

Reference: Keras tutorial : <https://www.tensorflow.org/tutorials/generative/autoencoder>

This file trains an autoencoder with the instances of normal ECGs in the training data. Then, it measures the reconstruction loss for both the normal and abnormal ECGs in the test data. The reconstruction loss for the instances of the abnormal ECGs in the test data is higher. A threshold is determined based on the distribution of the reconstruction losses of the normal training data (threshold = mean + 2.5*std of this distribution). Then, if the reconstruction loss of a normal ECG in the training data is higher than this threshold, it is classified as abnormal. By comparing with the known labels of test data (with T for normal ECG(s) and F for abnormal ECG(s)), the confusion matrix and the accuracy is calculated.

```
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import tensorflow as tf
from tensorflow import keras

from sklearn.metrics import accuracy_score, precision_score, recall_score, confusion_r
from sklearn.model_selection import train_test_split
from keras import layers, losses
from keras.models import Model
```

Loading the ECG5000 data

```
# Download the dataset
dataframe = pd.read_csv('http://storage.googleapis.com/download.tensorflow.org/data/ecg5000.csv')
raw_data = dataframe.values
dataframe.head()
```

	0	1	2	3	4	5	6	7
0	-0.112522	-2.827204	-3.773897	-4.349751	-4.376041	-3.474986	-2.181408	-1.818286
1	-1.100878	-3.996840	-4.285843	-4.506579	-4.022377	-3.234368	-1.566126	-0.992258
2	-0.567088	-2.593450	-3.874230	-4.584095	-4.187449	-3.151462	-1.742940	-1.490659
3	0.490473	-1.914407	-3.616364	-4.318823	-4.268016	-3.881110	-2.993280	-1.671131
4	0.800232	-0.874252	-2.384761	-3.973292	-4.338224	-3.802422	-2.534510	-1.783423

5 rows × 141 columns



Parse the data so it can be split creating a variable containing the labels and another containing the data. Splitting the data into train, validation, and test set.

```
# The last element contains the labels
labels = raw_data[:, -1]

# The other data points are the electrocardiogram data
data = raw_data[:, 0:-1]

train_data, test_data, train_labels, test_labels = train_test_split(
    data, labels, test_size=0.2, random_state=21
)

train_data, valid_data, train_labels, valid_labels = train_test_split(
    train_data, train_labels, test_size=.1, random_state=21
)
```

Normalize the data so the features are treated equally, normalizing using the overall min and max value of all training data (train/validation set).

```
min_val = tf.reduce_min(tf.concat([train_data, valid_data], 0))
max_val = tf.reduce_max(tf.concat([train_data, valid_data], 0))

train_data = (train_data - min_val) / (max_val - min_val)
valid_data = (valid_data - min_val) / (max_val - min_val)
test_data = (test_data - min_val) / (max_val - min_val)

train_data = tf.cast(train_data, tf.float32)
valid_data = tf.cast(valid_data, tf.float32)
test_data = tf.cast(test_data, tf.float32)
```

The autoencoder is trained using only the normal rhythms, which are labeled in this dataset as 1. Here the normal rhythms is separated from the abnormal rhythms, and the labels are casted as type bool.

```
train_labels = train_labels.astype(bool)
valid_labels = valid_labels.astype(bool)
test_labels = test_labels.astype(bool)

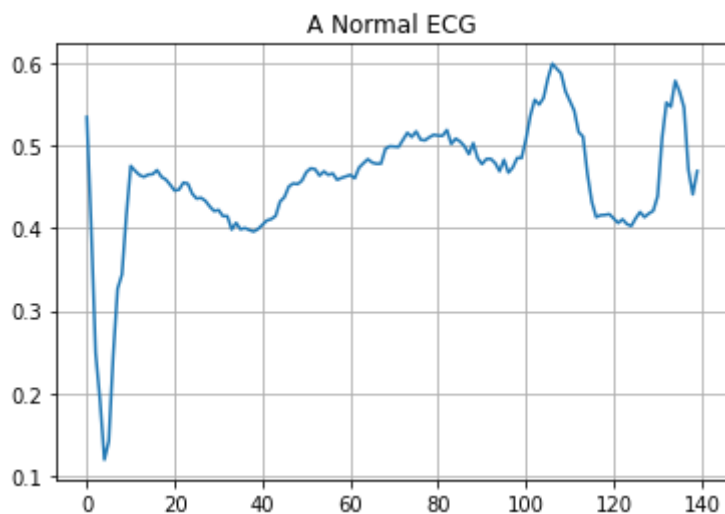
normal_train_data = train_data[train_labels]
normal_valid_data = valid_data[valid_labels]
normal_test_data = test_data[test_labels]

anomalous_train_data = train_data[~train_labels]
```

```
anomalous_valid_data = valid_data[~valid_labels]
anomalous_test_data = test_data[~test_labels]
```

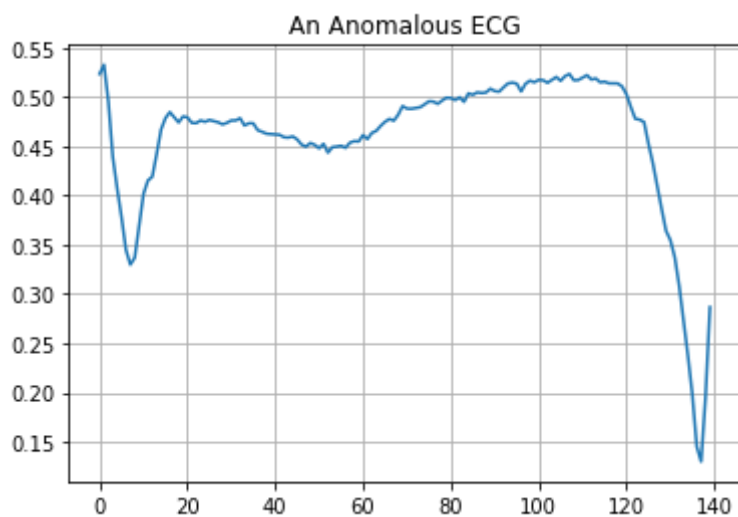
Plotting a normal ECG from the training set

```
plt.grid()
plt.plot(np.arange(140), normal_train_data[0])
plt.title("A Normal ECG")
plt.show()
```



Plotting an anomalous ECG.

```
plt.grid()
plt.plot(np.arange(140), anomalous_train_data[0])
plt.title("An Anomalous ECG")
plt.show()
```



Building the Anomaly Detection Model, the encoder architecture is $140 \rightarrow 32 \rightarrow 16 \rightarrow 8$. Thus,

```
class AnomalyDetector(Model):
    def __init__(self):
        super(AnomalyDetector, self).__init__()
        self.encoder = tf.keras.Sequential([
            layers.Dense(32, activation="selu"),
            layers.Dense(16, activation="selu"),
            layers.Dense(8, activation="selu")])

        self.decoder = tf.keras.Sequential([
            layers.Dense(16, activation="selu"),
            layers.Dense(32, activation="selu"),
            layers.Dense(140, activation="sigmoid")])

    def call(self, x):
        encoded = self.encoder(x)
        decoded = self.decoder(encoded)
        return decoded

autoencoder = AnomalyDetector()
```

Compiling the model using Adam optimizer and Mean Squared Error as the loss function:

```
autoencoder.compile(optimizer='adam', loss='mae')
```

Creating a callback to monitor validation loss to prevent overfitting of the model if the validation loss doesn't go down in 10 epochs, training is stopped.

```
callback = tf.keras.callbacks.EarlyStopping(monitor='val_loss', patience = 10)
```

Note we train the Autoencoder only on the normal ECG training set but both the normal and abnormal data is contained in the test set.

```
history = autoencoder.fit(normal_train_data, normal_train_data,
                          epochs=100,
                          batch_size=128,
                          callbacks = [callback],
                          validation_data=(normal_valid_data, normal_valid_data),
                          shuffle=True)

Epoch 72/100
17/17 [=====] - 0s 6ms/step - loss: 0.0104 - val_loss: 0.0104
Epoch 73/100
17/17 [=====] - 0s 6ms/step - loss: 0.0104 - val_loss: 0.0104
Epoch 74/100
17/17 [=====] - 0s 6ms/step - loss: 0.0103 - val_loss: 0.0103
Epoch 75/100
```

```

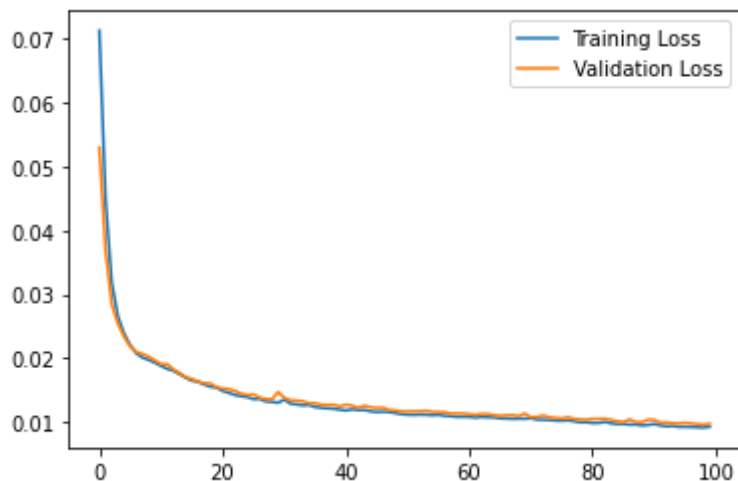
Epoch 75/100
17/17 [=====] - 0s 6ms/step - loss: 0.0103 - val_loss: 0.0103
Epoch 76/100
17/17 [=====] - 0s 5ms/step - loss: 0.0102 - val_loss: 0.0102
Epoch 77/100
17/17 [=====] - 0s 6ms/step - loss: 0.0103 - val_loss: 0.0103
Epoch 78/100
17/17 [=====] - 0s 7ms/step - loss: 0.0102 - val_loss: 0.0102
Epoch 79/100
17/17 [=====] - 0s 6ms/step - loss: 0.0100 - val_loss: 0.0100
Epoch 80/100
17/17 [=====] - 0s 5ms/step - loss: 0.0100 - val_loss: 0.0100
Epoch 81/100
17/17 [=====] - 0s 6ms/step - loss: 0.0099 - val_loss: 0.0099
Epoch 82/100
17/17 [=====] - 0s 6ms/step - loss: 0.0099 - val_loss: 0.0099
Epoch 83/100
17/17 [=====] - 0s 6ms/step - loss: 0.0101 - val_loss: 0.0101
Epoch 84/100
17/17 [=====] - 0s 6ms/step - loss: 0.0098 - val_loss: 0.0098
Epoch 85/100
17/17 [=====] - 0s 6ms/step - loss: 0.0097 - val_loss: 0.0097
Epoch 86/100
17/17 [=====] - 0s 6ms/step - loss: 0.0097 - val_loss: 0.0097
Epoch 87/100
17/17 [=====] - 0s 5ms/step - loss: 0.0096 - val_loss: 0.0096
Epoch 88/100
17/17 [=====] - 0s 6ms/step - loss: 0.0096 - val_loss: 0.0096
Epoch 89/100
17/17 [=====] - 0s 6ms/step - loss: 0.0095 - val_loss: 0.0095
Epoch 90/100
17/17 [=====] - 0s 6ms/step - loss: 0.0096 - val_loss: 0.0096
Epoch 91/100
17/17 [=====] - 0s 5ms/step - loss: 0.0097 - val_loss: 0.0097
Epoch 92/100
17/17 [=====] - 0s 6ms/step - loss: 0.0095 - val_loss: 0.0095
Epoch 93/100
17/17 [=====] - 0s 5ms/step - loss: 0.0094 - val_loss: 0.0094
Epoch 94/100
17/17 [=====] - 0s 6ms/step - loss: 0.0094 - val_loss: 0.0094
Epoch 95/100
17/17 [=====] - 0s 6ms/step - loss: 0.0093 - val_loss: 0.0093
Epoch 96/100
17/17 [=====] - 0s 6ms/step - loss: 0.0093 - val_loss: 0.0093
Epoch 97/100
17/17 [=====] - 0s 6ms/step - loss: 0.0093 - val_loss: 0.0093
Epoch 98/100
17/17 [=====] - 0s 5ms/step - loss: 0.0092 - val_loss: 0.0092
Epoch 99/100
17/17 [=====] - 0s 6ms/step - loss: 0.0092 - val_loss: 0.0092
Epoch 100/100
17/17 [=====] - 0s 6ms/step - loss: 0.0093 - val_loss: 0.0093

```

Plotting the training and validation loss for each epoch of training:

```
plt.plot(history.history["loss"], label="Training Loss")
plt.plot(history.history["val_loss"], label="Validation Loss")
plt.legend()
```

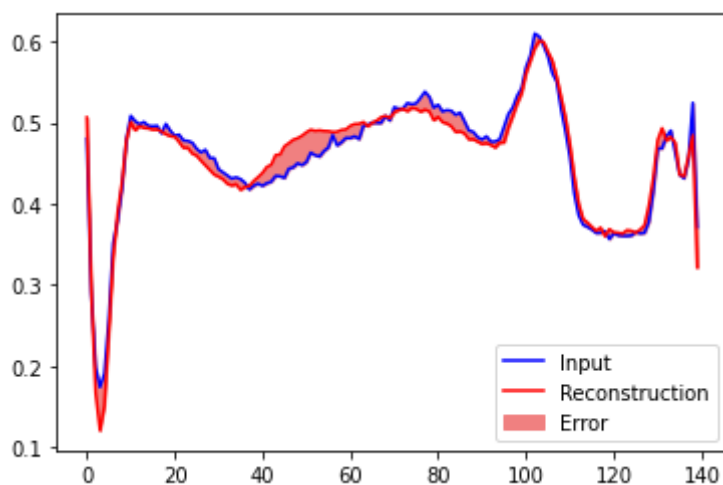
<matplotlib.legend.Legend at 0x7f9d91309ad0>



Plotting a normal ECG from the training set, the reconstruction after it's encoded and decoded by the autoencoder, and the reconstruction error.

```
encoded_data = autoencoder.encoder(normal_test_data).numpy()
decoded_data = autoencoder.decoder(encoded_data).numpy()

plt.plot(normal_test_data[0], 'b')
plt.plot(decoded_data[0], 'r')
plt.fill_between(np.arange(140), decoded_data[0], normal_test_data[0], color='lightcoral')
plt.legend(labels=["Input", "Reconstruction", "Error"])
plt.show()
```



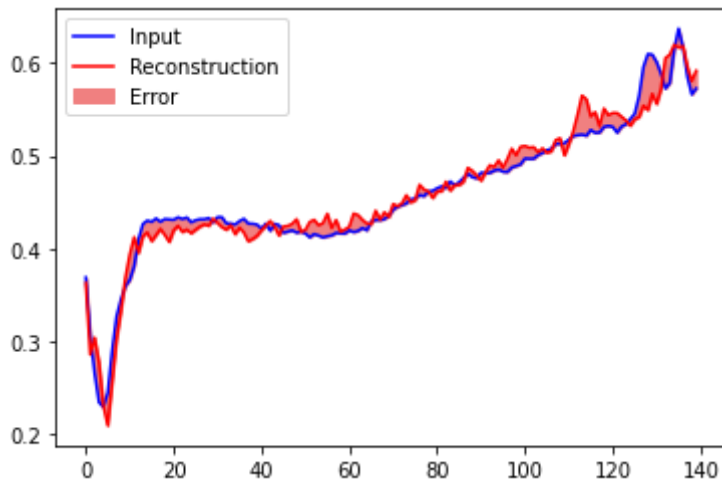
Now, we will do the same for the anomalous data:

```

encoded_data = autoencoder.encoder(anomalous_test_data).numpy()
decoded_data = autoencoder.decoder(encoded_data).numpy()

plt.plot(anomalous_test_data[0], 'b')
plt.plot(decoded_data[0], 'r')
plt.fill_between(np.arange(140), decoded_data[0], anomalous_test_data[0], color='lightred')
plt.legend(labels=["Input", "Reconstruction", "Error"])
plt.show()

```



Here will compute the normal/abnormal train/validation loss from the model using mean absolute error.

```

# Normal reconstructions
reconstructions_train = autoencoder.predict(normal_train_data)
train_loss = tf.keras.losses.mae(reconstructions_train, normal_train_data)
reconstructions_valid = autoencoder.predict(normal_valid_data)
valid_loss = tf.keras.losses.mae(reconstructions_valid, normal_valid_data)
# Abnormal reconstructions
ab_reconstructions_train = autoencoder.predict(anomalous_train_data)
ab_train_loss = tf.keras.losses.mae(ab_reconstructions_train, anomalous_train_data)
ab_reconstructions_valid = autoencoder.predict(anomalous_valid_data)
ab_valid_loss = tf.keras.losses.mae(ab_reconstructions_valid, anomalous_valid_data)

```

Defining a function predict which takes the model, data, and threshold. Computes the reconstruction loss and returns the truthy value for all elements if they are less than the threshold (True).

```

def predict(model, data, threshold):
    reconstructions = model.predict(data)
    loss = tf.keras.losses.mae(reconstructions, data)
    return tf.math.less(loss, threshold)

```

Computing the abnormal/normal mean of the validation loss

```
abnormal_valid_mean_loss = np.mean(ab_valid_loss)
normal_valid_mean_loss = np.mean(valid_loss)
```

Computing 100 different thresholds that start at the normal threshold and end at the abnormal threshold incrementing by their difference divided by 100.

```
increment = (abnormal_valid_mean_loss - normal_valid_mean_loss)/100
thresholds = np.arange(normal_valid_mean_loss, abnormal_valid_mean_loss,
increment)
```

Creating a numpy array to store the accuracy for each of the different threshold values.

```
thresh_size = thresholds.shape[0]
accuracies = np.zeros(thresh_size)
```

Calculation of the threshold that gives the best accuracy on the validation data. This is done by going through all thresholds and testing the accuracy of the model with each threshold.

```
for i in range(thresh_size):
    preds = predict(autoencoder, valid_data, thresholds[i])
    accuracies[i] = accuracy_score(preds, valid_labels)
```

Setting the threshold to the one in thresholds which gave the best accuracy.

```
argmax = np.argmax(accuracies)
best_threshold = thresholds[argmax]
print("The best threshold based on validation data: ", best_threshold)
```

```
The best threshold based on validation data:  0.019116752222180334
```

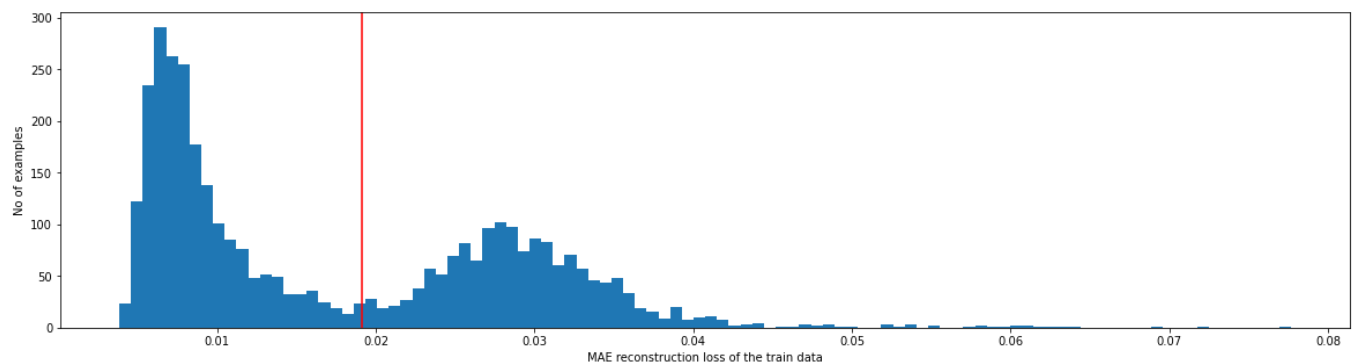
We now detect anomalies by calculating whether the reconstruction loss is greater than a fixed threshold we just computed. We then will classify future examples as anomalous if the reconstruction error is higher than this threshold.

Plotting the reconstruction error on all ECGs from the training set

```
reconstructions = autoencoder.predict(train_data)
train_loss = tf.keras.losses.mae(reconstructions, train_data)
```

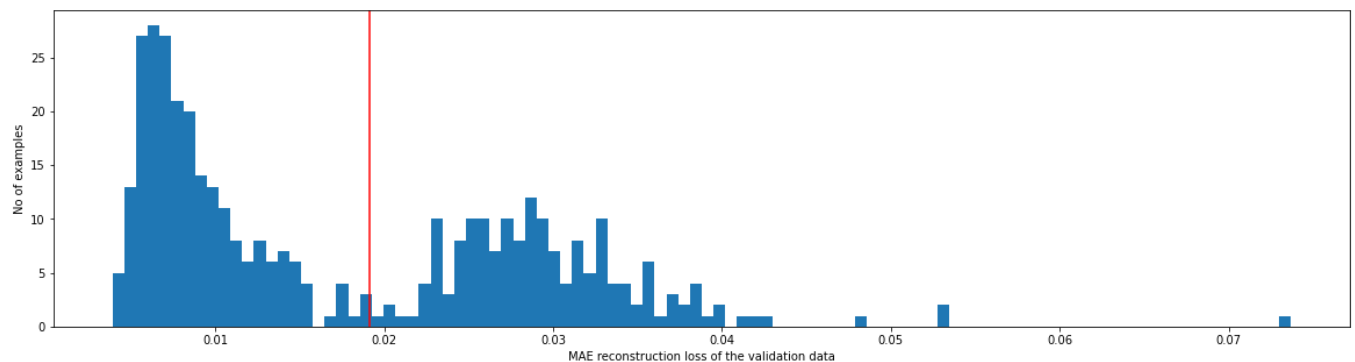


```
plt.figure(figsize=(20,5))
plt.hist(train_loss[None,:], bins=100)
plt.axvline(best_threshold, c='r')
plt.xlabel("MAE reconstruction loss of the train data")
plt.ylabel("No of examples")
plt.show()
```



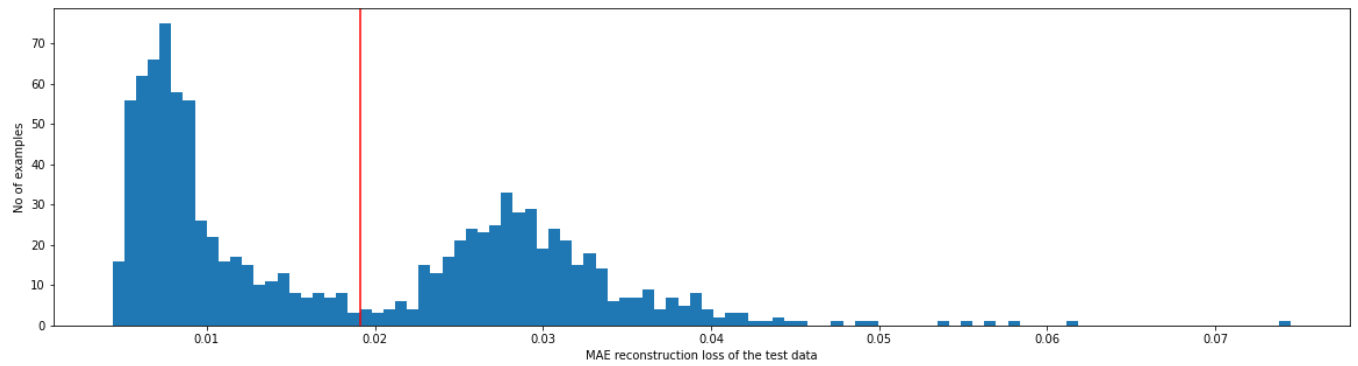
Plotting the reconstruction error on all ECGs from the validation set

```
reconstructions = autoencoder.predict(valid_data)
valid_loss = tf.keras.losses.mae(reconstructions, valid_data)
plt.figure(figsize=(20,5))
plt.hist(valid_loss[None,:], bins=100)
plt.axvline(best_threshold, c='r')
plt.xlabel("MAE reconstruction loss of the validation data")
plt.ylabel("No of examples")
plt.show()
```



Plotting the reconstruction error on all ECGs from the test set

```
reconstructions = autoencoder.predict(test_data)
test_loss = tf.keras.losses.mae(reconstructions, test_data)
plt.figure(figsize=(20,5))
plt.hist(test_loss[None,:], bins=100)
plt.axvline(best_threshold, c='r')
plt.xlabel("MAE reconstruction loss of the test data")
plt.ylabel("No of examples")
plt.show()
```



Classify an ECG as an anomaly if the reconstruction error is greater than the threshold.

```
def print_stats(predictions, labels, model, data):
    cf = confusion_matrix(labels, predictions)
    print("Confusion Matrix: \n prediction: F      T ")
    print("      {}      {}".format(preds[preds == False].shape[0], pred
    print(" label: F      [{]      {}".format(cf[0,0], cf[0,1], labels[lab
    print("      T      [{]      {}".format(cf[1,0], cf[1,1], labels[lab
    print("Accuracy = {}".format(accuracy_score(labels, predictions)))
    reconstructions = model.predict(data[labels])
    nl_test_loss = tf.keras.losses.mae(reconstructions, data[labels])
    print("Normal Test Data Mean = {}".format(np.mean(nl_test_loss)))
    print("Normal Test Data Standard Deviation = {}".format(np.std(nl_test_l
    reconstructions = model.predict(data[~labels])
    ab_test_loss = tf.keras.losses.mae(reconstructions, data[~labels])
    print("Abnormal Test Data Mean = {}".format(np.mean(ab_test_loss)))
    print("Abnormal Test Data Standard Deviation = {}".format(np.std(ab_test
    print("Precision = {}".format(precision_score(labels, predictions)))
    print("Recall = {}".format(recall_score(labels, predictions)))
```

```
thr_acc = np.zeros((thresh_size, 2))
thr_acc[:, 0] = thresholds
thr_acc[:, 1] = accuracies
thr_acc[argmax - 2 : argmax + 3]

array([[0.01871858, 0.9475 ],
       [0.01891766, 0.9475 ],
       [0.01911675, 0.95    ],
       [0.01931584, 0.95    ],
       [0.01951493, 0.95    ]])
```

Calculation of the accuracy and the confusion matrix on the test data with threshold set based on the best threshold from the validation data

```
preds = predict(autoencoder, test_data, best_threshold)
print_stats(preds, test_labels, autoencoder, test_data)
```

Confusion Matrix:

```

prediction: F      T
           440    560
label: F      [[420    20]    440
              T      [20    540]]    560
Accuracy = 0.96
Normal Test Data Mean = 0.009169315919280052
Normal Test Data Standard Deviation = 0.004234729800373316
Abnormal Test Data Mean = 0.029635341838002205
Abnormal Test Data Standard Deviation = 0.006848580669611692
Precision = 0.9642857142857143
Recall = 0.9642857142857143

```

```
accuracy = (0.975 + .979 + 0.978 + 0.974 + 0.976 + 0.975 + 0.979 + 0.965 +
```

```
round(accuracy, 4)
```

```
0.9744
```

```
precision = (0.9890310786106032 + 0.9908925318761385 + 0.9890909090909091 + 0.98545454
```

```
round(precision, 4)
```

```
0.9852
```

```
recall = (0.9660714285714286 + 0.9714285714285714 + 0.9714285714285714 + 0.96785714285
```

```
round(recall, 4)
```

```
0.9689
```

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