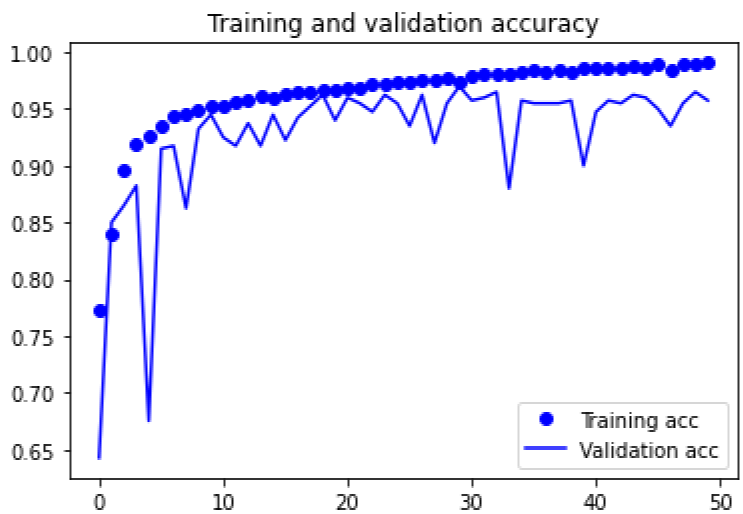
In [138…

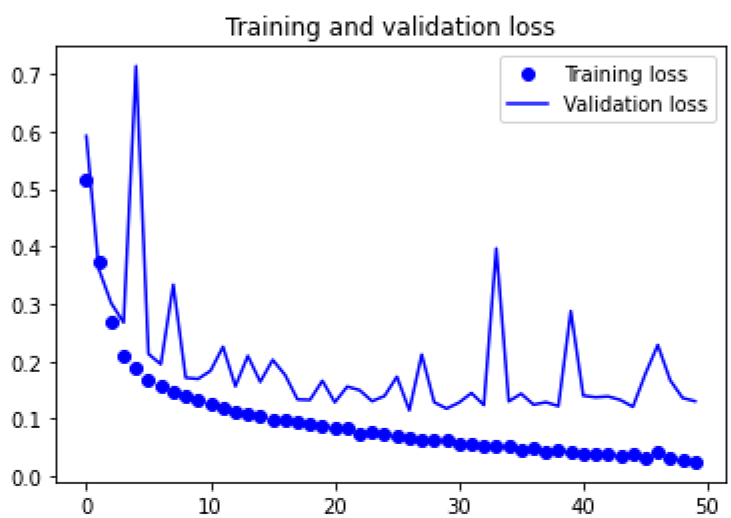
```python
# Results
print ('Train Results:', results_train)
print ('Test Results:', results_test)
```

```
Train Results: [0.019027573987841606, 0.9950980544090271]
Test Results: [0.1540239155292511, 0.9466292262077332]
```

In [139…

```python
acc = history.history['acc']
val_acc = history.history['val_acc']
loss = history.history['loss']
val_loss = history.history['val_loss']
epochs = range(len(acc))
plt.plot(epochs, acc, 'bo', label='Training acc')
plt.plot(epochs, val_acc, 'b', label='Validation acc')
plt.title('Training and validation accuracy')
plt.legend()
plt.figure()
plt.plot(epochs, loss, 'bo', label='Training loss')
plt.plot(epochs, val_loss, 'b', label='Validation loss')
plt.title('Training and validation loss')
plt.legend()
plt.show()
```





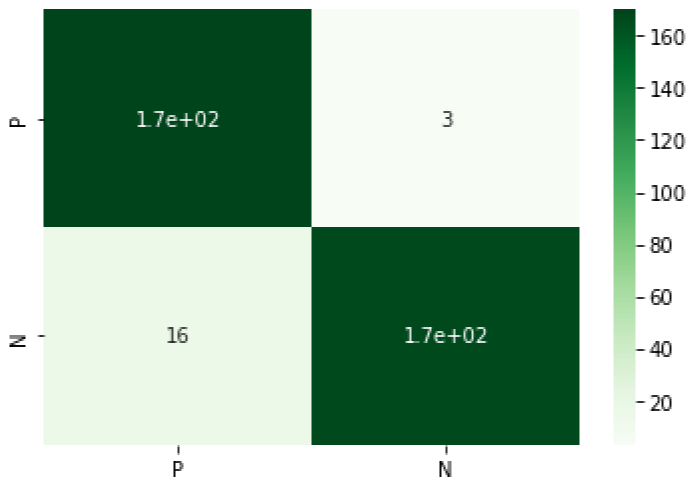
In [140…

```python
pred_y = (cnn.predict(test_images).ravel() > 0.5).astype(int)
```

In [141…

```python
# Confusion Matrix
cm = confusion_matrix(test_y, pred_y)
f = sns.heatmap(cm, annot=True, cmap='Greens',
                xticklabels='PN', yticklabels='PN')
```

```
plt.show()

# Classification Report
print(classification_report(test_y, pred_y))
```




```
              precision    recall  f1-score   support

         0.0       0.91      0.98      0.95       173
         1.0       0.98      0.91      0.95       183

    accuracy                           0.95       356
   macro avg       0.95      0.95      0.95       356
weighted avg       0.95      0.95      0.95       356
```

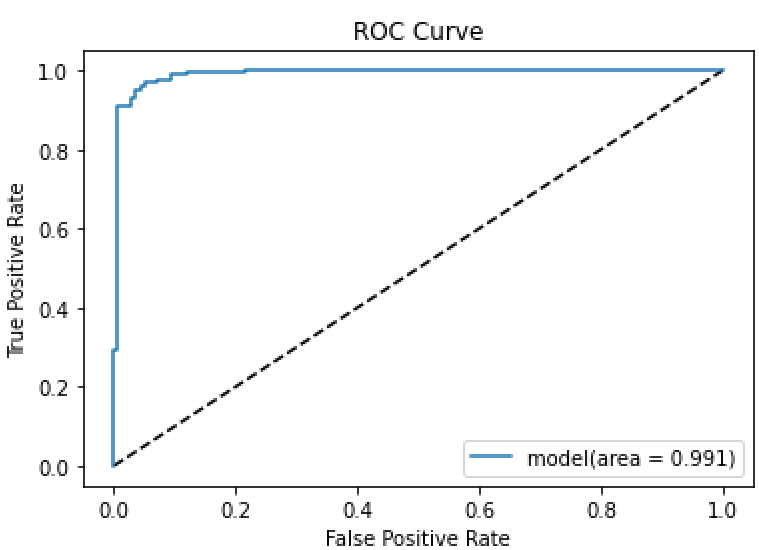
In [142…

```
print('False Normal Rate:', (3/b2)*100)
```

```
False Normal Rate: 1.7341040462427744
```

In [143…

```
plt.figure(1)
plt.plot([0, 1], [0, 1], 'k--')
plt.plot(fpr_, tpr_,
         label='model(area = {:.3f})'.format(auc_))
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('ROC Curve')
plt.legend(loc='best')
plt.show()
```



In [144…

```
auc_
```

Out[144…

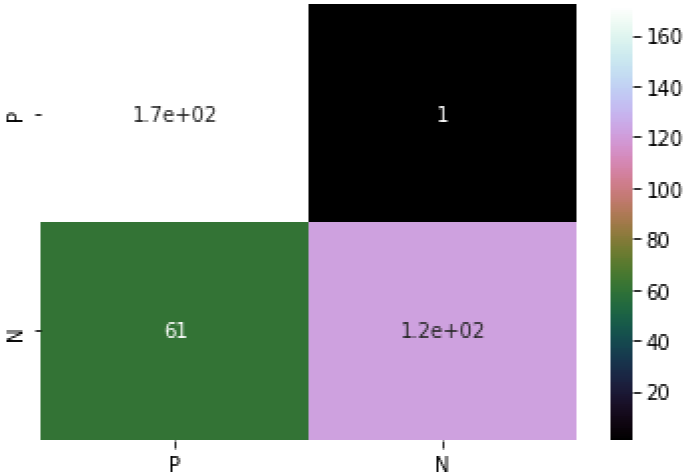
```
0.9909030607410215
```

In [145...

```
pred_y = (cnn.predict(test_images).ravel() > auc_).astype(int)
```

In [146...

```
# Confusion Matrix
cm = confusion_matrix(test_y, pred_y)
f = sns.heatmap(cm, annot=True, cmap='cubehelix',
                xticklabels='PN', yticklabels='PN')
plt.show()

# Classification Report
print(classification_report(test_y, pred_y))
```




```
              precision    recall  f1-score   support

         0.0       0.74      0.99      0.85       173
         1.0       0.99      0.67      0.80       183

    accuracy                           0.83       356
   macro avg       0.87      0.83      0.82       356
weighted avg       0.87      0.83      0.82       356
```

In [147...

```
print('False Normal Rate:', (1/b2)*100)
```

```
False Normal Rate: 0.5780346820809248
```

In [58]:

```
cnn.save('XRAY_CNN_Model.h5')
```

Image Classification Process (CNN)

Importing Necessary Libraries

In [60]:

```
from keras.models import load_model
from keras.preprocessing import image
from keras import models
import math
import numpy as np
import matplotlib.image as mpimg
import matplotlib.pyplot as plt
%matplotlib inline
```

Open/Load a Model

In [148...

```
model = load_model('XRAY_CNN_Model.h5')
model.summary()
```

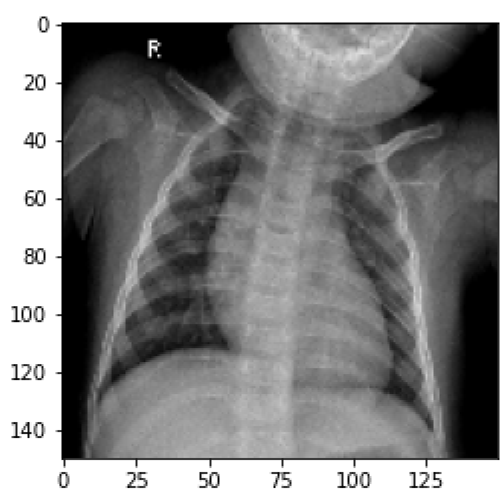
```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_3 (Conv2D)            (None, 148, 148, 32)      896
```

```
max_pooling2d_3 (MaxPooling2 (None, 74, 74, 32)         0
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 71, 71, 32)         16416
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 35, 35, 32)         0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 33, 33, 64)         18496
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 16, 16, 64)         0
_________________________________________________________________
flatten_1 (Flatten)          (None, 16384)              0
_________________________________________________________________
dense_6 (Dense)              (None, 64)                 1048640
_________________________________________________________________
dense_7 (Dense)              (None, 1)                  65
=================================================================
Total params: 1,084,513
Trainable params: 1,084,513
Non-trainable params: 0
_________________________________________________________________
```

Open/Load Sample Test Image

In [149…

```python
filename = 'data/test/normal/NORMAL-7725506-0001.jpeg'
img = image.load_img(filename, target_size=(150, 150))
plt.imshow(img)
plt.show()
```

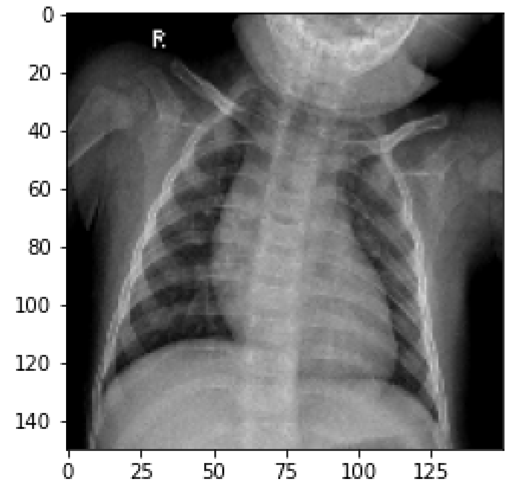


View Image as Tensor

In [150…

```python
img_tensor = image.img_to_array(img)
img_tensor = np.expand_dims(img_tensor, axis=0)

# Follow the Original Model Preprocessing
img_tensor /= 255.

# Check tensor shape
print(img_tensor.shape)

# Preview an image
plt.imshow(img_tensor[0])
plt.show()
```

```
(1, 150, 150, 3)
```



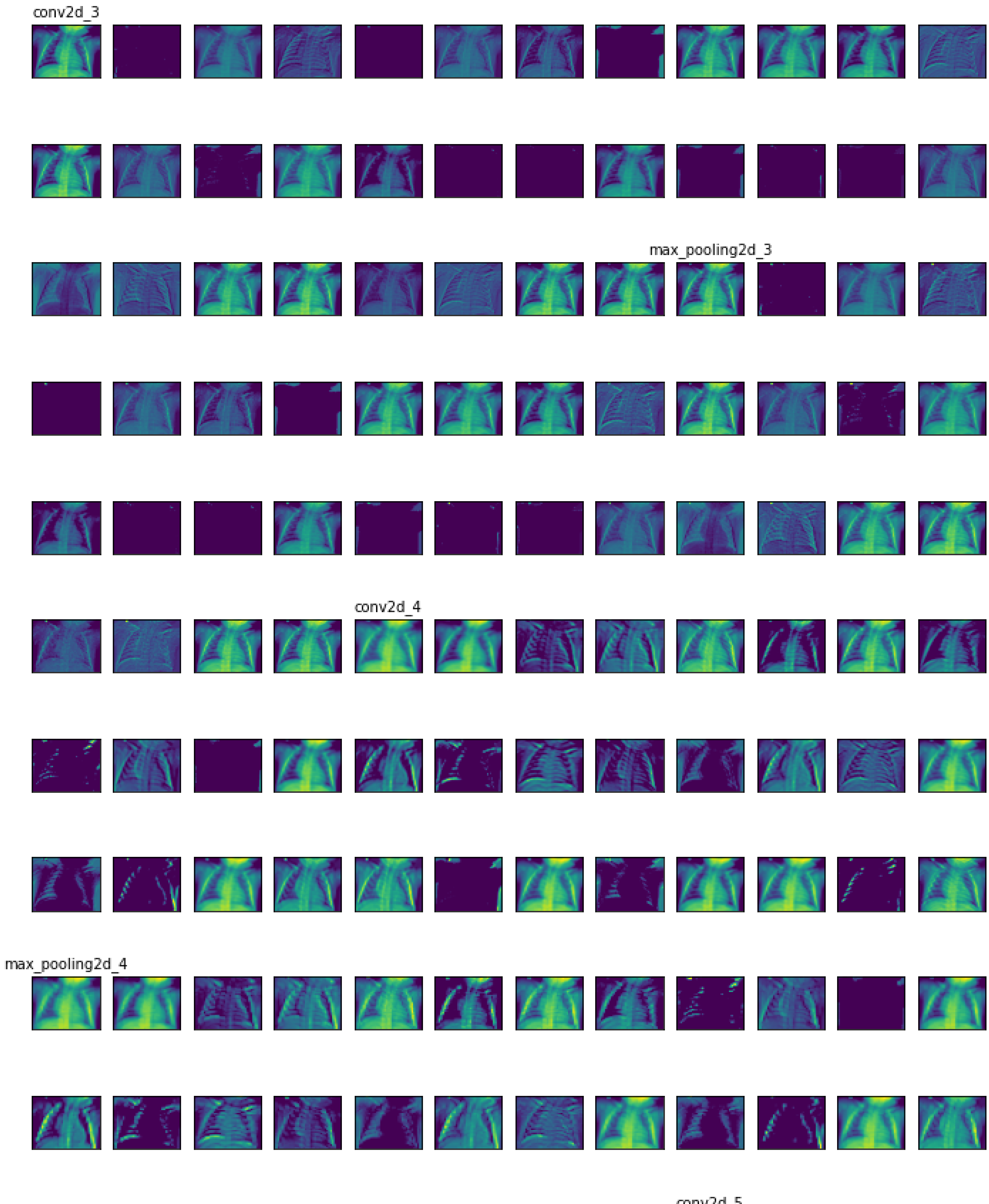
Visualization of Activation Layers

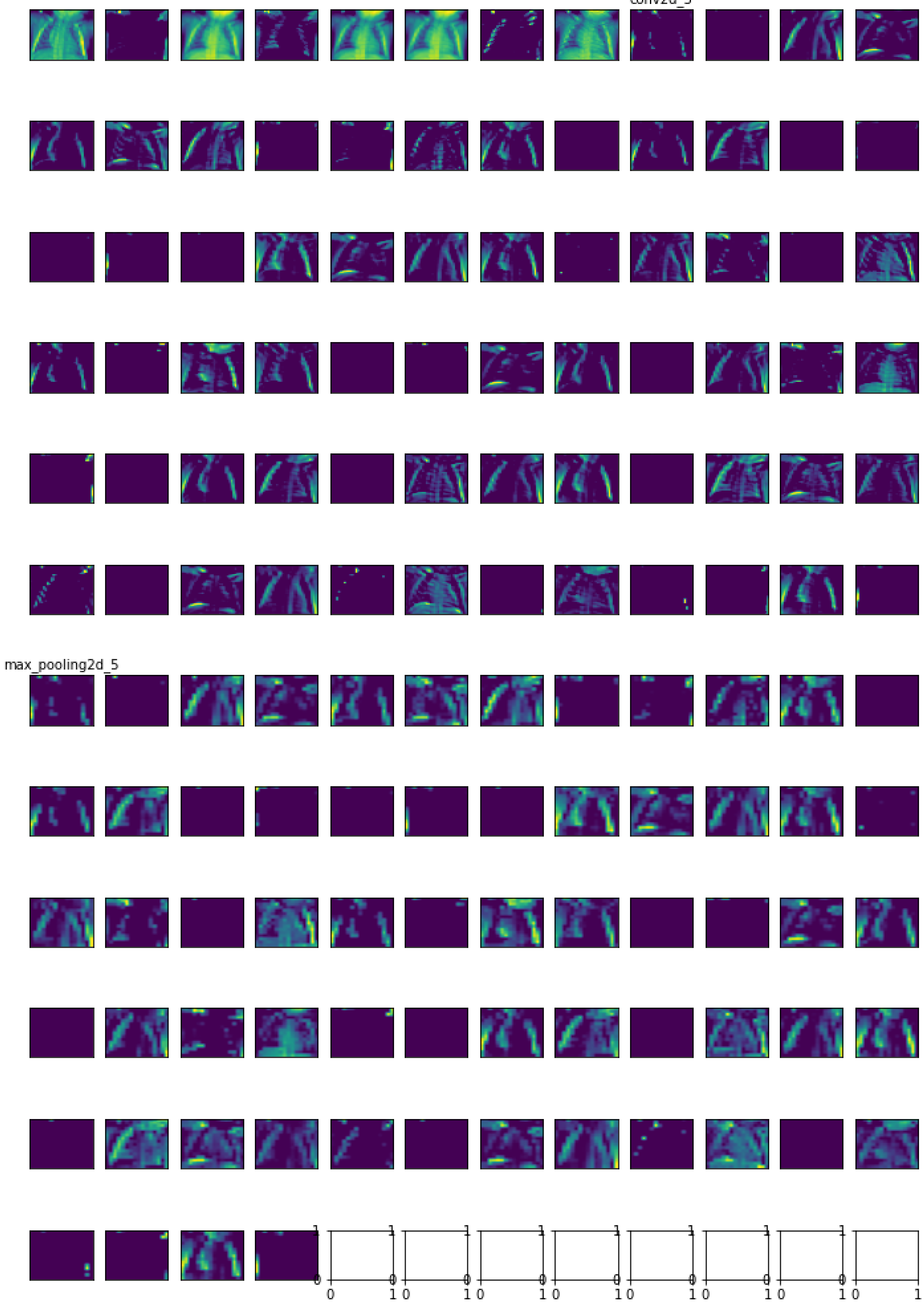
In [151…

```
# Extract model layer outputs
layer_outputs = [
    layer.output for layer in model.layers[:6]]

# Create a model for displaying the feature maps
activation_model = models.Model(
    inputs=model.input, outputs=layer_outputs)

activations = activation_model.predict(img_tensor)

# Extract Layer Names for Labelling
layer_names = []
for layer in model.layers[:6]:
    layer_names.append(layer.name)

total_features = sum([a.shape[-1] for a in activations])
total_features

n_cols = 12
n_rows = math.ceil(total_features / n_cols)


iteration = 0
fig , axes = plt.subplots(nrows=n_rows, ncols=n_cols,
                          figsize=(n_cols, n_rows*1.5))

for layer_n, layer_activation in enumerate(activations):
    n_channels = layer_activation.shape[-1]
    for ch_idx in range(n_channels):
        row = iteration // n_cols
        column = iteration % n_cols

        ax = axes[row, column]

        channel_image = layer_activation[0,
                                         :, :,
                                         ch_idx]

        channel_image -= channel_image.mean()
        channel_image /= channel_image.std()
        channel_image *= 32
        channel_image += 64
        channel_image = np.clip(
            channel_image, 0, 255).astype('uint8')

        ax.imshow(channel_image, aspect='auto',
                  cmap='viridis')
```

```
        ax.get_xaxis().set_ticks([])
        ax.get_yaxis().set_ticks([])

        if ch_idx == 0:
            ax.set_title(layer_names[layer_n], fontsize=10)
        iteration += 1

fig.subplots_adjust(hspace=1.25)
plt.savefig('Intermediate_Activations_Visualized.pdf')
plt.show()
```

```
<ipython-input-151-2441043dfcd8>:40: RuntimeWarning: invalid value encountered in true_divide
  channel_image /= channel_image.std()
```




conv2d_5
max_pooling2d_5