Importing required libraries

In [68]:

```
import numpy as np # linear algebra
import pandas as pd # data processing, CSV file I/O (e.g. pd.read_csv)
import matplotlib.pyplot as plt
import tensorflow as tf
from tensorflow.keras import layers
from tensorflow import keras
```

The images in data should should be resized to mentioned width and height as now we are proceeding to use another model.

In [69]:

```
SIZE = 224
```

Training Dataset

In [70]:

```
# loading training data
training_ds = tf.keras.preprocessing.image_dataset_from_directory(
    '../input/signature-verification-dataset/sign_data/train/',
    image_size=(224, 224)
)
```

```
Found 1649 files belonging to 128 classes.
```

Testing Dataset

In [71]:

```
# loading training data
testing_ds = tf.keras.preprocessing.image_dataset_from_directory(
    '../input/signature-verification-dataset/sign_data/test/',
    seed=42,
    image_size=(224, 224)
)
```

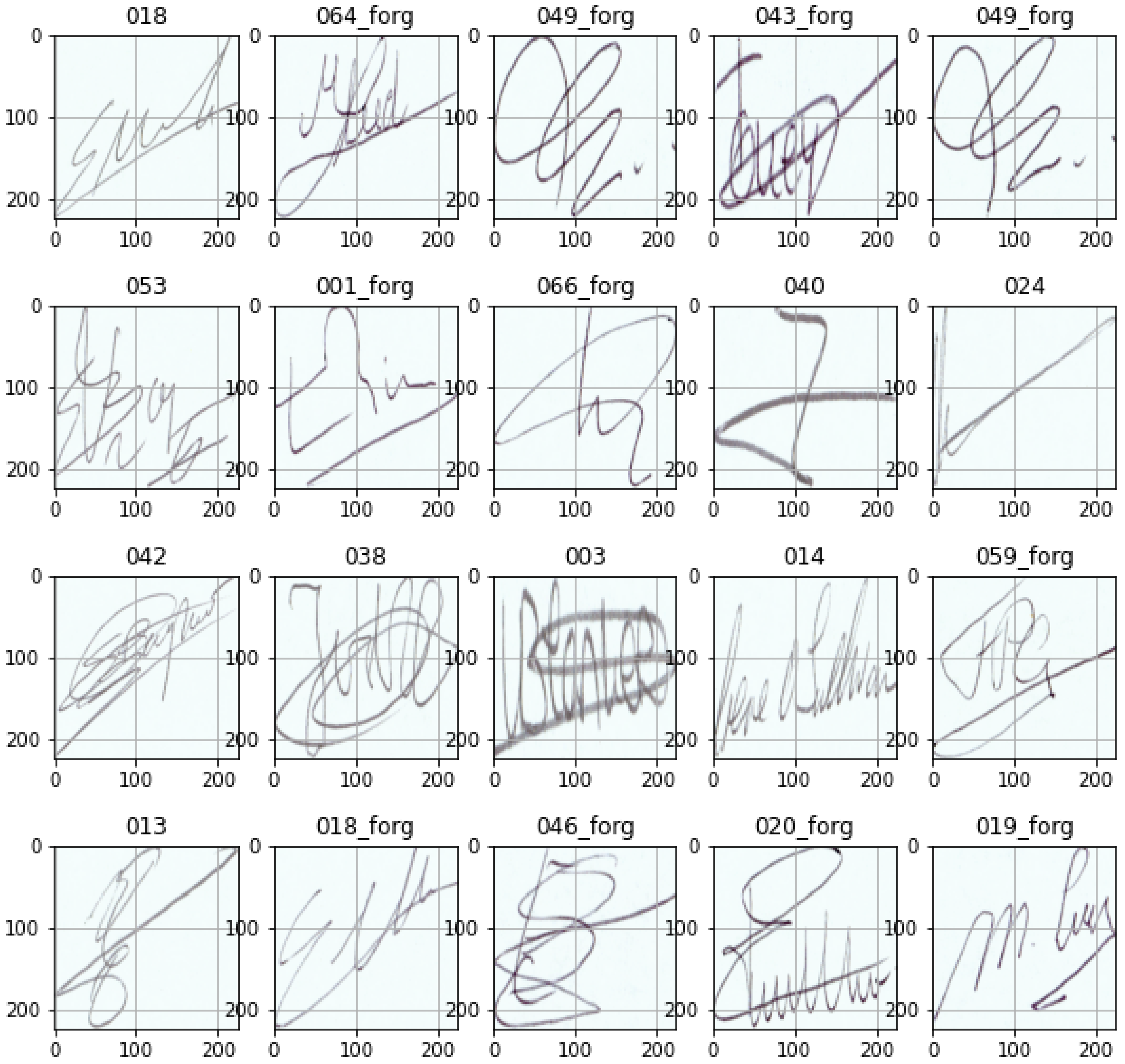
```
Found 500 files belonging to 42 classes.
```

Images

We have following images in training data.

In [72]:

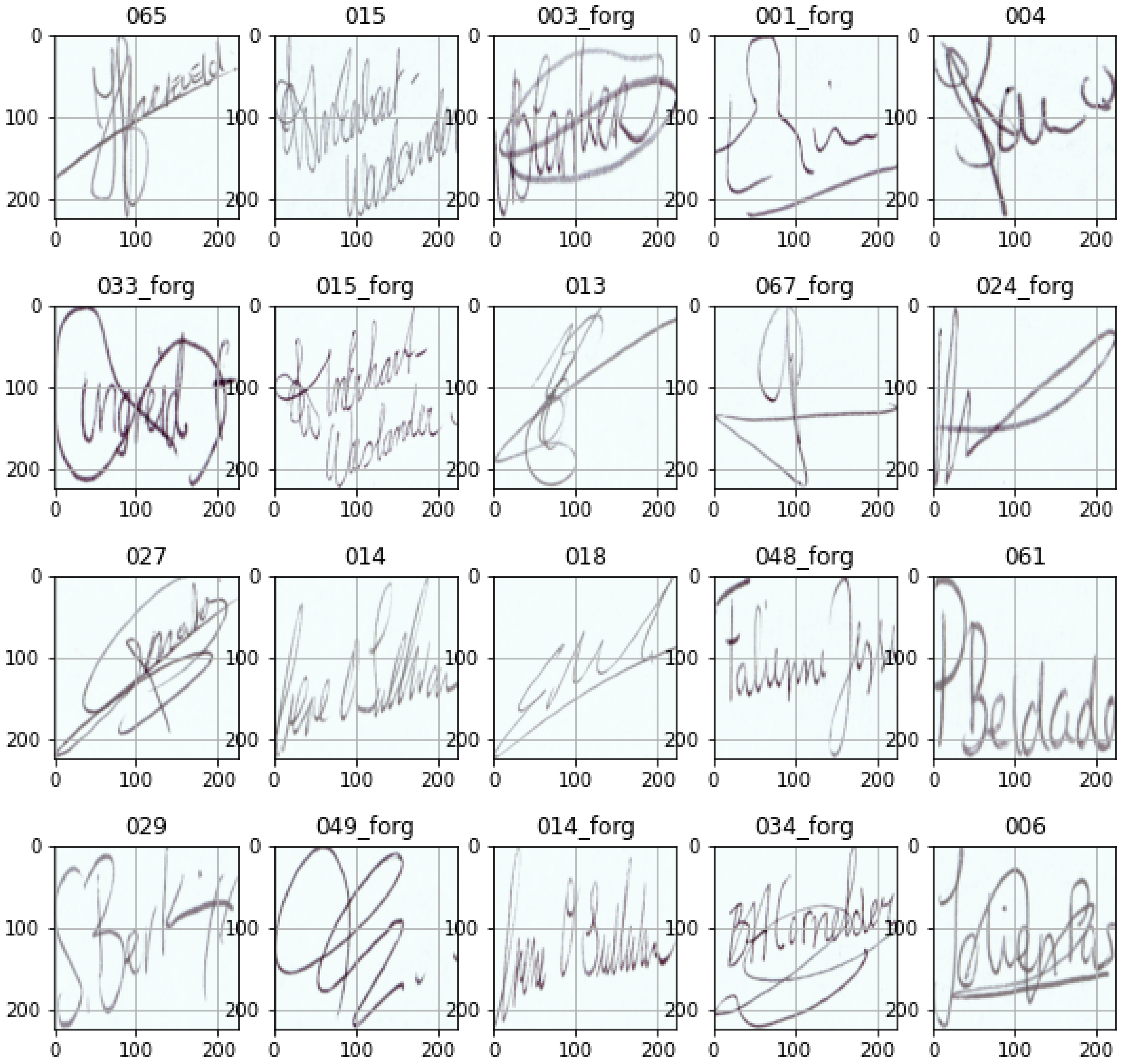
```
class_names = training_ds.class_names
plt.figure(figsize=(10, 10))
for images, labels in training_ds.take(1):
    for i in range(20):
        ax = plt.subplot(4, 5, i + 1)
        plt.imshow(images[i].numpy().astype("uint8"))
        # print(images[i])
        plt.title(class_names[labels[i]])
        plt.grid(True)
```


018
064_forg
049_forg
043_forg
049_forg
053
001_forg
066_forg
040
024
042
038
003
014
059_forg
013
018_forg
046_forg
020_forg
019_forg
0
100
200

These are the images in testing data.

In [73]:

```
class_names = training_ds.class_names
plt.figure(figsize=(10, 10))
for images, labels in training_ds.take(1):
    for i in range(20):
        ax = plt.subplot(4, 5, i + 1)
        plt.imshow(images[i].numpy().astype("uint8"))
        # print(images[i])
        plt.title(class_names[labels[i]])
        plt.grid(True)
```


065
015
003_forg
001_forg
004
033_forg
015_forg
013
067_forg
024_forg
027
014
018
048_forg
061
029
049_forg
014_forg
034_forg
006
0
100
200

Savind image data in numpy array

In [74]:

```
import cv2
import os
import glob

train_data = []
train_labels = []

for per in os.listdir('../input/signature-verification-dataset/sign_data/train/'):
    for data in glob.glob('../input/signature-verification-dataset/sign_data/train/'+per+'/*.*'):
        img = cv2.imread(data)
        img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
        img = cv2.resize(img, (SIZE,SIZE))
        train_data.append([img])
        if per[-1]=='g':
            train_labels.append(np.array(1))
        else:
            train_labels.append(np.array(0))
train_data = np.array(train_data)/255.0
train_labels = np.array(train_labels)

#Test Data
test_data = []
test_labels = []
```

```
for per in os.listdir('../input/signature-verification-dataset/sign_data/test/'):
    for data in glob.glob('../input/signature-verification-dataset/sign_data/test/'+per+'/*.*'):
        img = cv2.imread(data)
        img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
        img = cv2.resize(img, (SIZE,SIZE))
        test_data.append([img])
        if per[-1]=='g':
            test_labels.append(np.array(1))
        else:
            test_labels.append(np.array(0))
test_data = np.array(test_data)/255.0
test_labels = np.array(test_labels)
```

For use of categorical entropy loss we need to configure data.

In [75]:

```
from keras.utils import to_categorical
train_labels = to_categorical(train_labels)
```

Shapes of numpy array made above.

```
In [76]:
train_data.shape
```

```
Out[76]:
(1649, 1, 224, 224, 3)
```

```
In [77]:
train_data = train_data.reshape(-1, SIZE,SIZE, 3)
test_data = test_data.reshape(-1, SIZE,SIZE, 3)
```

```
In [78]:
train_data.shape
```

```
Out[78]:
(1649, 224, 224, 3)
```

```
In [79]:
train_labels.shape
```

```
Out[79]:
(1649, 2)
```

Shuffling

In [80]:

```
from sklearn.utils import shuffle
train_data,train_labels = shuffle(train_data,train_labels)
test_data,test_labels = shuffle(test_data,test_labels)
```

Importing base model (VGG-16)

In [81]:

```
from keras.models import Sequential, Model, load_model
from keras import applications
from keras import optimizers
from keras.layers import Dropout, Flatten, Dense
from keras.optimizers import Adam

base_model = applications.VGG16(weights='imagenet', include_top=False, input_shape=(224,224,
3))
base_model.summary()
```

```
Model: "vgg16"
-----------------------------------------------------------------
Layer (type)                 Output Shape              Param #
=================================================================
input_4 (InputLayer)         [(None, 224, 224, 3)]     0
-----------------------------------------------------------------
block1_conv1 (Conv2D)        (None, 224, 224, 64)      1792
-----------------------------------------------------------------
block1_conv2 (Conv2D)        (None, 224, 224, 64)      36928
-----------------------------------------------------------------
block1_pool (MaxPooling2D)   (None, 112, 112, 64)      0
-----------------------------------------------------------------
block2_conv1 (Conv2D)        (None, 112, 112, 128)     73856
-----------------------------------------------------------------
block2_conv2 (Conv2D)        (None, 112, 112, 128)     147584
-----------------------------------------------------------------
block2_pool (MaxPooling2D)   (None, 56, 56, 128)       0
-----------------------------------------------------------------
block3_conv1 (Conv2D)        (None, 56, 56, 256)       295168
-----------------------------------------------------------------
block3_conv2 (Conv2D)        (None, 56, 56, 256)       590080
-----------------------------------------------------------------
block3_conv3 (Conv2D)        (None, 56, 56, 256)       590080
-----------------------------------------------------------------
```

```
block3_pool (MaxPooling2D)   (None, 28, 28, 256)       0

_________________________________________________________________
block4_conv1 (Conv2D)        (None, 28, 28, 512)       1180160

_________________________________________________________________
block4_conv2 (Conv2D)        (None, 28, 28, 512)       2359808

_________________________________________________________________
block4_conv3 (Conv2D)        (None, 28, 28, 512)       2359808

_________________________________________________________________
block4_pool (MaxPooling2D)   (None, 14, 14, 512)       0

_________________________________________________________________
block5_conv1 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_conv2 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_conv3 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_pool (MaxPooling2D)   (None, 7, 7, 512)         0
=================================================================
Total params: 14,714,688
Trainable params: 14,714,688
Non-trainable params: 0

_________________________________________________________________
```

Our model

Here we are freezing first 5 layers og VGG-16 and adding top layers.

In [82]:

```
i=0
while i != 5:
    base_model.layers[i].trainable = False
    i+=1
add_model = Sequential()
add_model.add(Flatten(input_shape=base_model.output_shape[1:]))
add_model.add(Dense(256, activation='relu'))
add_model.add(Dense(2, activation='softmax'))

model = Model(inputs=base_model.input, outputs=add_model(base_model.output))
model.compile(loss='categorical_crossentropy', optimizer=optimizers.Adam(lr=1e-4),
              metrics=['accuracy'])

model.summary()
```

```
Model: "functional_7"

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_4 (InputLayer)         [(None, 224, 224, 3)]     0

_________________________________________________________________
block1_conv1 (Conv2D)        (None, 224, 224, 64)      1792

_________________________________________________________________
block1_conv2 (Conv2D)        (None, 224, 224, 64)      36928

_________________________________________________________________
block1_pool (MaxPooling2D)   (None, 112, 112, 64)      0

_________________________________________________________________
block2_conv1 (Conv2D)        (None, 112, 112, 128)     73856

_________________________________________________________________
block2_conv2 (Conv2D)        (None, 112, 112, 128)     147584

_________________________________________________________________
block2_pool (MaxPooling2D)   (None, 56, 56, 128)       0

_________________________________________________________________
block3_conv1 (Conv2D)        (None, 56, 56, 256)       295168

_________________________________________________________________
block3_conv2 (Conv2D)        (None, 56, 56, 256)       590080

_________________________________________________________________
block3_conv3 (Conv2D)        (None, 56, 56, 256)       590080

_________________________________________________________________
```

```
block3_pool (MaxPooling2D)   (None, 28, 28, 256)       0

_________________________________________________________________
block4_conv1 (Conv2D)        (None, 28, 28, 512)       1180160

_________________________________________________________________
block4_conv2 (Conv2D)        (None, 28, 28, 512)       2359808

_________________________________________________________________
block4_conv3 (Conv2D)        (None, 28, 28, 512)       2359808

_________________________________________________________________
block4_pool (MaxPooling2D)   (None, 14, 14, 512)       0

_________________________________________________________________
block5_conv1 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_conv2 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_conv3 (Conv2D)        (None, 14, 14, 512)       2359808

_________________________________________________________________
block5_pool (MaxPooling2D)   (None, 7, 7, 512)         0

_________________________________________________________________
sequential_3 (Sequential)    (None, 2)                 6423298
=================================================================
Total params: 21,137,986
Trainable params: 21,025,410
Non-trainable params: 112,576

_________________________________________________________________
```

Training our model

In [83]:

```
from keras.callbacks import ModelCheckpoint, LearningRateScheduler, EarlyStopping, ReduceLROnPlateau, TensorBoard
earlyStopping = EarlyStopping(monitor='val_loss',
                              min_delta=0,
                              patience=3,
                              verbose=1)

early_stop=[earlyStopping]

progess = model.fit(train_data,train_labels, batch_size=30,epochs=100, callbacks=early_stop, validation_split=.3)
```

```
Epoch 1/100
39/39 [==============================] - 7s 177ms/step - loss: 0.6905 - accuracy: 0.6075
- val_loss: 0.5346 - val_accuracy: 0.7232
Epoch 2/100
39/39 [==============================] - 6s 163ms/step - loss: 0.3807 - accuracy: 0.8432
- val_loss: 0.2396 - val_accuracy: 0.9394
Epoch 3/100
39/39 [==============================] - 6s 163ms/step - loss: 0.1658 - accuracy: 0.9376
- val_loss: 0.1039 - val_accuracy: 0.9636
Epoch 4/100
39/39 [==============================] - 6s 164ms/step - loss: 0.0922 - accuracy: 0.9679
- val_loss: 0.0862 - val_accuracy: 0.9576
Epoch 5/100
39/39 [==============================] - 6s 163ms/step - loss: 0.0848 - accuracy: 0.9705
- val_loss: 0.1830 - val_accuracy: 0.9253
Epoch 6/100
39/39 [==============================] - 6s 162ms/step - loss: 0.0690 - accuracy: 0.9714
- val_loss: 0.1066 - val_accuracy: 0.9697
Epoch 7/100
39/39 [==============================] - 6s 162ms/step - loss: 0.1310 - accuracy: 0.9541
- val_loss: 0.1236 - val_accuracy: 0.9636
Epoch 00007: early stopping
```

Accuracy plot.

In [84]:

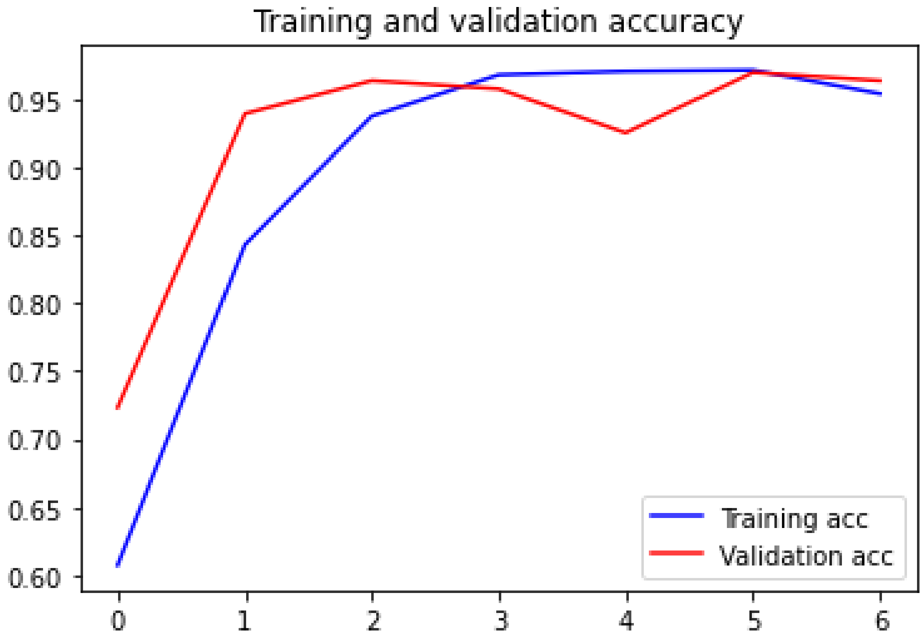
```
acc = progess.history['accuracy']
val_acc = progess.history['val_accuracy']
loss = progess.history['loss']
val_loss = progess.history['val_loss']

epochs = range(len(acc))

plt.plot(epochs, acc, 'b', label='Training acc')
plt.plot(epochs, val_acc, 'r', label='Validation acc')
plt.title('Training and validation accuracy')
plt.legend()

plt.figure()
```

```
Out[84]:
         <Figure size 432x288 with 0 Axes>
```



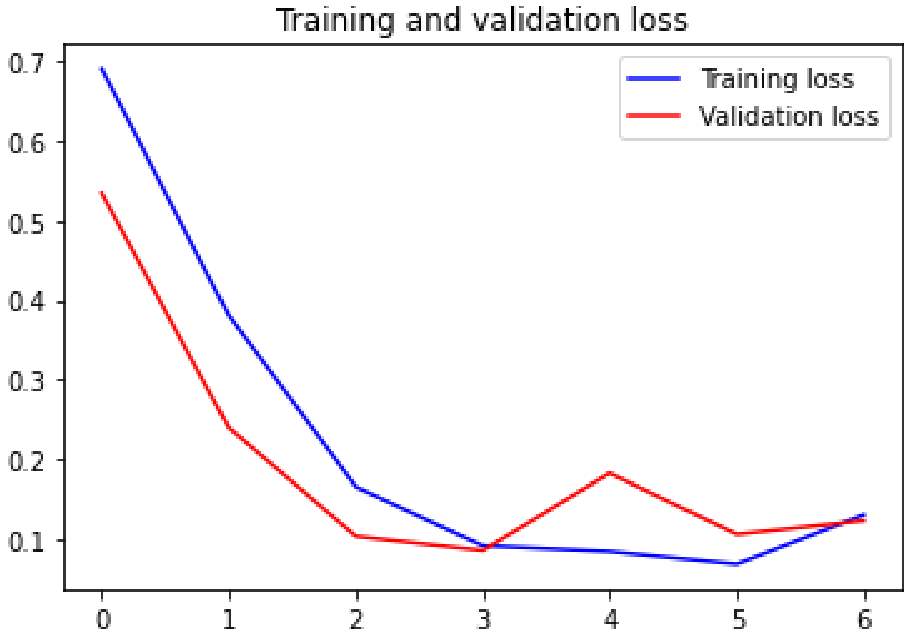
```
<Figure size 432x288 with 0 Axes>
```

Loss plot.

In [85]:

```
plt.plot(epochs, loss, 'b', label='Training loss')
plt.plot(epochs, val_loss, 'r', label='Validation loss')
plt.title('Training and validation loss')
plt.legend()

plt.show()
```



Accuracy Score.

In [89]:

```
pred = model.predict(test_data)
```

In [87]:

```
from sklearn.metrics import accuracy_score
accuracy_score(np.argmax(pred,axis=1), test_labels)
```

Out[87]:

```
0.998
```