Plant_Health_Model

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1 Visual Deep Learning: Plant Health Model

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This notebook describes the creation of a model to evaluate the health of plants. The model was trained with leaves from an apple tree. With this, an application should be able to identify if a tree is unhealthy, by providing a image form a leave of the tree.

The idea to create this model is based on a project that was started last semester. The project GreenThumb is a plant health tracking app, that allows the user to keep track of the health of a plant. With the addition of a trained ai model, the application could be improved a lot in its functionality.

All the steps for the creation of this model are described point by point in this notebook.

1.0.2 Steps to create this Machine Learning Model:

1. Setup
2. Load image data and apply data augmentation
3. Define model
4. Display model structure
5. Training model
6. Write history and plot graphs
7. Evaluate Model
8. Predict with model and display ROC
9. Save trained model
10. Load trained model
11. Test trained model

1.0.3 Experiments:

The notebook tries different experiments for the creation of the best model. As such, steps 3 - 8 are repeated three times with different models.

1.0.4 1. Setup

[1]:
```
import numpy as np
import tensorflow as tf
from tensorflow.keras import metrics
from sklearn import metrics as skmetrics

from sklearn.metrics import confusion_matrix, accuracy_score

import matplotlib.pyplot as plt
from tensorflow.keras.preprocessing import image
from tensorflow.keras.preprocessing.image import ImageDataGenerator
```

[2]:
```
#Environment Variables
EPOCHS = 50
BATCH_SIZE = 32
IMG_SIZE = (256, 256)
LEARNING_RATE = 0.001
MODEL_NAME = 'plant_health_model.h5'

#Folder for the data
train_data_dir = './plant_images/train'
valid_data_dir = './plant_images/valid'
test_data_dir = './plant_images/test'

#Different Metrics that get printed in the history
METRICS = [
      metrics.TruePositives(name='tp'),
      metrics.FalsePositives(name='fp'),
      metrics.TrueNegatives(name='tn'),
      metrics.FalseNegatives(name='fn'),
      metrics.CategoricalAccuracy(name='accuracy'),
      metrics.Precision(name='precision'),
      metrics.AUC(name='auc'),
      metrics.MeanAbsoluteError(name='mae'),
      metrics.MeanSquaredError(name='mse')
]
```

1.0.5 2. Load Image Data and apply data augmentation and preprocessing

The structure of the folder is the following: -root –plant_images —train —-Apple_healthy —-Apple_unhealthy —valid —-Apple_healthy —-Apple_unhealthy —test —-Apple_healthy —-Apple_unhealthy

The train folder includes around 1400 images for the training. The valid folder includes around 700 images to validate the trained model. The test folder includes again around 120 images to test the model.

Augmentation: For the augmentation a ImageDataGenerator is used. With this the images for the training and validation are rescaled, sheared, rotated, flipped and zoomed. The test images are only rescaled.

[3]:
```
#Create augmented training data
train_datagen = ImageDataGenerator(rescale=(1. / 255),
                                   shear_range=0.1,
                                   zoom_range=0.1,
                                   rotation_range=10,
                                   horizontal_flip=True,
                                   fill_mode='constant',
                                   validation_split=0.2,
                                   cval=0)

#Create augmented training data
train_dataset = train_datagen.flow_from_directory(train_data_dir,
                                                  target_size=IMG_SIZE,
                                                  batch_size=BATCH_SIZE,
                                                  class_mode='categorical',
                                                  subset='training')

#Create augmented validation data
validation_dataset = train_datagen.flow_from_directory(valid_data_dir,
                                                  target_size=IMG_SIZE,
                                                  batch_size=BATCH_SIZE,
                                                  class_mode='categorical',
                                                  subset='validation')

test_datagen = ImageDataGenerator(rescale=(1. / 255))

#Create test data
test_dataset = test_datagen.flow_from_directory(test_data_dir,
                                                  target_size=IMG_SIZE,
                                                  batch_size=1,
                                                  shuffle=False,
                                                  class_mode='categorical')
```

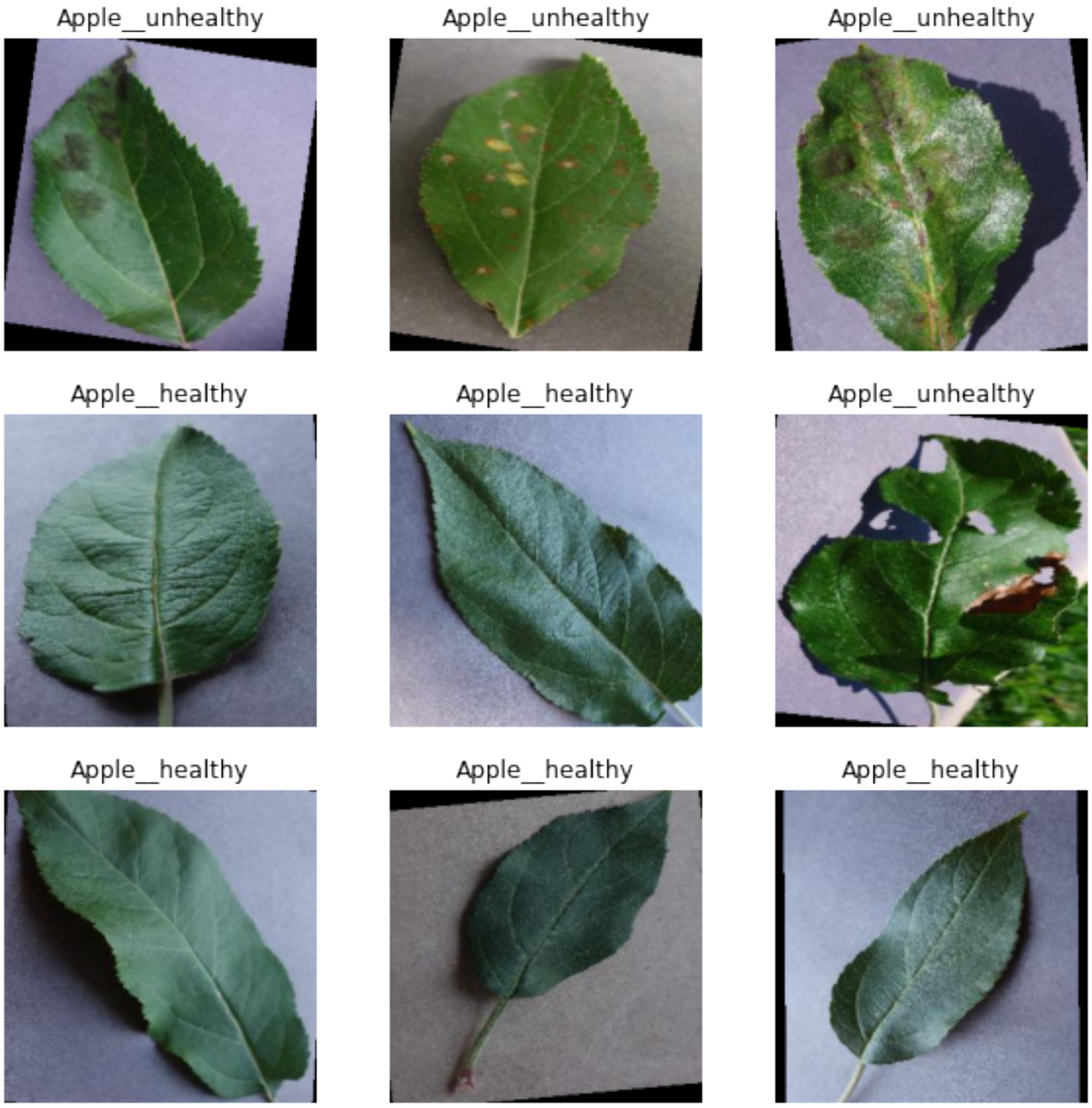
```
Found 1458 images belonging to 2 classes.
Found 126 images belonging to 2 classes.
Found 714 images belonging to 2 classes.
```

[4]:
```
# Checks if classes where found and displays them
num_classes = train_dataset.num_classes
class_names = list(train_dataset.class_indices.keys())
print(class_names)
```

```
['Apple__healthy', 'Apple__unhealthy']
```

1.0.6 Display augmented image data

[5]:
```
# display the random validation data for testing
x,y = validation_dataset.next()
labels = list(np.argmax(l) for l in y)
plt.figure(figsize=(10, 10))
for i in range(9):
  ax = plt.subplot(3, 3, i + 1)
  plt.imshow(x[i])
  plt.title(class_names[labels[i]])
  plt.axis("off")
```



1.1 Here the experiments start with different models

1.1.1 3. Create and compile model 1

This model uses two hidden convolution layers and one dense layer to analyse the images. In between the hidden layers, max-pooling manipulates the values, to create a better learning base. Based on literature the best hidden layer activation is the relu function and for the dense activation softmax. For the loss function, the categorical_crossentropy or the binary-crossentropy (since there are only two classes) was possible for image recognition. For this example, categoriacal crossentropy worked better.

[6]:
```
model1 = tf.keras.models.Sequential([
    tf.keras.layers.Conv2D(128, (3, 3), input_shape=(IMG_SIZE[0], IMG_SIZE[1],␣
 ↪3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.MaxPooling2D((2, 2)),
    tf.keras.layers.Conv2D(128, (3, 3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(num_classes, activation='softmax')
])
```

[7]:
```
opt = tf.keras.optimizers.Adam(lr=LEARNING_RATE)
model1.compile(optimizer=opt,
               loss='categorical_crossentropy',
               metrics=METRICS)
```

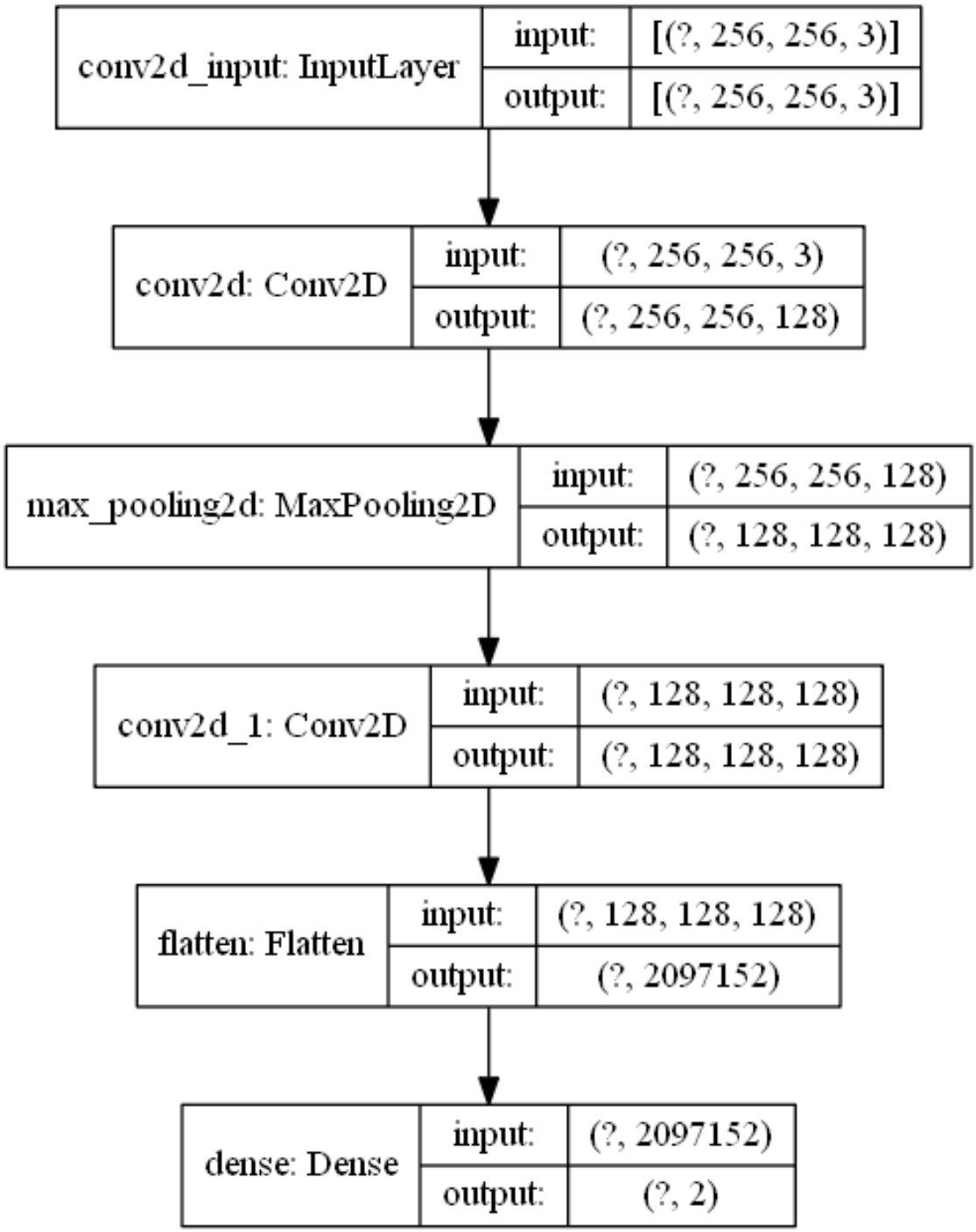
1.1.2 4. Display model structure 1

[8]:
```
model1.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 256, 256, 128)     3456
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 128, 128, 128)     0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 128, 128, 128)     147456
_________________________________________________________________
flatten (Flatten)            (None, 2097152)           0
_________________________________________________________________
dense (Dense)                (None, 2)                 4194306
=================================================================
Total params: 4,345,218
Trainable params: 4,345,218
Non-trainable params: 0
_________________________________________________________________
```

[9]:
```
tf.keras.utils.plot_model(model1, show_shapes=True)
```

[9]:



1.1.3 5. Training model 1

[10]:
```
def train_model(model, model_name):
    #filepath = './models/20210610_plant_' + model_name + '_{epoch:
↪02d}-{val_accuracy:.4f}.hdf5'
    #checkpoint = tf.keras.callbacks.ModelCheckpoint(filepath,␣
↪monitor='val_accuracy', verbose=1,
    #                                                 save_best_only=True,␣
↪mode='max')
    #callbacks_list = [checkpoint]

    history = model.fit(train_dataset,
                        epochs=EPOCHS,
                        validation_data=validation_dataset)
                        #,callbacks=callbacks_list)
    return history

history1 = train_model(model1, "Model_1")
```

```
Epoch 1/50
46/46 [==============================] - 16s 356ms/step - loss: 3.1057 - tp:
956.0000 - fp: 502.0000 - tn: 956.0000 - fn: 502.0000 - accuracy: 0.6557 -
precision: 0.6557 - auc: 0.6797 - mae: 0.4453 - mse: 0.2502 - val_loss: 0.4508 -
val_tp: 104.0000 - val_fp: 22.0000 - val_tn: 104.0000 - val_fn: 22.0000 -
val_accuracy: 0.8254 - val_precision: 0.8254 - val_auc: 0.9048 - val_mae: 0.3332
- val_mse: 0.1428
Epoch 2/50
46/46 [==============================] - 16s 338ms/step - loss: 0.3775 - tp:
1210.0000 - fp: 248.0000 - tn: 1210.0000 - fn: 248.0000 - accuracy: 0.8299 -
precision: 0.8299 - auc: 0.9110 - mae: 0.2464 - mse: 0.1199 - val_loss: 0.2627 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9607 - val_mae: 0.1745
- val_mse: 0.0766
Epoch 3/50
46/46 [==============================] - 16s 337ms/step - loss: 0.3092 - tp:
1278.0000 - fp: 180.0000 - tn: 1278.0000 - fn: 180.0000 - accuracy: 0.8765 -
precision: 0.8765 - auc: 0.9441 - mae: 0.1963 - mse: 0.0919 - val_loss: 0.2746 -
val_tp: 112.0000 - val_fp: 14.0000 - val_tn: 112.0000 - val_fn: 14.0000 -
val_accuracy: 0.8889 - val_precision: 0.8889 - val_auc: 0.9602 - val_mae: 0.1520
- val_mse: 0.0732
Epoch 4/50
46/46 [==============================] - 16s 338ms/step - loss: 0.3198 - tp:
1269.0000 - fp: 189.0000 - tn: 1269.0000 - fn: 189.0000 - accuracy: 0.8704 -
precision: 0.8704 - auc: 0.9374 - mae: 0.1904 - mse: 0.0979 - val_loss: 0.3726 -
val_tp: 107.0000 - val_fp: 19.0000 - val_tn: 107.0000 - val_fn: 19.0000 -
val_accuracy: 0.8492 - val_precision: 0.8492 - val_auc: 0.9238 - val_mae: 0.2567
- val_mse: 0.1147
Epoch 5/50
```

```
46/46 [==============================] - 16s 338ms/step - loss: 0.3149 - tp:
1281.0000 - fp: 177.0000 - tn: 1281.0000 - fn: 177.0000 - accuracy: 0.8786 -
precision: 0.8786 - auc: 0.9395 - mae: 0.1881 - mse: 0.0939 - val_loss: 0.2225 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9689 - val_mae: 0.1165
- val_mse: 0.0587
Epoch 6/50
46/46 [==============================] - 16s 338ms/step - loss: 0.3507 - tp:
1250.0000 - fp: 208.0000 - tn: 1250.0000 - fn: 208.0000 - accuracy: 0.8573 -
precision: 0.8573 - auc: 0.9273 - mae: 0.2080 - mse: 0.1060 - val_loss: 0.2439 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9678 - val_mae: 0.1422
- val_mse: 0.0646
Epoch 7/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2579 - tp:
1301.0000 - fp: 157.0000 - tn: 1301.0000 - fn: 157.0000 - accuracy: 0.8923 -
precision: 0.8923 - auc: 0.9593 - mae: 0.1553 - mse: 0.0786 - val_loss: 0.2648 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9620 - val_mae: 0.1374
- val_mse: 0.0660
Epoch 8/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2473 - tp:
1313.0000 - fp: 145.0000 - tn: 1313.0000 - fn: 145.0000 - accuracy: 0.9005 -
precision: 0.9005 - auc: 0.9621 - mae: 0.1512 - mse: 0.0744 - val_loss: 0.2394 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9653 - val_mae: 0.1260
- val_mse: 0.0680
Epoch 9/50
46/46 [==============================] - 16s 339ms/step - loss: 0.2763 - tp:
1300.0000 - fp: 158.0000 - tn: 1300.0000 - fn: 158.0000 - accuracy: 0.8916 -
precision: 0.8916 - auc: 0.9533 - mae: 0.1702 - mse: 0.0827 - val_loss: 0.4199 -
val_tp: 107.0000 - val_fp: 19.0000 - val_tn: 107.0000 - val_fn: 19.0000 -
val_accuracy: 0.8492 - val_precision: 0.8492 - val_auc: 0.9273 - val_mae: 0.1730
- val_mse: 0.1141
Epoch 10/50
46/46 [==============================] - 16s 340ms/step - loss: 0.2743 - tp:
1295.0000 - fp: 163.0000 - tn: 1295.0000 - fn: 163.0000 - accuracy: 0.8882 -
precision: 0.8882 - auc: 0.9553 - mae: 0.1547 - mse: 0.0824 - val_loss: 0.2262 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9686 - val_mae: 0.1446
- val_mse: 0.0661
Epoch 11/50
46/46 [==============================] - 16s 339ms/step - loss: 0.2594 - tp:
1303.0000 - fp: 155.0000 - tn: 1303.0000 - fn: 155.0000 - accuracy: 0.8937 -
precision: 0.8937 - auc: 0.9584 - mae: 0.1563 - mse: 0.0772 - val_loss: 0.1964 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9747 - val_mae: 0.1137
- val_mse: 0.0562
```

```
Epoch 12/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2601 - tp:
1306.0000 - fp: 152.0000 - tn: 1306.0000 - fn: 152.0000 - accuracy: 0.8957 -
precision: 0.8957 - auc: 0.9587 - mae: 0.1546 - mse: 0.0784 - val_loss: 0.2735 -
val_tp: 112.0000 - val_fp: 14.0000 - val_tn: 112.0000 - val_fn: 14.0000 -
val_accuracy: 0.8889 - val_precision: 0.8889 - val_auc: 0.9559 - val_mae: 0.1682
- val_mse: 0.0810
Epoch 13/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2672 - tp:
1317.0000 - fp: 141.0000 - tn: 1317.0000 - fn: 141.0000 - accuracy: 0.9033 -
precision: 0.9033 - auc: 0.9571 - mae: 0.1501 - mse: 0.0772 - val_loss: 0.2232 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9689 - val_mae: 0.1249
- val_mse: 0.0648
Epoch 14/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2539 - tp:
1311.0000 - fp: 147.0000 - tn: 1311.0000 - fn: 147.0000 - accuracy: 0.8992 -
precision: 0.8992 - auc: 0.9607 - mae: 0.1490 - mse: 0.0753 - val_loss: 0.2395 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9657 - val_mae: 0.1212
- val_mse: 0.0678
Epoch 15/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2664 - tp:
1305.0000 - fp: 153.0000 - tn: 1305.0000 - fn: 153.0000 - accuracy: 0.8951 -
precision: 0.8951 - auc: 0.9568 - mae: 0.1538 - mse: 0.0786 - val_loss: 0.4520 -
val_tp: 102.0000 - val_fp: 24.0000 - val_tn: 102.0000 - val_fn: 24.0000 -
val_accuracy: 0.8095 - val_precision: 0.8095 - val_auc: 0.8715 - val_mae: 0.3187
- val_mse: 0.1448
Epoch 16/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2807 - tp:
1290.0000 - fp: 168.0000 - tn: 1290.0000 - fn: 168.0000 - accuracy: 0.8848 -
precision: 0.8848 - auc: 0.9518 - mae: 0.1732 - mse: 0.0853 - val_loss: 0.2344 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9760 - val_mae: 0.1739
- val_mse: 0.0673
Epoch 17/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2591 - tp:
1307.0000 - fp: 151.0000 - tn: 1307.0000 - fn: 151.0000 - accuracy: 0.8964 -
precision: 0.8964 - auc: 0.9592 - mae: 0.1517 - mse: 0.0774 - val_loss: 0.4242 -
val_tp: 106.0000 - val_fp: 20.0000 - val_tn: 106.0000 - val_fn: 20.0000 -
val_accuracy: 0.8413 - val_precision: 0.8413 - val_auc: 0.9222 - val_mae: 0.1901
- val_mse: 0.1115
Epoch 18/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2789 - tp:
1298.0000 - fp: 160.0000 - tn: 1298.0000 - fn: 160.0000 - accuracy: 0.8903 -
precision: 0.8903 - auc: 0.9532 - mae: 0.1537 - mse: 0.0803 - val_loss: 0.2963 -
val_tp: 109.0000 - val_fp: 17.0000 - val_tn: 109.0000 - val_fn: 17.0000 -
val_accuracy: 0.8651 - val_precision: 0.8651 - val_auc: 0.9569 - val_mae: 0.1402
```

```
- val_mse: 0.0846
Epoch 19/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2679 - tp:
1304.0000 - fp: 154.0000 - tn: 1304.0000 - fn: 154.0000 - accuracy: 0.8944 -
precision: 0.8944 - auc: 0.9571 - mae: 0.1592 - mse: 0.0784 - val_loss: 0.2944 -
val_tp: 111.0000 - val_fp: 15.0000 - val_tn: 111.0000 - val_fn: 15.0000 -
val_accuracy: 0.8810 - val_precision: 0.8810 - val_auc: 0.9535 - val_mae: 0.1615
- val_mse: 0.0810
Epoch 20/50
46/46 [==============================] - 16s 339ms/step - loss: 0.3092 - tp:
1280.0000 - fp: 178.0000 - tn: 1280.0000 - fn: 178.0000 - accuracy: 0.8779 -
precision: 0.8779 - auc: 0.9436 - mae: 0.1757 - mse: 0.0954 - val_loss: 0.2356 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9678 - val_mae: 0.1193
- val_mse: 0.0695
Epoch 21/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2525 - tp:
1313.0000 - fp: 145.0000 - tn: 1313.0000 - fn: 145.0000 - accuracy: 0.9005 -
precision: 0.9005 - auc: 0.9607 - mae: 0.1498 - mse: 0.0753 - val_loss: 0.2327 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9689 - val_mae: 0.1322
- val_mse: 0.0732
Epoch 22/50
46/46 [==============================] - 16s 339ms/step - loss: 0.2509 - tp:
1317.0000 - fp: 141.0000 - tn: 1317.0000 - fn: 141.0000 - accuracy: 0.9033 -
precision: 0.9033 - auc: 0.9617 - mae: 0.1382 - mse: 0.0717 - val_loss: 0.2653 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9598 - val_mae: 0.1175
- val_mse: 0.0672
Epoch 23/50
46/46 [==============================] - 16s 342ms/step - loss: 0.2537 - tp:
1314.0000 - fp: 144.0000 - tn: 1314.0000 - fn: 144.0000 - accuracy: 0.9012 -
precision: 0.9012 - auc: 0.9606 - mae: 0.1449 - mse: 0.0753 - val_loss: 0.2878 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9514 - val_mae: 0.1595
- val_mse: 0.0836
Epoch 24/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2435 - tp:
1319.0000 - fp: 139.0000 - tn: 1319.0000 - fn: 139.0000 - accuracy: 0.9047 -
precision: 0.9047 - auc: 0.9637 - mae: 0.1378 - mse: 0.0713 - val_loss: 0.2963 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9486 - val_mae: 0.1906
- val_mse: 0.0855
Epoch 25/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2874 - tp:
1285.0000 - fp: 173.0000 - tn: 1285.0000 - fn: 173.0000 - accuracy: 0.8813 -
precision: 0.8813 - auc: 0.9512 - mae: 0.1690 - mse: 0.0851 - val_loss: 0.2369 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
```

```
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9652 - val_mae: 0.1428
- val_mse: 0.0684
Epoch 26/50
46/46 [==============================] - 16s 339ms/step - loss: 0.2471 - tp:
1310.0000 - fp: 148.0000 - tn: 1310.0000 - fn: 148.0000 - accuracy: 0.8985 -
precision: 0.8985 - auc: 0.9627 - mae: 0.1412 - mse: 0.0746 - val_loss: 0.2409 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9666 - val_mae: 0.1438
- val_mse: 0.0693
Epoch 27/50
46/46 [==============================] - 16s 341ms/step - loss: 0.2507 - tp:
1321.0000 - fp: 137.0000 - tn: 1321.0000 - fn: 137.0000 - accuracy: 0.9060 -
precision: 0.9060 - auc: 0.9623 - mae: 0.1393 - mse: 0.0719 - val_loss: 0.2217 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9703 - val_mae: 0.1069
- val_mse: 0.0605
Epoch 28/50
46/46 [==============================] - 16s 341ms/step - loss: 0.2678 - tp:
1297.0000 - fp: 161.0000 - tn: 1297.0000 - fn: 161.0000 - accuracy: 0.8896 -
precision: 0.8896 - auc: 0.9574 - mae: 0.1527 - mse: 0.0799 - val_loss: 0.3336 -
val_tp: 112.0000 - val_fp: 14.0000 - val_tn: 112.0000 - val_fn: 14.0000 -
val_accuracy: 0.8889 - val_precision: 0.8889 - val_auc: 0.9449 - val_mae: 0.1452
- val_mse: 0.0881
Epoch 29/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2468 - tp:
1315.0000 - fp: 143.0000 - tn: 1315.0000 - fn: 143.0000 - accuracy: 0.9019 -
precision: 0.9019 - auc: 0.9625 - mae: 0.1447 - mse: 0.0723 - val_loss: 0.1973 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9786 - val_mae: 0.1327
- val_mse: 0.0591
Epoch 30/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2197 - tp:
1335.0000 - fp: 123.0000 - tn: 1335.0000 - fn: 123.0000 - accuracy: 0.9156 -
precision: 0.9156 - auc: 0.9711 - mae: 0.1309 - mse: 0.0644 - val_loss: 0.2448 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9667 - val_mae: 0.1521
- val_mse: 0.0695
Epoch 31/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2140 - tp:
1331.0000 - fp: 127.0000 - tn: 1331.0000 - fn: 127.0000 - accuracy: 0.9129 -
precision: 0.9129 - auc: 0.9725 - mae: 0.1255 - mse: 0.0630 - val_loss: 0.2556 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9660 - val_mae: 0.1794
- val_mse: 0.0777
Epoch 32/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2312 - tp:
1321.0000 - fp: 137.0000 - tn: 1321.0000 - fn: 137.0000 - accuracy: 0.9060 -
precision: 0.9060 - auc: 0.9676 - mae: 0.1367 - mse: 0.0695 - val_loss: 0.2516 -
```

```
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9616 - val_mae: 0.1261
- val_mse: 0.0647
Epoch 33/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2324 - tp:
1326.0000 - fp: 132.0000 - tn: 1326.0000 - fn: 132.0000 - accuracy: 0.9095 -
precision: 0.9095 - auc: 0.9667 - mae: 0.1327 - mse: 0.0689 - val_loss: 0.1911 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9782 - val_mae: 0.1135
- val_mse: 0.0587
Epoch 34/50
46/46 [==============================] - 16s 339ms/step - loss: 0.2318 - tp:
1332.0000 - fp: 126.0000 - tn: 1332.0000 - fn: 126.0000 - accuracy: 0.9136 -
precision: 0.9136 - auc: 0.9683 - mae: 0.1313 - mse: 0.0673 - val_loss: 0.2536 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9640 - val_mae: 0.1669
- val_mse: 0.0729
Epoch 35/50
46/46 [==============================] - 16s 338ms/step - loss: 0.4999 - tp:
1129.0000 - fp: 329.0000 - tn: 1129.0000 - fn: 329.0000 - accuracy: 0.7743 -
precision: 0.7743 - auc: 0.8484 - mae: 0.3105 - mse: 0.1599 - val_loss: 0.5549 -
val_tp: 108.0000 - val_fp: 18.0000 - val_tn: 108.0000 - val_fn: 18.0000 -
val_accuracy: 0.8571 - val_precision: 0.8571 - val_auc: 0.8745 - val_mae: 0.2766
- val_mse: 0.1474
Epoch 36/50
46/46 [==============================] - 15s 337ms/step - loss: 0.4832 - tp:
1153.0000 - fp: 305.0000 - tn: 1153.0000 - fn: 305.0000 - accuracy: 0.7908 -
precision: 0.7908 - auc: 0.8562 - mae: 0.3000 - mse: 0.1547 - val_loss: 0.4154 -
val_tp: 108.0000 - val_fp: 18.0000 - val_tn: 108.0000 - val_fn: 18.0000 -
val_accuracy: 0.8571 - val_precision: 0.8571 - val_auc: 0.9145 - val_mae: 0.2922
- val_mse: 0.1303
Epoch 37/50
46/46 [==============================] - 16s 337ms/step - loss: 0.4453 - tp:
1184.0000 - fp: 274.0000 - tn: 1184.0000 - fn: 274.0000 - accuracy: 0.8121 -
precision: 0.8121 - auc: 0.8795 - mae: 0.2784 - mse: 0.1409 - val_loss: 0.4285 -
val_tp: 104.0000 - val_fp: 22.0000 - val_tn: 104.0000 - val_fn: 22.0000 -
val_accuracy: 0.8254 - val_precision: 0.8254 - val_auc: 0.9086 - val_mae: 0.2352
- val_mse: 0.1218
Epoch 38/50
46/46 [==============================] - 16s 337ms/step - loss: 0.4062 - tp:
1249.0000 - fp: 209.0000 - tn: 1249.0000 - fn: 209.0000 - accuracy: 0.8567 -
precision: 0.8567 - auc: 0.9070 - mae: 0.2235 - mse: 0.1184 - val_loss: 0.3565 -
val_tp: 106.0000 - val_fp: 20.0000 - val_tn: 106.0000 - val_fn: 20.0000 -
val_accuracy: 0.8413 - val_precision: 0.8413 - val_auc: 0.9238 - val_mae: 0.2337
- val_mse: 0.1105
Epoch 39/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3689 - tp:
1246.0000 - fp: 212.0000 - tn: 1246.0000 - fn: 212.0000 - accuracy: 0.8546 -
```

```
precision: 0.8546 - auc: 0.9182 - mae: 0.2110 - mse: 0.1105 - val_loss: 0.2857 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9523 - val_mae: 0.1426
- val_mse: 0.0733
Epoch 40/50
46/46 [==============================] - 15s 337ms/step - loss: 0.3129 - tp:
1286.0000 - fp: 172.0000 - tn: 1286.0000 - fn: 172.0000 - accuracy: 0.8820 -
precision: 0.8820 - auc: 0.9468 - mae: 0.1580 - mse: 0.0859 - val_loss: 0.3209 -
val_tp: 107.0000 - val_fp: 19.0000 - val_tn: 107.0000 - val_fn: 19.0000 -
val_accuracy: 0.8492 - val_precision: 0.8492 - val_auc: 0.9405 - val_mae: 0.1820
- val_mse: 0.1016
Epoch 41/50
46/46 [==============================] - 16s 337ms/step - loss: 0.3089 - tp:
1290.0000 - fp: 168.0000 - tn: 1290.0000 - fn: 168.0000 - accuracy: 0.8848 -
precision: 0.8848 - auc: 0.9477 - mae: 0.1538 - mse: 0.0894 - val_loss: 0.2159 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9710 - val_mae: 0.1162
- val_mse: 0.0599
Epoch 42/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2365 - tp:
1322.0000 - fp: 136.0000 - tn: 1322.0000 - fn: 136.0000 - accuracy: 0.9067 -
precision: 0.9067 - auc: 0.9662 - mae: 0.1312 - mse: 0.0701 - val_loss: 0.2409 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9646 - val_mae: 0.1387
- val_mse: 0.0738
Epoch 43/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2628 - tp:
1304.0000 - fp: 154.0000 - tn: 1304.0000 - fn: 154.0000 - accuracy: 0.8944 -
precision: 0.8944 - auc: 0.9589 - mae: 0.1458 - mse: 0.0779 - val_loss: 0.2772 -
val_tp: 110.0000 - val_fp: 16.0000 - val_tn: 110.0000 - val_fn: 16.0000 -
val_accuracy: 0.8730 - val_precision: 0.8730 - val_auc: 0.9544 - val_mae: 0.1520
- val_mse: 0.0836
Epoch 44/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2094 - tp:
1339.0000 - fp: 119.0000 - tn: 1339.0000 - fn: 119.0000 - accuracy: 0.9184 -
precision: 0.9184 - auc: 0.9726 - mae: 0.1180 - mse: 0.0591 - val_loss: 0.2771 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9528 - val_mae: 0.1416
- val_mse: 0.0790
Epoch 45/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2531 - tp:
1316.0000 - fp: 142.0000 - tn: 1316.0000 - fn: 142.0000 - accuracy: 0.9026 -
precision: 0.9026 - auc: 0.9624 - mae: 0.1370 - mse: 0.0725 - val_loss: 0.2379 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9679 - val_mae: 0.1522
- val_mse: 0.0650
Epoch 46/50
46/46 [==============================] - 16s 341ms/step - loss: 0.2234 - tp:
```

```
1330.0000 - fp: 128.0000 - tn: 1330.0000 - fn: 128.0000 - accuracy: 0.9122 -
precision: 0.9122 - auc: 0.9698 - mae: 0.1253 - mse: 0.0652 - val_loss: 0.2621 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9703 - val_mae: 0.0978
- val_mse: 0.0608
Epoch 47/50
46/46 [==============================] - 16s 338ms/step - loss: 0.2217 - tp:
1333.0000 - fp: 125.0000 - tn: 1333.0000 - fn: 125.0000 - accuracy: 0.9143 -
precision: 0.9143 - auc: 0.9712 - mae: 0.1208 - mse: 0.0637 - val_loss: 0.2922 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9516 - val_mae: 0.1557
- val_mse: 0.0714
Epoch 48/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2050 - tp:
1332.0000 - fp: 126.0000 - tn: 1332.0000 - fn: 126.0000 - accuracy: 0.9136 -
precision: 0.9136 - auc: 0.9741 - mae: 0.1192 - mse: 0.0612 - val_loss: 0.1921 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9781 - val_mae: 0.1091
- val_mse: 0.0571
Epoch 49/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2267 - tp:
1325.0000 - fp: 133.0000 - tn: 1325.0000 - fn: 133.0000 - accuracy: 0.9088 -
precision: 0.9088 - auc: 0.9697 - mae: 0.1235 - mse: 0.0667 - val_loss: 0.2111 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9727 - val_mae: 0.1363
- val_mse: 0.0596
Epoch 50/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2178 - tp:
1334.0000 - fp: 124.0000 - tn: 1334.0000 - fn: 124.0000 - accuracy: 0.9150 -
precision: 0.9150 - auc: 0.9713 - mae: 0.1209 - mse: 0.0620 - val_loss: 0.2280 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9657 - val_mae: 0.1104
- val_mse: 0.0590
```

1.1.4 6. Write history and plot graphs 1

[11]:
```python
def print_history(history):
    acc = history.history['accuracy']
    val_acc = history.history['val_accuracy']

    loss = history.history['loss']
    val_loss = history.history['val_loss']

    auc = history.history['auc']
    val_auc = history.history['val_auc']

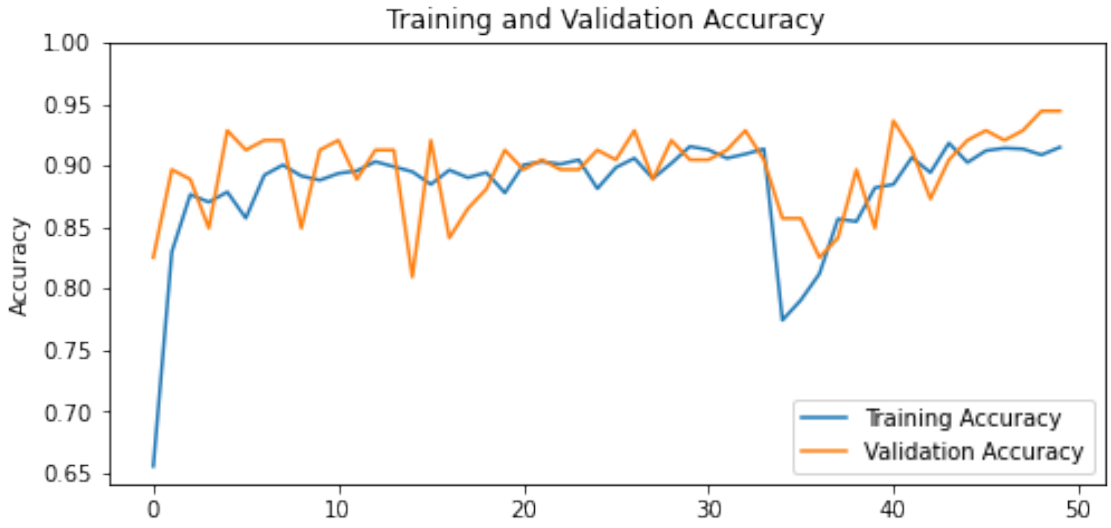
    plt.figure(figsize=(8, 8))
```

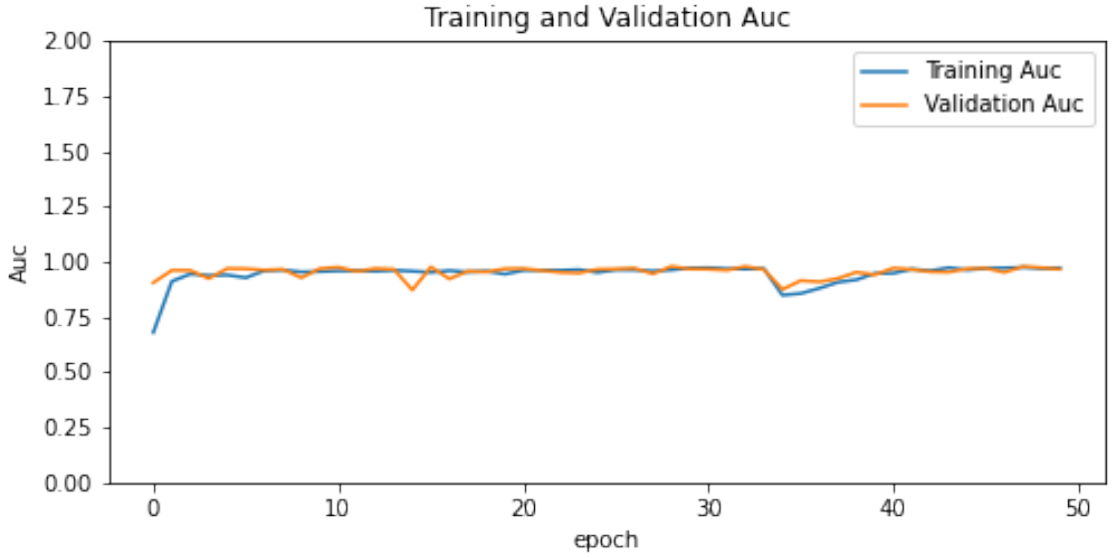
```
    plt.subplot(2, 1, 1)
    plt.plot(acc, label='Training Accuracy')
    plt.plot(val_acc, label='Validation Accuracy')
    plt.legend(loc='lower right')
    plt.ylabel('Accuracy')
    plt.ylim([min(plt.ylim()),1])
    plt.title('Training and Validation Accuracy')

    plt.figure(figsize=(8, 8))
    plt.subplot(2, 1, 2)
    plt.plot(loss, label='Training Loss')
    plt.plot(val_loss, label='Validation Loss')
    plt.legend(loc='upper right')
    plt.ylabel('Cross Entropy')
    plt.ylim([0,1.0])
    plt.title('Training and Validation Loss')
    plt.xlabel('epoch')
    plt.show()

    plt.figure(figsize=(8, 8))
    plt.subplot(2, 1, 1)
    plt.plot(auc, label='Training Auc')
    plt.plot(val_auc, label='Validation Auc')
    plt.legend(loc='upper right')
    plt.ylabel('Auc')
    plt.ylim([0,2.0])
    plt.title('Training and Validation Auc')
    plt.xlabel('epoch')
    plt.show()

print_history(history1)
```





1.1.5 7. Evaluate the model 1

[12]:
```
def print_model_evaluation(model):
    result = model.evaluate(test_dataset)
    metrics = ["loss", "tp", "fp", "tn", "fn", "accuracy", "precision", "auc",␣
 ↪"mae", "mse"]
```

```
    for i in range(len(result)):
        print("{} : {}".format(metrics[i],round(result[i], 3)))

print_model_evaluation(model1);
```

```
714/714 [==============================] - 3s 5ms/step - loss: 0.3188 - tp:
624.0000 - fp: 90.0000 - tn: 624.0000 - fn: 90.0000 - accuracy: 0.8739 -
precision: 0.8739 - auc: 0.9494 - mae: 0.1503 - mse: 0.0966
loss : 0.319
tp : 624.0
fp : 90.0
tn : 624.0
fn : 90.0
accuracy : 0.874
precision : 0.874
auc : 0.949
mae : 0.15
mse : 0.097
```

1.1.6 8. Predict with model 1

[33]:
```
def predict_and_print_roc(model):
    #Retrieve one batch of images from the test set
    train_dataset.reset()
    image_batch, label_batch = train_dataset.next()

    # Predict the images from the batch
    predictions = model.predict(image_batch)

    # Visualise the actual value and the prediction in numerical form
    probs = list(np.argmax(x) for x in predictions)
    labels = list(np.argmax(x) for x in label_batch)
    print('Label Predictions:\n', probs)
    print('Real Labels:\n', labels)

    confusion = confusion_matrix(labels, probs)
    print('\nConfusion Matrix:')
    print(confusion)

    print('\nAccuracy: {:.2f}\n'.format(accuracy_score(labels, probs)))

    #Print the first 9 Images from the batch and the estimated prediction.
    plt.figure(figsize=(10, 10))
    for i in range(9):
      ax = plt.subplot(3, 3, i + 1)
      plt.imshow(image_batch[i])
      plt.title(class_names[probs[i]])
```

```
      plt.axis("off")

    #Calculate the roc curve
    fpr, tpr, _ = skmetrics.roc_curve(label_batch.ravel(), predictions.ravel())
    roc_auc = skmetrics.auc(fpr, tpr)

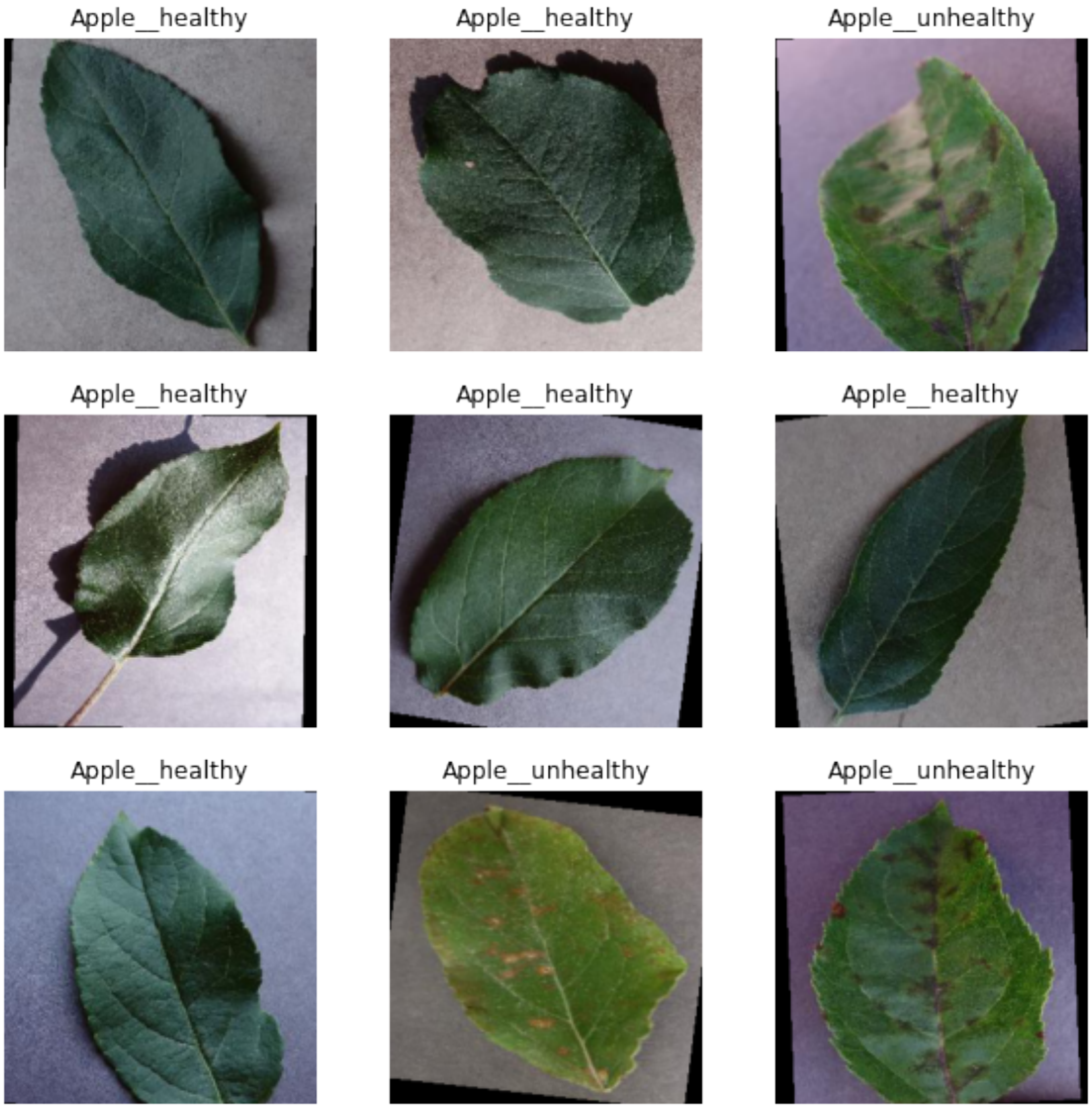
    #Display ROC curve and the AUC
    plt.figure(figsize=(5, 5))
    plt.title('ROC')
    plt.plot(fpr, tpr, 'b', label = 'AUC = %0.2f' % roc_auc)
    plt.legend(loc = 'lower right')
    plt.plot([0, 1], [0, 1],'r--')
    plt.xlim([0, 1])
    plt.ylim([0, 1])
    plt.ylabel('True Positive Rate')
    plt.xlabel('False Positive Rate')
    plt.show()

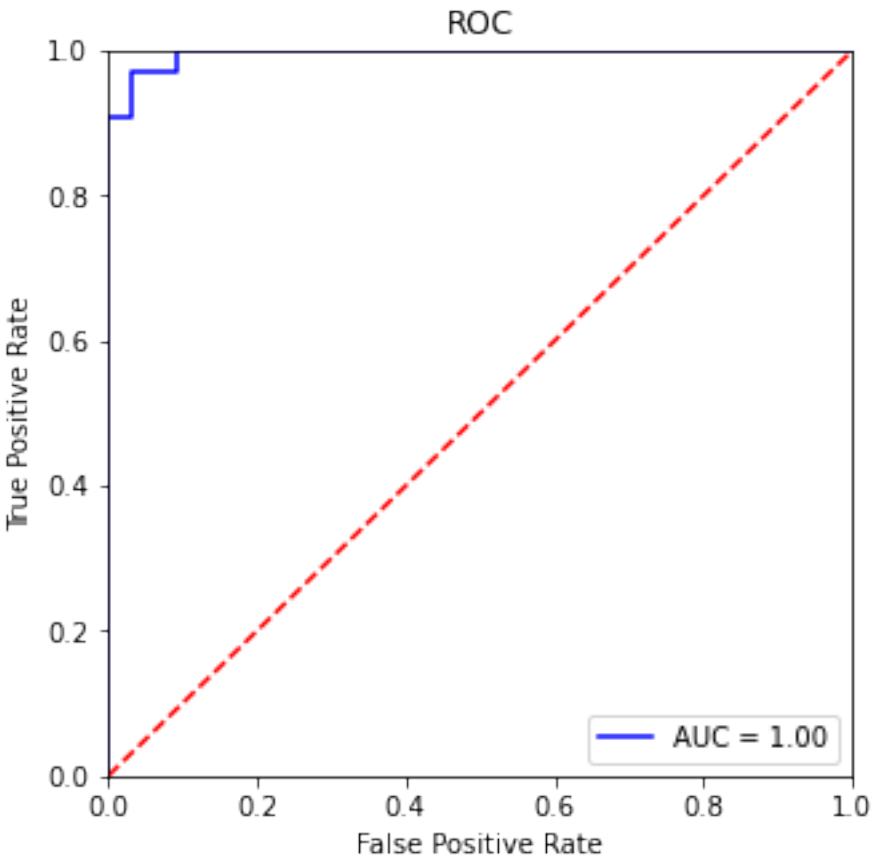
predict_and_print_roc(model1);
```

```
Label Predictions:
 [0, 0, 1, 0, 0, 0, 0, 1, 1, 0, 0, 0, 1, 0, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 0, 1,
1, 0, 0, 1, 1, 0]
Real Labels:
 [0, 0, 1, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 0, 1,
1, 0, 0, 1, 1, 0]

Confusion Matrix:
[[19  0]
 [ 1 12]]

Accuracy: 0.97
```


Apple__healthy
Apple__healthy
Apple__unhealthy
Apple__healthy
Apple__healthy
Apple__healthy
Apple__healthy
Apple__unhealthy
Apple__unhealthy



1.1.7 3. Create and compile model 2

This model uses compared to the previouse model three convolution layers and two dense layers. The value of the neurons are decreased at each layer.

[14]:
```
model2 = tf.keras.models.Sequential([
    tf.keras.layers.Conv2D(128, (3, 3), input_shape=(IMG_SIZE[0], IMG_SIZE[1],␣
 ↪3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.MaxPooling2D((2, 2)),
    tf.keras.layers.Conv2D(32, (3, 3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(8, activation='relu', use_bias=False),
    tf.keras.layers.Dense(num_classes, activation='softmax')
])
```

[15]:
```
opt = tf.keras.optimizers.Adam(lr=LEARNING_RATE)
model2.compile(optimizer=opt,
```

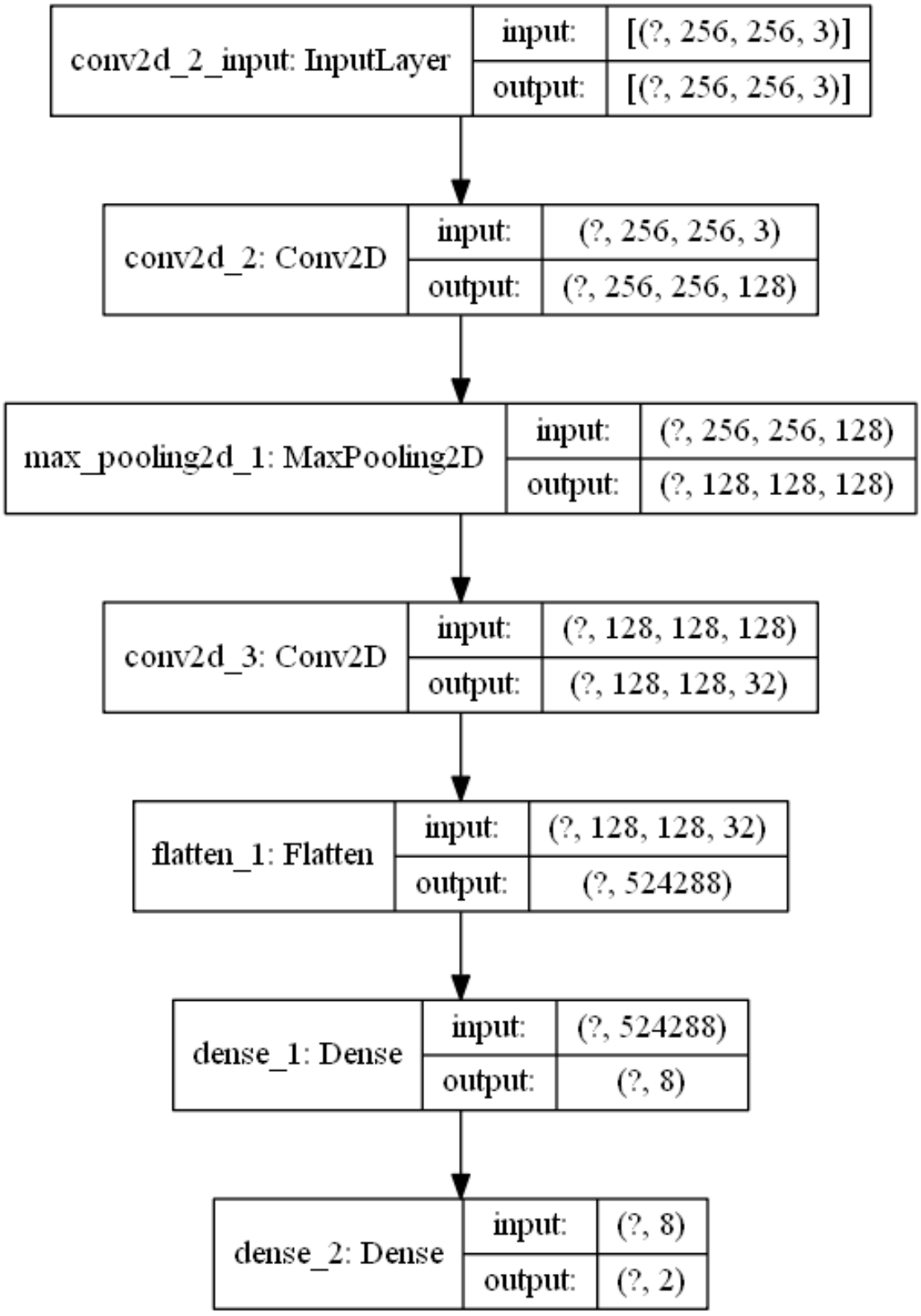
```
              loss='categorical_crossentropy',
              metrics=METRICS)
```

1.1.8 4. Display model structure 2

[16]:
```
model2.summary()
tf.keras.utils.plot_model(model2, show_shapes=True)
```

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_2 (Conv2D)            (None, 256, 256, 128)     3456
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 128, 128, 128)     0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 128, 128, 32)      36864
_________________________________________________________________
flatten_1 (Flatten)          (None, 524288)            0
_________________________________________________________________
dense_1 (Dense)              (None, 8)                 4194304
_________________________________________________________________
dense_2 (Dense)              (None, 2)                 18
=================================================================
Total params: 4,234,642
Trainable params: 4,234,642
Non-trainable params: 0
_________________________________________________________________
```

[16]:


conv2d_2_input: InputLayer
input: [(?, 256, 256, 3)]
output: [(?, 256, 256, 3)]
conv2d_2: Conv2D
input: (?, 256, 256, 3)
output: (?, 256, 256, 128)
max_pooling2d_1: MaxPooling2D
input: (?, 256, 256, 128)
output: (?, 128, 128, 128)
conv2d_3: Conv2D
input: (?, 128, 128, 128)
output: (?, 128, 128, 32)
flatten_1: Flatten
input: (?, 128, 128, 32)
output: (?, 524288)
dense_1: Dense
input: (?, 524288)
output: (?, 8)
dense_2: Dense
input: (?, 8)
output: (?, 2)

1.1.9 5. Training model 2

[17]:
```
history2 = train_model(model2, "Model_2")
```

```
Epoch 1/50
46/46 [==============================] - 16s 357ms/step - loss: 0.8398 - tp:
1539.0000 - fp: 632.0000 - tn: 1540.0000 - fn: 633.0000 - accuracy: 0.7086 -
precision: 0.7089 - auc: 0.7869 - mae: 0.3603 - mse: 0.1921 - val_loss: 0.5052 -
val_tp: 103.0000 - val_fp: 23.0000 - val_tn: 103.0000 - val_fn: 23.0000 -
val_accuracy: 0.8175 - val_precision: 0.8175 - val_auc: 0.8818 - val_mae: 0.3769
- val_mse: 0.1639
Epoch 2/50
46/46 [==============================] - 16s 337ms/step - loss: 0.4783 - tp:
1178.0000 - fp: 280.0000 - tn: 1178.0000 - fn: 280.0000 - accuracy: 0.8080 -
precision: 0.8080 - auc: 0.8622 - mae: 0.3090 - mse: 0.1499 - val_loss: 0.3890 -
val_tp: 106.0000 - val_fp: 20.0000 - val_tn: 106.0000 - val_fn: 20.0000 -
val_accuracy: 0.8413 - val_precision: 0.8413 - val_auc: 0.9121 - val_mae: 0.2112
- val_mse: 0.1145
Epoch 3/50
46/46 [==============================] - 15s 335ms/step - loss: 0.3931 - tp:
1223.0000 - fp: 235.0000 - tn: 1223.0000 - fn: 235.0000 - accuracy: 0.8388 -
precision: 0.8388 - auc: 0.9075 - mae: 0.2422 - mse: 0.1192 - val_loss: 0.2747 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9609 - val_mae: 0.2014
- val_mse: 0.0779
Epoch 4/50
46/46 [==============================] - 16s 338ms/step - loss: 0.3778 - tp:
1222.0000 - fp: 236.0000 - tn: 1222.0000 - fn: 236.0000 - accuracy: 0.8381 -
precision: 0.8381 - auc: 0.9133 - mae: 0.2372 - mse: 0.1164 - val_loss: 0.3615 -
val_tp: 106.0000 - val_fp: 20.0000 - val_tn: 106.0000 - val_fn: 20.0000 -
val_accuracy: 0.8413 - val_precision: 0.8413 - val_auc: 0.9323 - val_mae: 0.2656
- val_mse: 0.1112
Epoch 5/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3617 - tp:
1237.0000 - fp: 221.0000 - tn: 1237.0000 - fn: 221.0000 - accuracy: 0.8484 -
precision: 0.8484 - auc: 0.9203 - mae: 0.2201 - mse: 0.1100 - val_loss: 0.4808 -
val_tp: 94.0000 - val_fp: 32.0000 - val_tn: 94.0000 - val_fn: 32.0000 -
val_accuracy: 0.7460 - val_precision: 0.7460 - val_auc: 0.8553 - val_mae: 0.2768
- val_mse: 0.1641
Epoch 6/50
46/46 [==============================] - 15s 336ms/step - loss: 0.4156 - tp:
1189.0000 - fp: 269.0000 - tn: 1189.0000 - fn: 269.0000 - accuracy: 0.8155 -
precision: 0.8155 - auc: 0.8952 - mae: 0.2515 - mse: 0.1299 - val_loss: 0.2465 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9707 - val_mae: 0.1823
- val_mse: 0.0692
Epoch 7/50
46/46 [==============================] - 16s 337ms/step - loss: 0.4017 - tp:
```

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1217.0000 - fp: 241.0000 - tn: 1217.0000 - fn: 241.0000 - accuracy: 0.8347 -
precision: 0.8347 - auc: 0.9033 - mae: 0.2448 - mse: 0.1230 - val_loss: 0.2629 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9718 - val_mae: 0.2012
- val_mse: 0.0764
Epoch 8/50
46/46 [==============================] - 16s 337ms/step - loss: 0.3391 - tp:
1259.0000 - fp: 199.0000 - tn: 1259.0000 - fn: 199.0000 - accuracy: 0.8635 -
precision: 0.8635 - auc: 0.9302 - mae: 0.2109 - mse: 0.1026 - val_loss: 0.2602 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9592 - val_mae: 0.1683
- val_mse: 0.0771
Epoch 9/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3346 - tp:
1272.0000 - fp: 186.0000 - tn: 1272.0000 - fn: 186.0000 - accuracy: 0.8724 -
precision: 0.8724 - auc: 0.9326 - mae: 0.2013 - mse: 0.0996 - val_loss: 0.2840 -
val_tp: 108.0000 - val_fp: 18.0000 - val_tn: 108.0000 - val_fn: 18.0000 -
val_accuracy: 0.8571 - val_precision: 0.8571 - val_auc: 0.9499 - val_mae: 0.1718
- val_mse: 0.0935
Epoch 10/50
46/46 [==============================] - 15s 335ms/step - loss: 0.3758 - tp:
1228.0000 - fp: 230.0000 - tn: 1228.0000 - fn: 230.0000 - accuracy: 0.8422 -
precision: 0.8422 - auc: 0.9163 - mae: 0.2221 - mse: 0.1136 - val_loss: 0.3727 -
val_tp: 110.0000 - val_fp: 16.0000 - val_tn: 110.0000 - val_fn: 16.0000 -
val_accuracy: 0.8730 - val_precision: 0.8730 - val_auc: 0.9259 - val_mae: 0.1660
- val_mse: 0.1002
Epoch 11/50
46/46 [==============================] - 16s 337ms/step - loss: 0.3782 - tp:
1228.0000 - fp: 230.0000 - tn: 1228.0000 - fn: 230.0000 - accuracy: 0.8422 -
precision: 0.8422 - auc: 0.9147 - mae: 0.2322 - mse: 0.1147 - val_loss: 0.2341 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9678 - val_mae: 0.1438
- val_mse: 0.0672
Epoch 12/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3143 - tp:
1275.0000 - fp: 183.0000 - tn: 1275.0000 - fn: 183.0000 - accuracy: 0.8745 -
precision: 0.8745 - auc: 0.9403 - mae: 0.1911 - mse: 0.0936 - val_loss: 0.2696 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9560 - val_mae: 0.1497
- val_mse: 0.0801
Epoch 13/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3255 - tp:
1270.0000 - fp: 188.0000 - tn: 1270.0000 - fn: 188.0000 - accuracy: 0.8711 -
precision: 0.8711 - auc: 0.9358 - mae: 0.2004 - mse: 0.0980 - val_loss: 0.2789 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9535 - val_mae: 0.1661
- val_mse: 0.0818
Epoch 14/50
```

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46/46 [==============================] - 16s 338ms/step - loss: 0.3405 - tp:
1252.0000 - fp: 206.0000 - tn: 1252.0000 - fn: 206.0000 - accuracy: 0.8587 -
precision: 0.8587 - auc: 0.9308 - mae: 0.2023 - mse: 0.1029 - val_loss: 0.2067 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9737 - val_mae: 0.1297
- val_mse: 0.0583
Epoch 15/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3265 - tp:
1271.0000 - fp: 187.0000 - tn: 1271.0000 - fn: 187.0000 - accuracy: 0.8717 -
precision: 0.8717 - auc: 0.9359 - mae: 0.2002 - mse: 0.0974 - val_loss: 0.1776 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9836 - val_mae: 0.1248
- val_mse: 0.0526
Epoch 16/50
46/46 [==============================] - 15s 335ms/step - loss: 0.3243 - tp:
1263.0000 - fp: 195.0000 - tn: 1263.0000 - fn: 195.0000 - accuracy: 0.8663 -
precision: 0.8663 - auc: 0.9364 - mae: 0.1963 - mse: 0.0985 - val_loss: 0.2259 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9691 - val_mae: 0.1452
- val_mse: 0.0679
Epoch 17/50
46/46 [==============================] - 15s 337ms/step - loss: 0.3145 - tp:
1289.0000 - fp: 169.0000 - tn: 1289.0000 - fn: 169.0000 - accuracy: 0.8841 -
precision: 0.8841 - auc: 0.9401 - mae: 0.1920 - mse: 0.0937 - val_loss: 0.2119 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9695 - val_mae: 0.1265
- val_mse: 0.0596
Epoch 18/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3350 - tp:
1255.0000 - fp: 203.0000 - tn: 1255.0000 - fn: 203.0000 - accuracy: 0.8608 -
precision: 0.8608 - auc: 0.9335 - mae: 0.1974 - mse: 0.1006 - val_loss: 0.2512 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9692 - val_mae: 0.1822
- val_mse: 0.0725
Epoch 19/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3100 - tp:
1288.0000 - fp: 170.0000 - tn: 1288.0000 - fn: 170.0000 - accuracy: 0.8834 -
precision: 0.8834 - auc: 0.9423 - mae: 0.1869 - mse: 0.0910 - val_loss: 0.6489 -
val_tp: 86.0000 - val_fp: 40.0000 - val_tn: 86.0000 - val_fn: 40.0000 -
val_accuracy: 0.6825 - val_precision: 0.6825 - val_auc: 0.8376 - val_mae: 0.2780
- val_mse: 0.1991
Epoch 20/50
46/46 [==============================] - 15s 337ms/step - loss: 0.3894 - tp:
1216.0000 - fp: 242.0000 - tn: 1216.0000 - fn: 242.0000 - accuracy: 0.8340 -
precision: 0.8340 - auc: 0.9104 - mae: 0.2232 - mse: 0.1181 - val_loss: 0.4272 -
val_tp: 100.0000 - val_fp: 26.0000 - val_tn: 100.0000 - val_fn: 26.0000 -
val_accuracy: 0.7937 - val_precision: 0.7937 - val_auc: 0.9030 - val_mae: 0.3156
- val_mse: 0.1363
```

```
Epoch 21/50
46/46 [==============================] - 15s 337ms/step - loss: 0.4102 - tp:
1190.0000 - fp: 268.0000 - tn: 1190.0000 - fn: 268.0000 - accuracy: 0.8162 -
precision: 0.8162 - auc: 0.8994 - mae: 0.2470 - mse: 0.1264 - val_loss: 0.2247 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9750 - val_mae: 0.1631
- val_mse: 0.0645
Epoch 22/50
46/46 [==============================] - 15s 337ms/step - loss: 0.4122 - tp:
1178.0000 - fp: 280.0000 - tn: 1178.0000 - fn: 280.0000 - accuracy: 0.8080 -
precision: 0.8080 - auc: 0.8956 - mae: 0.2705 - mse: 0.1334 - val_loss: 0.2553 -
val_tp: 112.0000 - val_fp: 14.0000 - val_tn: 112.0000 - val_fn: 14.0000 -
val_accuracy: 0.8889 - val_precision: 0.8889 - val_auc: 0.9595 - val_mae: 0.1517
- val_mse: 0.0764
Epoch 23/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3001 - tp:
1299.0000 - fp: 159.0000 - tn: 1299.0000 - fn: 159.0000 - accuracy: 0.8909 -
precision: 0.8909 - auc: 0.9466 - mae: 0.1781 - mse: 0.0864 - val_loss: 0.2006 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9769 - val_mae: 0.1328
- val_mse: 0.0607
Epoch 24/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3766 - tp:
1217.0000 - fp: 241.0000 - tn: 1217.0000 - fn: 241.0000 - accuracy: 0.8347 -
precision: 0.8347 - auc: 0.9158 - mae: 0.2188 - mse: 0.1150 - val_loss: 0.2136 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9744 - val_mae: 0.1435
- val_mse: 0.0637
Epoch 25/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2960 - tp:
1299.0000 - fp: 159.0000 - tn: 1299.0000 - fn: 159.0000 - accuracy: 0.8909 -
precision: 0.8909 - auc: 0.9466 - mae: 0.1813 - mse: 0.0874 - val_loss: 0.2084 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9728 - val_mae: 0.1315
- val_mse: 0.0601
Epoch 26/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2922 - tp:
1292.0000 - fp: 166.0000 - tn: 1292.0000 - fn: 166.0000 - accuracy: 0.8861 -
precision: 0.8861 - auc: 0.9484 - mae: 0.1769 - mse: 0.0864 - val_loss: 0.2885 -
val_tp: 109.0000 - val_fp: 17.0000 - val_tn: 109.0000 - val_fn: 17.0000 -
val_accuracy: 0.8651 - val_precision: 0.8651 - val_auc: 0.9517 - val_mae: 0.1998
- val_mse: 0.0906
Epoch 27/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3076 - tp:
1281.0000 - fp: 177.0000 - tn: 1281.0000 - fn: 177.0000 - accuracy: 0.8786 -
precision: 0.8786 - auc: 0.9422 - mae: 0.1858 - mse: 0.0919 - val_loss: 0.2063 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9747 - val_mae: 0.1389
```

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- val_mse: 0.0587
Epoch 28/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2852 - tp:
1279.0000 - fp: 179.0000 - tn: 1279.0000 - fn: 179.0000 - accuracy: 0.8772 -
precision: 0.8772 - auc: 0.9502 - mae: 0.1775 - mse: 0.0885 - val_loss: 0.1913 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9789 - val_mae: 0.1259
- val_mse: 0.0545
Epoch 29/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2818 - tp:
1299.0000 - fp: 159.0000 - tn: 1299.0000 - fn: 159.0000 - accuracy: 0.8909 -
precision: 0.8909 - auc: 0.9517 - mae: 0.1693 - mse: 0.0842 - val_loss: 0.2666 -
val_tp: 112.0000 - val_fp: 14.0000 - val_tn: 112.0000 - val_fn: 14.0000 -
val_accuracy: 0.8889 - val_precision: 0.8889 - val_auc: 0.9569 - val_mae: 0.1515
- val_mse: 0.0836
Epoch 30/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2992 - tp:
1281.0000 - fp: 177.0000 - tn: 1281.0000 - fn: 177.0000 - accuracy: 0.8786 -
precision: 0.8786 - auc: 0.9461 - mae: 0.1743 - mse: 0.0903 - val_loss: 0.2772 -
val_tp: 108.0000 - val_fp: 18.0000 - val_tn: 108.0000 - val_fn: 18.0000 -
val_accuracy: 0.8571 - val_precision: 0.8571 - val_auc: 0.9538 - val_mae: 0.2005
- val_mse: 0.0898
Epoch 31/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3136 - tp:
1272.0000 - fp: 186.0000 - tn: 1272.0000 - fn: 186.0000 - accuracy: 0.8724 -
precision: 0.8724 - auc: 0.9401 - mae: 0.1950 - mse: 0.0963 - val_loss: 0.2658 -
val_tp: 110.0000 - val_fp: 16.0000 - val_tn: 110.0000 - val_fn: 16.0000 -
val_accuracy: 0.8730 - val_precision: 0.8730 - val_auc: 0.9562 - val_mae: 0.1762
- val_mse: 0.0850
Epoch 32/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3012 - tp:
1286.0000 - fp: 172.0000 - tn: 1286.0000 - fn: 172.0000 - accuracy: 0.8820 -
precision: 0.8820 - auc: 0.9457 - mae: 0.1767 - mse: 0.0902 - val_loss: 0.1955 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9772 - val_mae: 0.1308
- val_mse: 0.0552
Epoch 33/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2937 - tp:
1283.0000 - fp: 175.0000 - tn: 1283.0000 - fn: 175.0000 - accuracy: 0.8800 -
precision: 0.8800 - auc: 0.9484 - mae: 0.1844 - mse: 0.0878 - val_loss: 0.1881 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9793 - val_mae: 0.1270
- val_mse: 0.0577
Epoch 34/50
46/46 [==============================] - 16s 340ms/step - loss: 0.2705 - tp:
1293.0000 - fp: 165.0000 - tn: 1293.0000 - fn: 165.0000 - accuracy: 0.8868 -
precision: 0.8868 - auc: 0.9560 - mae: 0.1653 - mse: 0.0805 - val_loss: 0.2080 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
```

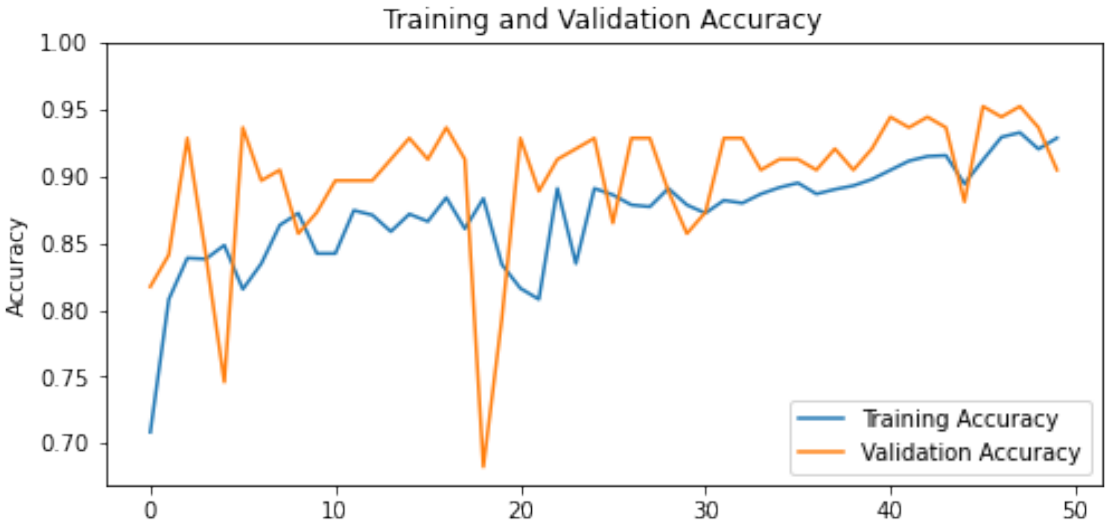
```
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9783 - val_mae: 0.1524
- val_mse: 0.0627
Epoch 35/50
46/46 [==============================] - 15s 335ms/step - loss: 0.2640 - tp:
1300.0000 - fp: 158.0000 - tn: 1300.0000 - fn: 158.0000 - accuracy: 0.8916 -
precision: 0.8916 - auc: 0.9574 - mae: 0.1612 - mse: 0.0792 - val_loss: 0.2017 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9785 - val_mae: 0.1425
- val_mse: 0.0611
Epoch 36/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2697 - tp:
1305.0000 - fp: 153.0000 - tn: 1305.0000 - fn: 153.0000 - accuracy: 0.8951 -
precision: 0.8951 - auc: 0.9559 - mae: 0.1649 - mse: 0.0813 - val_loss: 0.1875 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9791 - val_mae: 0.1182
- val_mse: 0.0567
Epoch 37/50
46/46 [==============================] - 15s 335ms/step - loss: 0.2768 - tp:
1293.0000 - fp: 165.0000 - tn: 1293.0000 - fn: 165.0000 - accuracy: 0.8868 -
precision: 0.8868 - auc: 0.9536 - mae: 0.1617 - mse: 0.0832 - val_loss: 0.2027 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9754 - val_mae: 0.1188
- val_mse: 0.0604
Epoch 38/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2664 - tp:
1298.0000 - fp: 160.0000 - tn: 1298.0000 - fn: 160.0000 - accuracy: 0.8903 -
precision: 0.8903 - auc: 0.9575 - mae: 0.1671 - mse: 0.0801 - val_loss: 0.2131 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9715 - val_mae: 0.1263
- val_mse: 0.0640
Epoch 39/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2792 - tp:
1302.0000 - fp: 156.0000 - tn: 1302.0000 - fn: 156.0000 - accuracy: 0.8930 -
precision: 0.8930 - auc: 0.9527 - mae: 0.1625 - mse: 0.0818 - val_loss: 0.2298 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9682 - val_mae: 0.1411
- val_mse: 0.0713
Epoch 40/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2619 - tp:
1309.0000 - fp: 149.0000 - tn: 1309.0000 - fn: 149.0000 - accuracy: 0.8978 -
precision: 0.8978 - auc: 0.9577 - mae: 0.1540 - mse: 0.0766 - val_loss: 0.1848 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9807 - val_mae: 0.1281
- val_mse: 0.0551
Epoch 41/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2389 - tp:
1319.0000 - fp: 139.0000 - tn: 1319.0000 - fn: 139.0000 - accuracy: 0.9047 -
precision: 0.9047 - auc: 0.9650 - mae: 0.1495 - mse: 0.0715 - val_loss: 0.1717 -
```

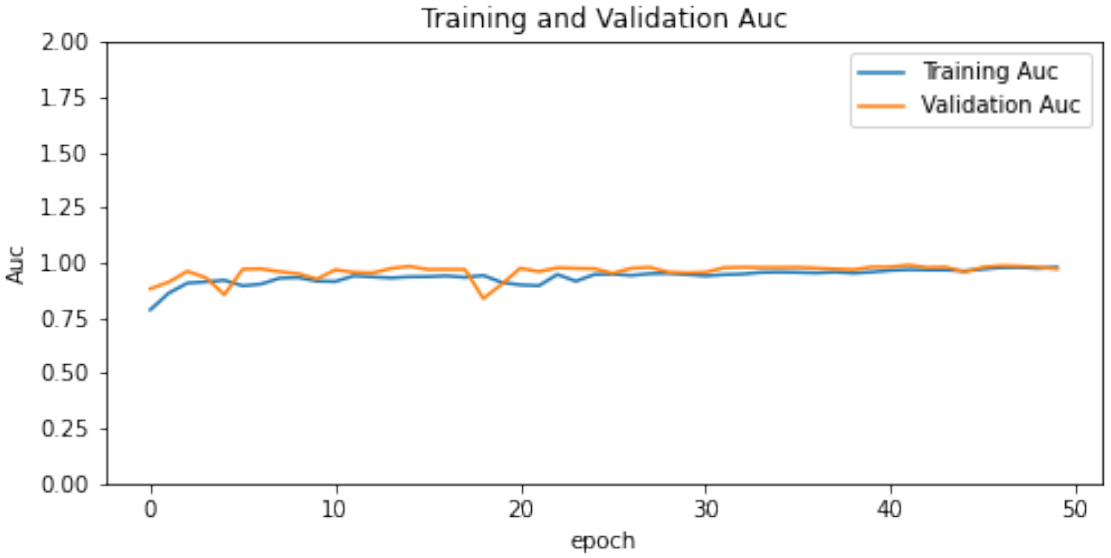
```
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9808 - val_mae: 0.1039
- val_mse: 0.0456
Epoch 42/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2268 - tp:
1329.0000 - fp: 129.0000 - tn: 1329.0000 - fn: 129.0000 - accuracy: 0.9115 -
precision: 0.9115 - auc: 0.9684 - mae: 0.1351 - mse: 0.0668 - val_loss: 0.1439 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9891 - val_mae: 0.0973
- val_mse: 0.0394
Epoch 43/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2318 - tp:
1334.0000 - fp: 124.0000 - tn: 1334.0000 - fn: 124.0000 - accuracy: 0.9150 -
precision: 0.9150 - auc: 0.9670 - mae: 0.1385 - mse: 0.0669 - val_loss: 0.1750 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9779 - val_mae: 0.0967
- val_mse: 0.0457
Epoch 44/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2322 - tp:
1335.0000 - fp: 123.0000 - tn: 1335.0000 - fn: 123.0000 - accuracy: 0.9156 -
precision: 0.9156 - auc: 0.9665 - mae: 0.1366 - mse: 0.0656 - val_loss: 0.1869 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9798 - val_mae: 0.1221
- val_mse: 0.0534
Epoch 45/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2472 - tp:
1304.0000 - fp: 154.0000 - tn: 1304.0000 - fn: 154.0000 - accuracy: 0.8944 -
precision: 0.8944 - auc: 0.9624 - mae: 0.1496 - mse: 0.0745 - val_loss: 0.2966 -
val_tp: 111.0000 - val_fp: 15.0000 - val_tn: 111.0000 - val_fn: 15.0000 -
val_accuracy: 0.8810 - val_precision: 0.8810 - val_auc: 0.9577 - val_mae: 0.1384
- val_mse: 0.0907
Epoch 46/50
46/46 [==============================] - 16s 356ms/step - loss: 0.2202 - tp:
1330.0000 - fp: 128.0000 - tn: 1330.0000 - fn: 128.0000 - accuracy: 0.9122 -
precision: 0.9122 - auc: 0.9703 - mae: 0.1247 - mse: 0.0659 - val_loss: 0.1660 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9796 - val_mae: 0.0994
- val_mse: 0.0451
Epoch 47/50
46/46 [==============================] - 15s 337ms/step - loss: 0.1867 - tp:
1355.0000 - fp: 103.0000 - tn: 1355.0000 - fn: 103.0000 - accuracy: 0.9294 -
precision: 0.9294 - auc: 0.9779 - mae: 0.1045 - mse: 0.0534 - val_loss: 0.1484 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9862 - val_mae: 0.0911
- val_mse: 0.0419
Epoch 48/50
46/46 [==============================] - 15s 337ms/step - loss: 0.1854 - tp:
1360.0000 - fp: 98.0000 - tn: 1360.0000 - fn: 98.0000 - accuracy: 0.9328 -
```

```
precision: 0.9328 - auc: 0.9782 - mae: 0.1090 - mse: 0.0534 - val_loss: 0.1619 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9840 - val_mae: 0.0862
- val_mse: 0.0451
Epoch 49/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2046 - tp:
1342.0000 - fp: 116.0000 - tn: 1342.0000 - fn: 116.0000 - accuracy: 0.9204 -
precision: 0.9204 - auc: 0.9740 - mae: 0.1198 - mse: 0.0599 - val_loss: 0.1784 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9792 - val_mae: 0.1056
- val_mse: 0.0495
Epoch 50/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1822 - tp:
1354.0000 - fp: 104.0000 - tn: 1354.0000 - fn: 104.0000 - accuracy: 0.9287 -
precision: 0.9287 - auc: 0.9797 - mae: 0.1066 - mse: 0.0543 - val_loss: 0.2075 -
val_tp: 114.0000 - val_fp: 12.0000 - val_tn: 114.0000 - val_fn: 12.0000 -
val_accuracy: 0.9048 - val_precision: 0.9048 - val_auc: 0.9716 - val_mae: 0.1031
- val_mse: 0.0596
```

1.1.10 6. Display History 2

[18]:
```
print_history(history2)
```





1.1.11 7. Evaluate the model 2

[19]:
```
print_model_evaluation(model2);
```

```
714/714 [==============================] - 3s 4ms/step - loss: 0.2949 - tp:
650.0000 - fp: 64.0000 - tn: 650.0000 - fn: 64.0000 - accuracy: 0.9104 -
precision: 0.9104 - auc: 0.9596 - mae: 0.1102 - mse: 0.0753
loss : 0.295
tp : 650.0
```

```
fp : 64.0
tn : 650.0
fn : 64.0
accuracy : 0.91
precision : 0.91
auc : 0.96
mae : 0.11
mse : 0.075
```

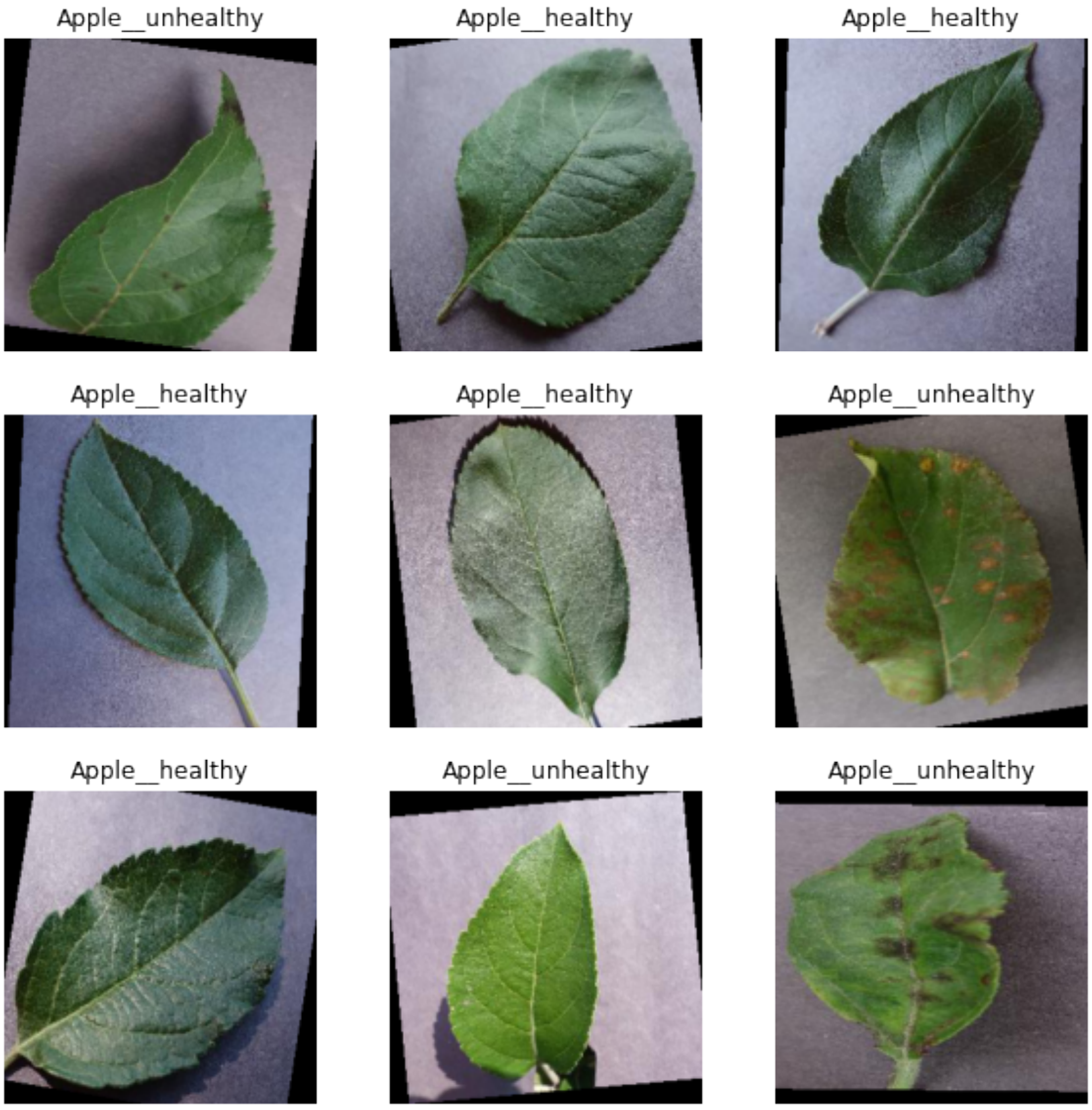
1.1.12 8. Predict with model 2

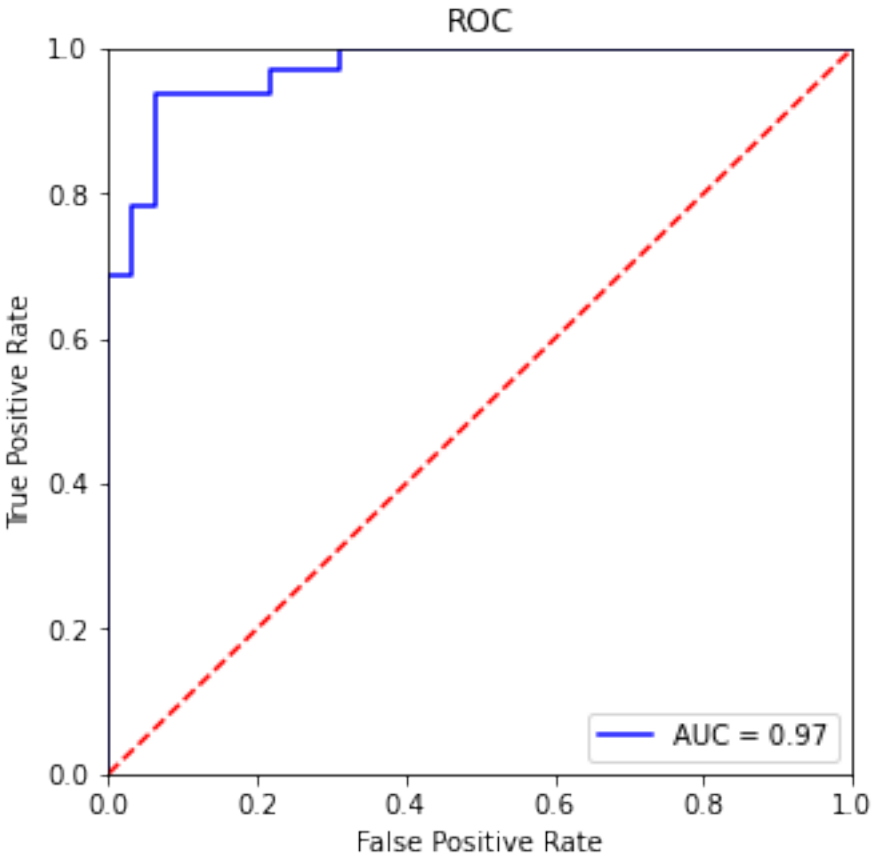
[20]:
```
predict_and_print_roc(model2);
```

```
Label Predictions:
 [1, 0, 0, 0, 0, 1, 0, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1,
1, 0, 1, 0, 0, 0]
Real Labels:
 [1, 0, 0, 0, 0, 1, 0, 0, 1, 1, 1, 1, 0, 0, 1, 1, 0, 1, 0, 1, 1, 0, 1, 1, 1, 1,
1, 0, 1, 0, 0, 0]

Confusion Matrix:
[[13  2]
 [ 0 17]]

Accuracy: 0.94
```


Apple__unhealthy
Apple__healthy
Apple__healthy
Apple__healthy
Apple__healthy
Apple__unhealthy
Apple__healthy
Apple__unhealthy
Apple__unhealthy



1.1.13 3. Create and compile model 3

This model has like the previous model three convolution layers. It starts with a small number of neurons and gradually increases its neuron amount. In between every convolution layer, a max pooling layer manipulates the values. Additionally, 20% of random values are dropped at the end of the hidden layers. The result from the hidden layers is then flattened with three dense layers that again gradually become smaller.

[21]:
```
model3 = tf.keras.models.Sequential([
    tf.keras.layers.Conv2D(32, (3, 3), input_shape=(IMG_SIZE[0], IMG_SIZE[1],␣
↪3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.MaxPooling2D((2, 2)),
    tf.keras.layers.Conv2D(64, (3, 3),
                           padding='same', activation='relu', use_bias=False),
    tf.keras.layers.MaxPooling2D((2, 2)),
    tf.keras.layers.Conv2D(128, (3, 3),
                       padding='same', activation='relu', use_bias=False),
    tf.keras.layers.Dropout(0.2),
    tf.keras.layers.Flatten(),
```

```
    tf.keras.layers.Dense(16, activation='relu', use_bias=False),
    tf.keras.layers.Dense(8, activation='relu', use_bias=False),
    tf.keras.layers.Dense(num_classes, activation='softmax')
])
```

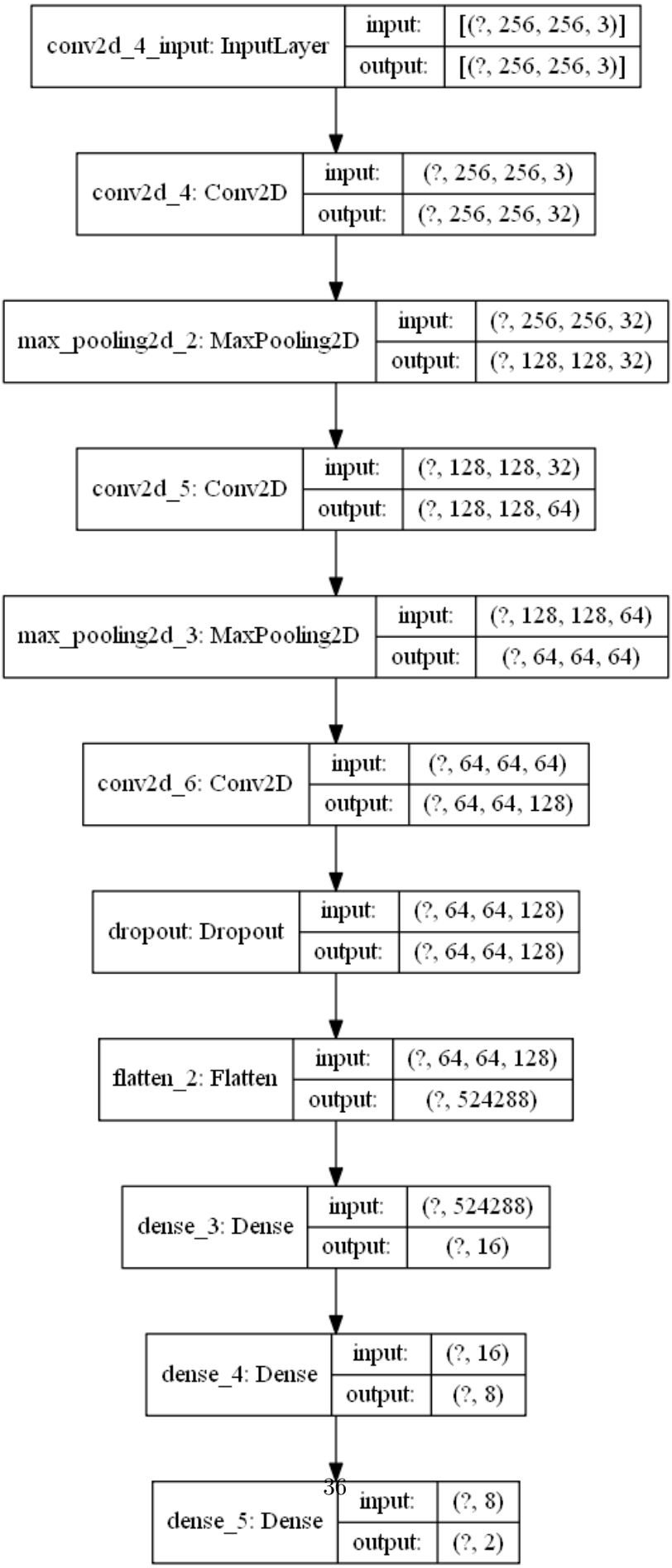
[22]:
```
opt = tf.keras.optimizers.Adam(lr=LEARNING_RATE)
model3.compile(optimizer=opt,
               loss='categorical_crossentropy',
               metrics=METRICS)
```

1.1.14 4. Display model structure 3

[23]:
```
model3.summary()
tf.keras.utils.plot_model(model3, show_shapes=True)
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 256, 256, 32)      864
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 128, 128, 32)      0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 128, 128, 64)      18432
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 64, 64, 64)        0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 64, 64, 128)       73728
_________________________________________________________________
dropout (Dropout)            (None, 64, 64, 128)       0
_________________________________________________________________
flatten_2 (Flatten)          (None, 524288)            0
_________________________________________________________________
dense_3 (Dense)              (None, 16)                8388608
_________________________________________________________________
dense_4 (Dense)              (None, 8)                 128
_________________________________________________________________
dense_5 (Dense)              (None, 2)                 18
=================================================================
Total params: 8,481,778
Trainable params: 8,481,778
Non-trainable params: 0
_________________________________________________________________
```

[23]:


conv2d_4_input: InputLayer
input: [(?, 256, 256, 3)]
output: [(?, 256, 256, 3)]
conv2d_4: Conv2D
input: (?, 256, 256, 3)
output: (?, 256, 256, 32)
max_pooling2d_2: MaxPooling2D
input: (?, 256, 256, 32)
output: (?, 128, 128, 32)
conv2d_5: Conv2D
input: (?, 128, 128, 32)
output: (?, 128, 128, 64)
max_pooling2d_3: MaxPooling2D
input: (?, 128, 128, 64)
output: (?, 64, 64, 64)
conv2d_6: Conv2D
input: (?, 64, 64, 64)
output: (?, 64, 64, 128)
dropout: Dropout
input: (?, 64, 64, 128)
output: (?, 64, 64, 128)
flatten_2: Flatten
input: (?, 64, 64, 128)
output: (?, 524288)
dense_3: Dense
input: (?, 524288)
output: (?, 16)
dense_4: Dense
input: (?, 16)
output: (?, 8)
dense_5: Dense
input: (?, 8)
output: (?, 2)

1.1.15 5. Training model 3

[24]:
```
history3 = train_model(model3, "Model_3")
```

```
Epoch 1/50
46/46 [==============================] - 16s 356ms/step - loss: 0.7928 - tp:
1475.0000 - fp: 697.0000 - tn: 1475.0000 - fn: 697.0000 - accuracy: 0.6791 -
precision: 0.6791 - auc: 0.7693 - mae: 0.3551 - mse: 0.1954 - val_loss: 0.5186 -
val_tp: 106.0000 - val_fp: 20.0000 - val_tn: 106.0000 - val_fn: 20.0000 -
val_accuracy: 0.8413 - val_precision: 0.8413 - val_auc: 0.8693 - val_mae: 0.3842
- val_mse: 0.1738
Epoch 2/50
46/46 [==============================] - 15s 336ms/step - loss: 0.5012 - tp:
1149.0000 - fp: 309.0000 - tn: 1149.0000 - fn: 309.0000 - accuracy: 0.7881 -
precision: 0.7881 - auc: 0.8445 - mae: 0.3200 - mse: 0.1626 - val_loss: 0.2349 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9697 - val_mae: 0.1596
- val_mse: 0.0633
Epoch 3/50
46/46 [==============================] - 15s 336ms/step - loss: 0.3193 - tp:
1268.0000 - fp: 190.0000 - tn: 1268.0000 - fn: 190.0000 - accuracy: 0.8697 -
precision: 0.8697 - auc: 0.9383 - mae: 0.1915 - mse: 0.0964 - val_loss: 0.2989 -
val_tp: 111.0000 - val_fp: 15.0000 - val_tn: 111.0000 - val_fn: 15.0000 -
val_accuracy: 0.8810 - val_precision: 0.8810 - val_auc: 0.9448 - val_mae: 0.1800
- val_mse: 0.0942
Epoch 4/50
46/46 [==============================] - 16s 337ms/step - loss: 0.2667 - tp:
1300.0000 - fp: 158.0000 - tn: 1300.0000 - fn: 158.0000 - accuracy: 0.8916 -
precision: 0.8916 - auc: 0.9568 - mae: 0.1661 - mse: 0.0807 - val_loss: 0.2337 -
val_tp: 115.0000 - val_fp: 11.0000 - val_tn: 115.0000 - val_fn: 11.0000 -
val_accuracy: 0.9127 - val_precision: 0.9127 - val_auc: 0.9677 - val_mae: 0.1440
- val_mse: 0.0648
Epoch 5/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2768 - tp:
1287.0000 - fp: 171.0000 - tn: 1287.0000 - fn: 171.0000 - accuracy: 0.8827 -
precision: 0.8827 - auc: 0.9531 - mae: 0.1712 - mse: 0.0847 - val_loss: 0.2156 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9732 - val_mae: 0.1203
- val_mse: 0.0645
Epoch 6/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2313 - tp:
1325.0000 - fp: 133.0000 - tn: 1325.0000 - fn: 133.0000 - accuracy: 0.9088 -
precision: 0.9088 - auc: 0.9678 - mae: 0.1384 - mse: 0.0679 - val_loss: 0.1876 -
val_tp: 113.0000 - val_fp: 13.0000 - val_tn: 113.0000 - val_fn: 13.0000 -
val_accuracy: 0.8968 - val_precision: 0.8968 - val_auc: 0.9792 - val_mae: 0.1202
```

```
- val_mse: 0.0571
Epoch 7/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2256 - tp:
1316.0000 - fp: 142.0000 - tn: 1316.0000 - fn: 142.0000 - accuracy: 0.9026 -
precision: 0.9026 - auc: 0.9693 - mae: 0.1342 - mse: 0.0704 - val_loss: 0.1771 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9795 - val_mae: 0.1113
- val_mse: 0.0455
Epoch 8/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2123 - tp:
1344.0000 - fp: 114.0000 - tn: 1344.0000 - fn: 114.0000 - accuracy: 0.9218 -
precision: 0.9218 - auc: 0.9723 - mae: 0.1265 - mse: 0.0621 - val_loss: 0.1875 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9774 - val_mae: 0.1129
- val_mse: 0.0550
Epoch 9/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2096 - tp:
1339.0000 - fp: 119.0000 - tn: 1339.0000 - fn: 119.0000 - accuracy: 0.9184 -
precision: 0.9184 - auc: 0.9730 - mae: 0.1252 - mse: 0.0613 - val_loss: 0.1542 -
val_tp: 123.0000 - val_fp: 3.0000 - val_tn: 123.0000 - val_fn: 3.0000 -
val_accuracy: 0.9762 - val_precision: 0.9762 - val_auc: 0.9879 - val_mae: 0.1076
- val_mse: 0.0347
Epoch 10/50
46/46 [==============================] - 15s 337ms/step - loss: 0.2674 - tp:
1297.0000 - fp: 161.0000 - tn: 1297.0000 - fn: 161.0000 - accuracy: 0.8896 -
precision: 0.8896 - auc: 0.9562 - mae: 0.1605 - mse: 0.0809 - val_loss: 0.1716 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9799 - val_mae: 0.1057
- val_mse: 0.0419
Epoch 11/50
46/46 [==============================] - 15s 336ms/step - loss: 0.2047 - tp:
1340.0000 - fp: 118.0000 - tn: 1340.0000 - fn: 118.0000 - accuracy: 0.9191 -
precision: 0.9191 - auc: 0.9744 - mae: 0.1249 - mse: 0.0600 - val_loss: 0.1713 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9832 - val_mae: 0.1120
- val_mse: 0.0422
Epoch 12/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1853 - tp:
1356.0000 - fp: 102.0000 - tn: 1356.0000 - fn: 102.0000 - accuracy: 0.9300 -
precision: 0.9300 - auc: 0.9786 - mae: 0.1089 - mse: 0.0532 - val_loss: 0.1316 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9921 - val_mae: 0.0964
- val_mse: 0.0365
Epoch 13/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1788 - tp:
1354.0000 - fp: 104.0000 - tn: 1354.0000 - fn: 104.0000 - accuracy: 0.9287 -
precision: 0.9287 - auc: 0.9800 - mae: 0.1032 - mse: 0.0521 - val_loss: 0.1179 -
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
```

```
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9949 - val_mae: 0.0912
- val_mse: 0.0318
Epoch 14/50
46/46 [==============================] - 15s 337ms/step - loss: 0.1901 - tp:
1352.0000 - fp: 106.0000 - tn: 1352.0000 - fn: 106.0000 - accuracy: 0.9273 -
precision: 0.9273 - auc: 0.9775 - mae: 0.1081 - mse: 0.0554 - val_loss: 0.2081 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9735 - val_mae: 0.1125
- val_mse: 0.0558
Epoch 15/50
46/46 [==============================] - 16s 339ms/step - loss: 0.1688 - tp:
1362.0000 - fp: 96.0000 - tn: 1362.0000 - fn: 96.0000 - accuracy: 0.9342 -
precision: 0.9342 - auc: 0.9823 - mae: 0.1017 - mse: 0.0487 - val_loss: 0.1201 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9906 - val_mae: 0.0758
- val_mse: 0.0286
Epoch 16/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1528 - tp:
1370.0000 - fp: 88.0000 - tn: 1370.0000 - fn: 88.0000 - accuracy: 0.9396 -
precision: 0.9396 - auc: 0.9857 - mae: 0.0922 - mse: 0.0446 - val_loss: 0.1256 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9918 - val_mae: 0.0855
- val_mse: 0.0347
Epoch 17/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1270 - tp:
1387.0000 - fp: 71.0000 - tn: 1387.0000 - fn: 71.0000 - accuracy: 0.9513 -
precision: 0.9513 - auc: 0.9896 - mae: 0.0769 - mse: 0.0357 - val_loss: 0.1224 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9912 - val_mae: 0.0802
- val_mse: 0.0376
Epoch 18/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1452 - tp:
1375.0000 - fp: 83.0000 - tn: 1375.0000 - fn: 83.0000 - accuracy: 0.9431 -
precision: 0.9431 - auc: 0.9873 - mae: 0.0802 - mse: 0.0429 - val_loss: 0.1627 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9852 - val_mae: 0.1114
- val_mse: 0.0468
Epoch 19/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1505 - tp:
1368.0000 - fp: 90.0000 - tn: 1368.0000 - fn: 90.0000 - accuracy: 0.9383 -
precision: 0.9383 - auc: 0.9856 - mae: 0.0901 - mse: 0.0442 - val_loss: 0.1131 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9921 - val_mae: 0.0646
- val_mse: 0.0336
Epoch 20/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1284 - tp:
1383.0000 - fp: 75.0000 - tn: 1383.0000 - fn: 75.0000 - accuracy: 0.9486 -
precision: 0.9486 - auc: 0.9893 - mae: 0.0792 - mse: 0.0373 - val_loss: 0.1152 -
```

```
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9917 - val_mae: 0.0644
- val_mse: 0.0326
Epoch 21/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1126 - tp:
1397.0000 - fp: 61.0000 - tn: 1397.0000 - fn: 61.0000 - accuracy: 0.9582 -
precision: 0.9582 - auc: 0.9918 - mae: 0.0689 - mse: 0.0323 - val_loss: 0.1342 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9880 - val_mae: 0.0655
- val_mse: 0.0356
Epoch 22/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1593 - tp:
1366.0000 - fp: 92.0000 - tn: 1366.0000 - fn: 92.0000 - accuracy: 0.9369 -
precision: 0.9369 - auc: 0.9838 - mae: 0.0911 - mse: 0.0466 - val_loss: 0.1058 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9936 - val_mae: 0.0614
- val_mse: 0.0316
Epoch 23/50
46/46 [==============================] - 15s 337ms/step - loss: 0.1158 - tp:
1387.0000 - fp: 71.0000 - tn: 1387.0000 - fn: 71.0000 - accuracy: 0.9513 -
precision: 0.9513 - auc: 0.9914 - mae: 0.0672 - mse: 0.0350 - val_loss: 0.1229 -
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9905 - val_mae: 0.0673
- val_mse: 0.0367
Epoch 24/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0934 - tp:
1415.0000 - fp: 43.0000 - tn: 1415.0000 - fn: 43.0000 - accuracy: 0.9705 -
precision: 0.9705 - auc: 0.9941 - mae: 0.0578 - mse: 0.0256 - val_loss: 0.0988 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9890 - val_mae: 0.0390
- val_mse: 0.0241
Epoch 25/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1272 - tp:
1399.0000 - fp: 59.0000 - tn: 1399.0000 - fn: 59.0000 - accuracy: 0.9595 -
precision: 0.9595 - auc: 0.9896 - mae: 0.0678 - mse: 0.0358 - val_loss: 0.1041 -
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9926 - val_mae: 0.0563
- val_mse: 0.0272
Epoch 26/50
46/46 [==============================] - 16s 338ms/step - loss: 0.1126 - tp:
1393.0000 - fp: 65.0000 - tn: 1393.0000 - fn: 65.0000 - accuracy: 0.9554 -
precision: 0.9554 - auc: 0.9913 - mae: 0.0642 - mse: 0.0323 - val_loss: 0.1520 -
val_tp: 117.0000 - val_fp: 9.0000 - val_tn: 117.0000 - val_fn: 9.0000 -
val_accuracy: 0.9286 - val_precision: 0.9286 - val_auc: 0.9879 - val_mae: 0.0745
- val_mse: 0.0461
Epoch 27/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1266 - tp:
1392.0000 - fp: 66.0000 - tn: 1392.0000 - fn: 66.0000 - accuracy: 0.9547 -
```

```
precision: 0.9547 - auc: 0.9895 - mae: 0.0716 - mse: 0.0360 - val_loss: 0.1181 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9866 - val_mae: 0.0499
- val_mse: 0.0303
Epoch 28/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1007 - tp:
1402.0000 - fp: 56.0000 - tn: 1402.0000 - fn: 56.0000 - accuracy: 0.9616 -
precision: 0.9616 - auc: 0.9938 - mae: 0.0566 - mse: 0.0291 - val_loss: 0.1010 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9940 - val_mae: 0.0473
- val_mse: 0.0274
Epoch 29/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0749 - tp:
1414.0000 - fp: 44.0000 - tn: 1414.0000 - fn: 44.0000 - accuracy: 0.9698 -
precision: 0.9698 - auc: 0.9966 - mae: 0.0437 - mse: 0.0221 - val_loss: 0.1248 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9931 - val_mae: 0.0536
- val_mse: 0.0360
Epoch 30/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1030 - tp:
1405.0000 - fp: 53.0000 - tn: 1405.0000 - fn: 53.0000 - accuracy: 0.9636 -
precision: 0.9636 - auc: 0.9922 - mae: 0.0534 - mse: 0.0278 - val_loss: 0.1238 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9893 - val_mae: 0.0550
- val_mse: 0.0307
Epoch 31/50
46/46 [==============================] - 16s 339ms/step - loss: 0.0822 - tp:
1408.0000 - fp: 50.0000 - tn: 1408.0000 - fn: 50.0000 - accuracy: 0.9657 -
precision: 0.9657 - auc: 0.9955 - mae: 0.0508 - mse: 0.0240 - val_loss: 0.1061 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9934 - val_mae: 0.0470
- val_mse: 0.0251
Epoch 32/50
46/46 [==============================] - 16s 338ms/step - loss: 0.0967 - tp:
1405.0000 - fp: 53.0000 - tn: 1405.0000 - fn: 53.0000 - accuracy: 0.9636 -
precision: 0.9636 - auc: 0.9938 - mae: 0.0527 - mse: 0.0278 - val_loss: 0.1130 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9932 - val_mae: 0.0567
- val_mse: 0.0350
Epoch 33/50
46/46 [==============================] - 16s 340ms/step - loss: 0.0923 - tp:
1411.0000 - fp: 47.0000 - tn: 1411.0000 - fn: 47.0000 - accuracy: 0.9678 -
precision: 0.9678 - auc: 0.9933 - mae: 0.0496 - mse: 0.0246 - val_loss: 0.1569 -
val_tp: 119.0000 - val_fp: 7.0000 - val_tn: 119.0000 - val_fn: 7.0000 -
val_accuracy: 0.9444 - val_precision: 0.9444 - val_auc: 0.9858 - val_mae: 0.0531
- val_mse: 0.0385
Epoch 34/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0551 - tp:
```

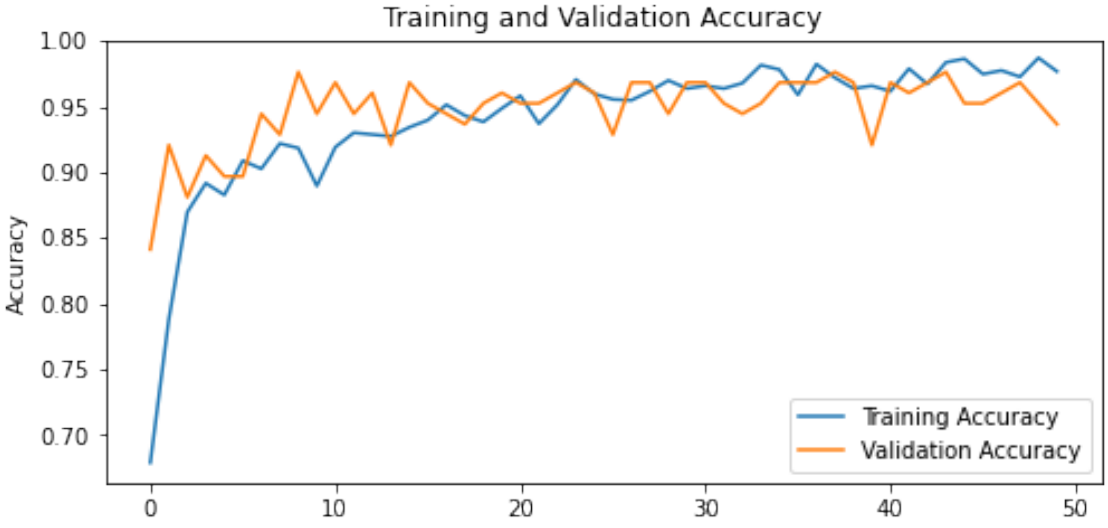
```
1431.0000 - fp: 27.0000 - tn: 1431.0000 - fn: 27.0000 - accuracy: 0.9815 -
precision: 0.9815 - auc: 0.9976 - mae: 0.0339 - mse: 0.0153 - val_loss: 0.1376 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9865 - val_mae: 0.0542
- val_mse: 0.0354
Epoch 35/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0533 - tp:
1426.0000 - fp: 32.0000 - tn: 1426.0000 - fn: 32.0000 - accuracy: 0.9781 -
precision: 0.9781 - auc: 0.9983 - mae: 0.0316 - mse: 0.0158 - val_loss: 0.1557 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9849 - val_mae: 0.0468
- val_mse: 0.0338
Epoch 36/50
46/46 [==============================] - 15s 336ms/step - loss: 0.1060 - tp:
1398.0000 - fp: 60.0000 - tn: 1398.0000 - fn: 60.0000 - accuracy: 0.9588 -
precision: 0.9588 - auc: 0.9930 - mae: 0.0546 - mse: 0.0311 - val_loss: 0.1469 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9852 - val_mae: 0.0502
- val_mse: 0.0298
Epoch 37/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0485 - tp:
1432.0000 - fp: 26.0000 - tn: 1432.0000 - fn: 26.0000 - accuracy: 0.9822 -
precision: 0.9822 - auc: 0.9989 - mae: 0.0348 - mse: 0.0137 - val_loss: 0.1379 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9880 - val_mae: 0.0348
- val_mse: 0.0282
Epoch 38/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0742 - tp:
1417.0000 - fp: 41.0000 - tn: 1417.0000 - fn: 41.0000 - accuracy: 0.9719 -
precision: 0.9719 - auc: 0.9962 - mae: 0.0389 - mse: 0.0215 - val_loss: 0.0659 -
val_tp: 123.0000 - val_fp: 3.0000 - val_tn: 123.0000 - val_fn: 3.0000 -
val_accuracy: 0.9762 - val_precision: 0.9762 - val_auc: 0.9977 - val_mae: 0.0455
- val_mse: 0.0205
Epoch 39/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0947 - tp:
1405.0000 - fp: 53.0000 - tn: 1405.0000 - fn: 53.0000 - accuracy: 0.9636 -
precision: 0.9636 - auc: 0.9941 - mae: 0.0540 - mse: 0.0271 - val_loss: 0.1701 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9790 - val_mae: 0.0472
- val_mse: 0.0318
Epoch 40/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0858 - tp:
1408.0000 - fp: 50.0000 - tn: 1408.0000 - fn: 50.0000 - accuracy: 0.9657 -
precision: 0.9657 - auc: 0.9956 - mae: 0.0457 - mse: 0.0253 - val_loss: 0.3218 -
val_tp: 116.0000 - val_fp: 10.0000 - val_tn: 116.0000 - val_fn: 10.0000 -
val_accuracy: 0.9206 - val_precision: 0.9206 - val_auc: 0.9604 - val_mae: 0.0901
- val_mse: 0.0677
Epoch 41/50
```

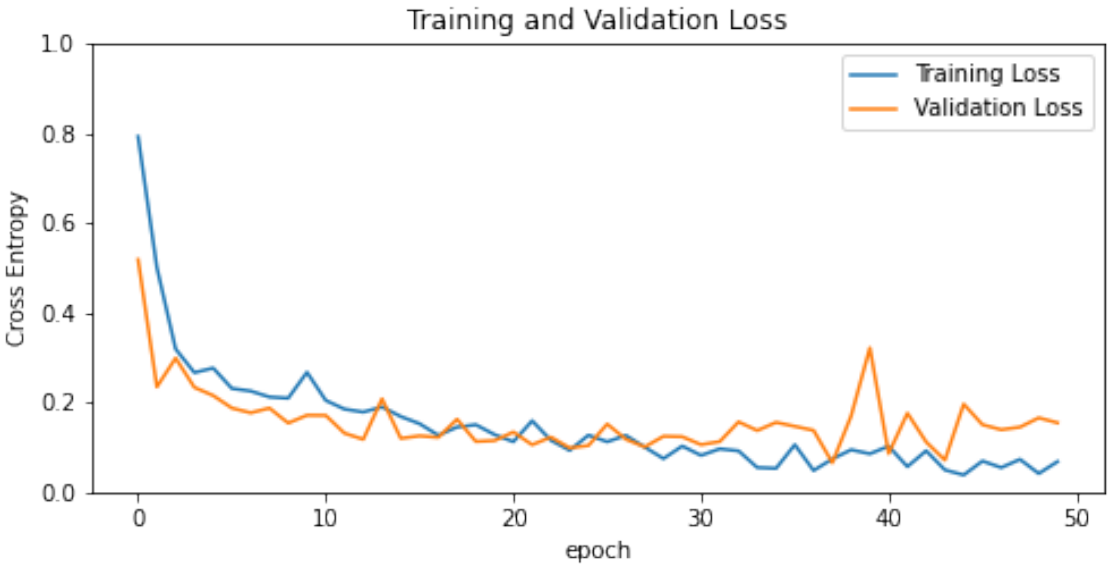
```
46/46 [==============================] - 16s 338ms/step - loss: 0.1026 - tp:
1402.0000 - fp: 56.0000 - tn: 1402.0000 - fn: 56.0000 - accuracy: 0.9616 -
precision: 0.9616 - auc: 0.9933 - mae: 0.0562 - mse: 0.0301 - val_loss: 0.0863 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9955 - val_mae: 0.0472
- val_mse: 0.0252
Epoch 42/50
46/46 [==============================] - 15s 337ms/step - loss: 0.0572 - tp:
1427.0000 - fp: 31.0000 - tn: 1427.0000 - fn: 31.0000 - accuracy: 0.9787 -
precision: 0.9787 - auc: 0.9980 - mae: 0.0352 - mse: 0.0170 - val_loss: 0.1763 -
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9866 - val_mae: 0.0540
- val_mse: 0.0330
Epoch 43/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0924 - tp:
1410.0000 - fp: 48.0000 - tn: 1410.0000 - fn: 48.0000 - accuracy: 0.9671 -
precision: 0.9671 - auc: 0.9941 - mae: 0.0474 - mse: 0.0251 - val_loss: 0.1121 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9892 - val_mae: 0.0393
- val_mse: 0.0230
Epoch 44/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0498 - tp:
1434.0000 - fp: 24.0000 - tn: 1434.0000 - fn: 24.0000 - accuracy: 0.9835 -
precision: 0.9835 - auc: 0.9979 - mae: 0.0292 - mse: 0.0131 - val_loss: 0.0717 -
val_tp: 123.0000 - val_fp: 3.0000 - val_tn: 123.0000 - val_fn: 3.0000 -
val_accuracy: 0.9762 - val_precision: 0.9762 - val_auc: 0.9971 - val_mae: 0.0310
- val_mse: 0.0189
Epoch 45/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0385 - tp:
1438.0000 - fp: 20.0000 - tn: 1438.0000 - fn: 20.0000 - accuracy: 0.9863 -
precision: 0.9863 - auc: 0.9991 - mae: 0.0242 - mse: 0.0105 - val_loss: 0.1966 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9819 - val_mae: 0.0607
- val_mse: 0.0454
Epoch 46/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0696 - tp:
1421.0000 - fp: 37.0000 - tn: 1421.0000 - fn: 37.0000 - accuracy: 0.9746 -
precision: 0.9746 - auc: 0.9966 - mae: 0.0370 - mse: 0.0194 - val_loss: 0.1506 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9917 - val_mae: 0.0556
- val_mse: 0.0414
Epoch 47/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0550 - tp:
1425.0000 - fp: 33.0000 - tn: 1425.0000 - fn: 33.0000 - accuracy: 0.9774 -
precision: 0.9774 - auc: 0.9977 - mae: 0.0338 - mse: 0.0164 - val_loss: 0.1395 -
val_tp: 121.0000 - val_fp: 5.0000 - val_tn: 121.0000 - val_fn: 5.0000 -
val_accuracy: 0.9603 - val_precision: 0.9603 - val_auc: 0.9795 - val_mae: 0.0439
- val_mse: 0.0306
```

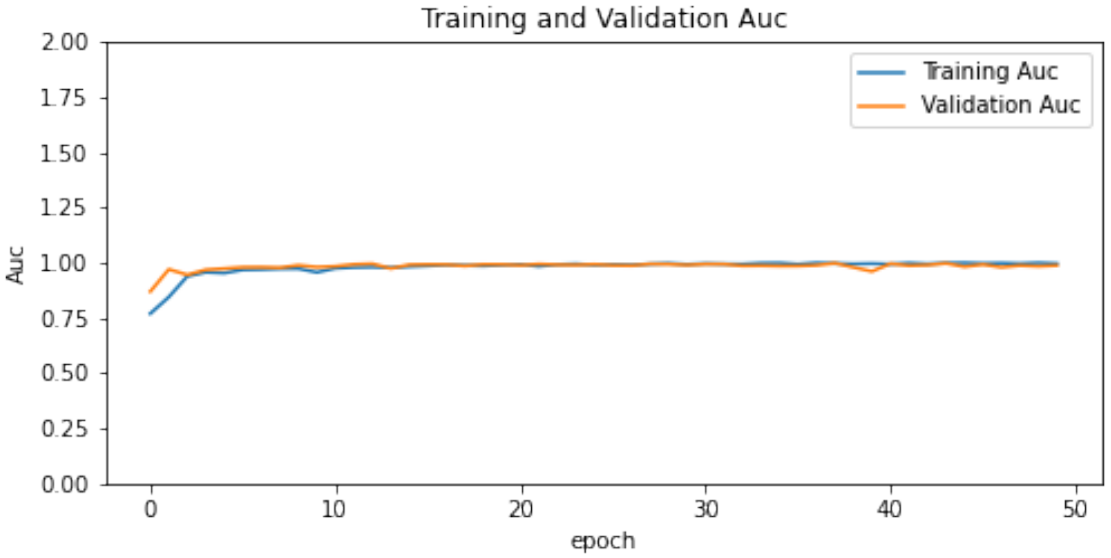
```
Epoch 48/50
46/46 [==============================] - 15s 336ms/step - loss: 0.0733 - tp:
1418.0000 - fp: 40.0000 - tn: 1418.0000 - fn: 40.0000 - accuracy: 0.9726 -
precision: 0.9726 - auc: 0.9956 - mae: 0.0378 - mse: 0.0199 - val_loss: 0.1452 -
val_tp: 122.0000 - val_fp: 4.0000 - val_tn: 122.0000 - val_fn: 4.0000 -
val_accuracy: 0.9683 - val_precision: 0.9683 - val_auc: 0.9873 - val_mae: 0.0370
- val_mse: 0.0294
Epoch 49/50
46/46 [==============================] - 15s 335ms/step - loss: 0.0418 - tp:
1439.0000 - fp: 19.0000 - tn: 1439.0000 - fn: 19.0000 - accuracy: 0.9870 -
precision: 0.9870 - auc: 0.9988 - mae: 0.0238 - mse: 0.0109 - val_loss: 0.1659 -
val_tp: 120.0000 - val_fp: 6.0000 - val_tn: 120.0000 - val_fn: 6.0000 -
val_accuracy: 0.9524 - val_precision: 0.9524 - val_auc: 0.9839 - val_mae: 0.0575
- val_mse: 0.0413
Epoch 50/50
46/46 [==============================] - 15s 335ms/step - loss: 0.0684 - tp:
1424.0000 - fp: 34.0000 - tn: 1424.0000 - fn: 34.0000 - accuracy: 0.9767 -
precision: 0.9767 - auc: 0.9957 - mae: 0.0343 - mse: 0.0186 - val_loss: 0.1548 -
val_tp: 118.0000 - val_fp: 8.0000 - val_tn: 118.0000 - val_fn: 8.0000 -
val_accuracy: 0.9365 - val_precision: 0.9365 - val_auc: 0.9874 - val_mae: 0.0773
- val_mse: 0.0470
```

1.1.16 6. Display History 3

[25]:
```
print_history(history3)
```







1.1.17 7. Evaluate the model 3

[26]:
```
print_model_evaluation(model3);
```

```
714/714 [==============================] - 3s 4ms/step - loss: 0.1899 - tp:
669.0000 - fp: 45.0000 - tn: 669.0000 - fn: 45.0000 - accuracy: 0.9370 -
precision: 0.9370 - auc: 0.9823 - mae: 0.0709 - mse: 0.0514
loss : 0.19
tp : 669.0
```

```
fp : 45.0
tn : 669.0
fn : 45.0
accuracy : 0.937
precision : 0.937
auc : 0.982
mae : 0.071
mse : 0.051
```

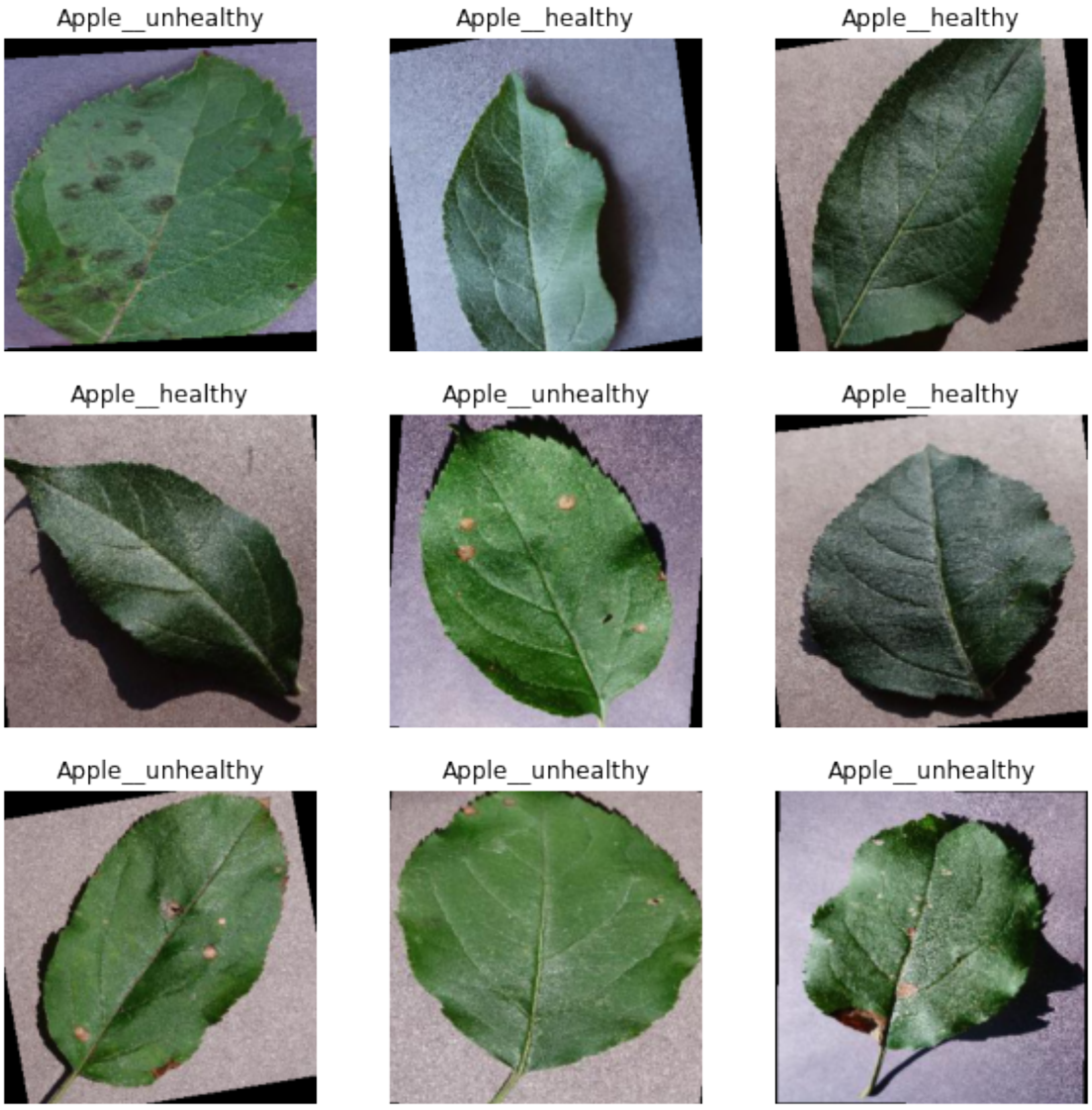
1.1.18 8. Predict with model 3

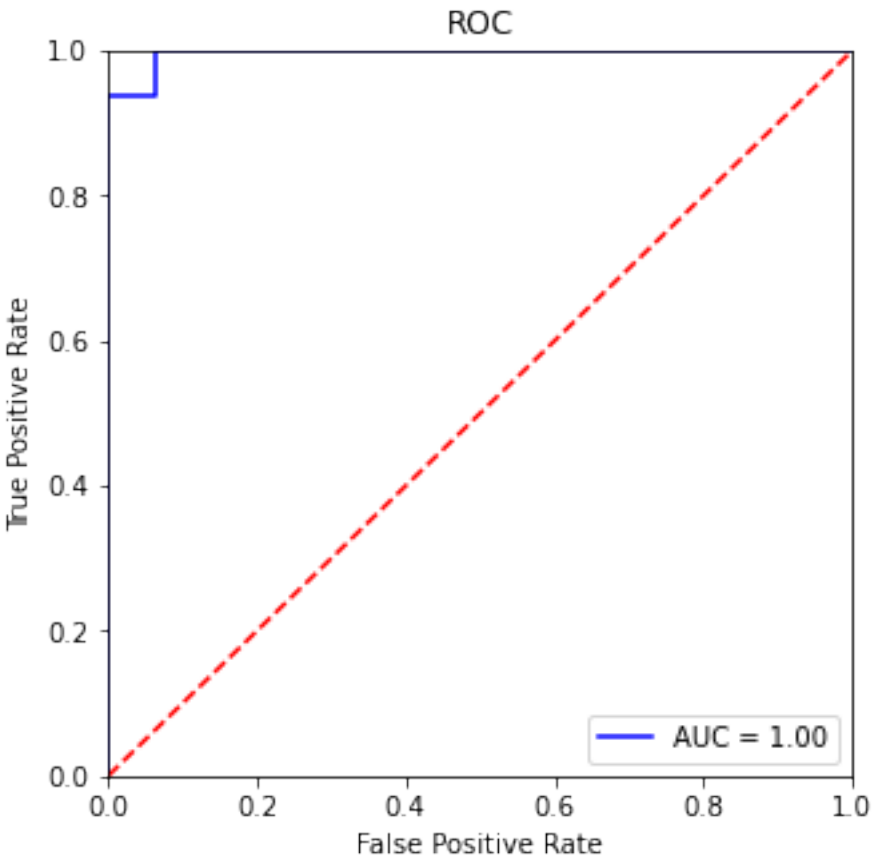
[27]:
```
predict_and_print_roc(model3);
```

```
Label Predictions:
 [1, 0, 0, 0, 1, 0, 1, 1, 1, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0,
0, 1, 1, 0, 0, 1]
Real Labels:
 [1, 0, 0, 0, 1, 0, 1, 1, 1, 1, 0, 1, 0, 0, 1, 1, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0,
0, 1, 1, 0, 0, 1]

Confusion Matrix:
[[14  2]
 [ 0 16]]

Accuracy: 0.94
```


Apple__unhealthy
Apple__healthy
Apple__healthy
Apple__healthy
Apple__unhealthy
Apple__healthy
Apple__unhealthy
Apple__unhealthy
Apple__unhealthy



1.1.19 9. Save test model

[28]:
```
model3.save(MODEL_NAME)
```

1.1.20 10. Load test model

[29]:
```
loaded_model = tf.keras.models.load_model(MODEL_NAME)
```

1.1.21 11. Test loaded model on image:

[30]:
```
healthyTestImagePath = "./plant_images/test/Apple__healthy/
↪2d7f4c07-f4f4-4589-aa82-49e05e5b253b___RS_HL 8056.jpg"

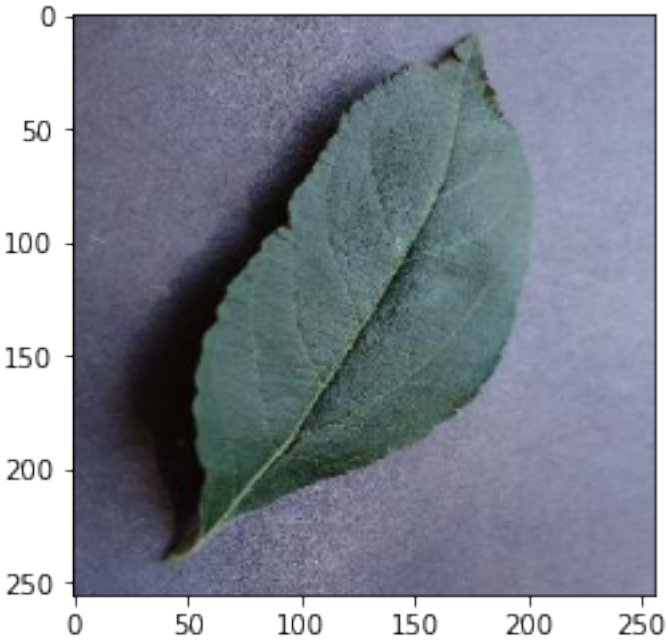
healthyTestImage = image.load_img(healthyTestImagePath)
plt.imshow(healthyTestImage)
healthyTestImage = (np.expand_dims(healthyTestImage,0))
predictions = loaded_model.predict(healthyTestImage)

print('Expected result: [1, 0] \n')
```

```
print('Result: ', predictions, '\n')
```

```
Expected result: [1, 0]

Result:  [[1. 0.]]
```

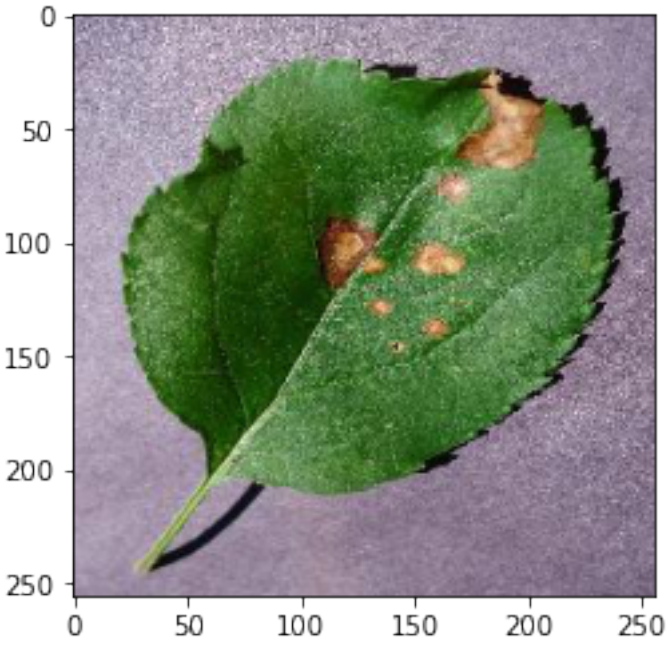


[34]:
```
unhealthyTestImagePath = "./plant_images/test/Apple__unhealthy/
 ↪0ebea6f4-08e4-4380-86f8-34d854697e32___JR_FrgE.S 2877.jpg"
unhealthyTestImage = image.load_img(unhealthyTestImagePath)
plt.imshow(unhealthyTestImage)
unhealthyTestImage = (np.expand_dims(unhealthyTestImage,0))
predictions = loaded_model.predict(unhealthyTestImage)

print('Expected result: [0, 1] \n')
print('Result: ', predictions, '\n')
```

```
Expected result: [0, 1]

Result:  [[0. 1.]]
```



1.2 Summary

All the models were trained with 50 epochs. The reason for this is that after this amount no special improvments could be observed anymore and overfitting started to become a problem (tested with 100 epochs before).

1.2.1 Model 1:

This is a very simple model that already works very well. Showing that a small amount of layers can already create a very good model.

1.2.2 Model 2:

Has more hidden and dense layers than model 1. Increasing the amount of neurons each layer, however, didn't seem to work as well as expected. Nonetheless, more layers created a better accuracy overall.

1.2.3 Model 3:

This model seems to perform the best, based on the false positive and false negative validation. Decreasing the size of the image and the neurons and leaving the amount of layers around 2-3 seemed to have the best effect.

[ ]: