05_model_t_tl_feat_ext_rmsprop

June 10, 2024

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1 Model T - Transfer Learning, Feature Extraction, RMSProp

- **128 x 128 x 3** Image size.

- **64** Batch size.
- **Feature Extraction**.
  - **VGG16** Convolutional Base.
  - **4 x 4 x 512** Feature Maps.
- **Classifier**:
  - **Root Mean Square Propagation (RMSProp)** optimizer.
  - **0.01** Initial Learning rate.
  - **Sparse Categorical Cross-Entropy** loss function.
  - **Reduce Learning Rate on Plateau** callback with a **0.1** factor and patience of **3**.
  - **Early Stopping** callback with patience of **6** and restore best weights.
  - **Model Checkpoint** callback to save the best model based on validation loss.
  - **4 x 4 x 512** Tensor before the **Flatten** layer.
  - **512** Dense layer with **ReLU** activation.
  - **10** Dense output layer with **Softmax** activation.
  - **Dropout** layers with **0.5** rate after the Flatten and Dense layers.
  - **L2** regularization with **0.0001** rate on the Dense layers.
  - **4 199 946** Trainable Parameters.
  - **30 Epochs** to train the classifier.

- Build the **full model** with the **VGG16 Convolutional Base** and the **Classifier**.
- **Test** the model on the **Test Dataset**.

Imports and Setup

[1]:
```
import os
os.environ['TF_CPP_MIN_LOG_LEVEL'] = '3'
import tensorflow as tf
print(f'TensorFlow version: {tf.__version__}')
tf.get_logger().setLevel('ERROR')
tf.autograph.set_verbosity(3)
import matplotlib.pyplot as plt
```

```python
import pickle
import numpy as np
from tensorflow.keras.utils import image_dataset_from_directory
from tensorflow import keras
from tensorflow.keras import callbacks, layers, optimizers
from keras import regularizers, Model
from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay␣
↪,accuracy_score, precision_score, recall_score, f1_score, roc_curve, auc
from sklearn.preprocessing import label_binarize
from itertools import cycle
```

```
TensorFlow version: 2.15.0
```

Group Datasets

[2]:
```python
IMG_SIZE = 128

train_dirs = [f'../data/train1_resized_{IMG_SIZE}',
              f'../data/train3_resized_{IMG_SIZE}',
              f'../data/train4_resized_{IMG_SIZE}',
              f'../data/train5_resized_{IMG_SIZE}']
validation_dir = f'../data/train2_resized_{IMG_SIZE}'
test_dir = f'../data/test_resized_{IMG_SIZE}'
```

Create Datasets

[3]:
```python
BATCH_SIZE = 64
NUM_CLASSES = 10

train_datasets = [image_dataset_from_directory(directory, image_size=(IMG_SIZE,␣
↪IMG_SIZE), batch_size=BATCH_SIZE) for directory in train_dirs]

train_dataset = train_datasets[0]
for dataset in train_datasets[1:]:
    train_dataset = train_dataset.concatenate(dataset)

train_dataset = train_dataset.shuffle(buffer_size=1000).prefetch(buffer_size=tf.
↪data.AUTOTUNE)
validation_dataset = image_dataset_from_directory(validation_dir,␣
↪image_size=(IMG_SIZE, IMG_SIZE), batch_size=BATCH_SIZE).
↪prefetch(buffer_size=tf.data.AUTOTUNE)
test_dataset = image_dataset_from_directory(test_dir, image_size=(IMG_SIZE,␣
↪IMG_SIZE), batch_size=BATCH_SIZE).prefetch(buffer_size=tf.data.AUTOTUNE)

class_names = train_datasets[0].class_names
```

```
for data_batch, labels_batch in train_dataset.take(1):
    print('data batch shape:', data_batch.shape)
    print('labels batch shape:', labels_batch.shape)
```

```
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Found 10000 files belonging to 10 classes.
data batch shape: (64, 128, 128, 3)
labels batch shape: (64,)
```

- We define the image size of 128 x 128 x 3, batch size of 64 and create an array with the label's names.
- We create the train dataset by concatenating them, we **shuffle** the samples before each epoch and **prefetch** them to memory.
- We do the same for the validation and test dataset except **shuffling** which is **unwanted** for these datasets.

Loading the VGG16 Model

[4]:
```
from tensorflow.keras.applications.vgg16 import VGG16
conv_base = VGG16(weights='imagenet', include_top=False, input_shape=(IMG_SIZE,␣
↪IMG_SIZE, 3))
conv_base.trainable = False
conv_base.summary()
```

```
Model: "vgg16"

_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 128, 128, 3)]     0

 block1_conv1 (Conv2D)       (None, 128, 128, 64)      1792

 block1_conv2 (Conv2D)       (None, 128, 128, 64)      36928

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

 block2_conv1 (Conv2D)       (None, 64, 64, 128)       73856

 block2_conv2 (Conv2D)       (None, 64, 64, 128)       147584
```

```
 block2_pool (MaxPooling2D)  (None, 32, 32, 128)       0

 block3_conv1 (Conv2D)       (None, 32, 32, 256)       295168

 block3_conv2 (Conv2D)       (None, 32, 32, 256)       590080

 block3_conv3 (Conv2D)       (None, 32, 32, 256)       590080

 block3_pool (MaxPooling2D)  (None, 16, 16, 256)       0

 block4_conv1 (Conv2D)       (None, 16, 16, 512)       1180160

 block4_conv2 (Conv2D)       (None, 16, 16, 512)       2359808

 block4_conv3 (Conv2D)       (None, 16, 16, 512)       2359808

 block4_pool (MaxPooling2D)  (None, 8, 8, 512)         0

 block5_conv1 (Conv2D)       (None, 8, 8, 512)         2359808

 block5_conv2 (Conv2D)       (None, 8, 8, 512)         2359808

 block5_conv3 (Conv2D)       (None, 8, 8, 512)         2359808

 block5_pool (MaxPooling2D)  (None, 4, 4, 512)         0

=================================================================
Total params: 14714688 (56.13 MB)
Trainable params: 0 (0.00 Byte)
Non-trainable params: 14714688 (56.13 MB)
_________________________________________________________________
```

- We **load the VGG16** model with the **imagenet weights**, **without the top layer** and with the input shape of **128 x 128 pixels and 3 channels**.

Feature Extraction

[5]:
```python
def get_features_and_labels(dataset):
    all_features = []
    all_labels = []
    for images, labels in dataset:
        preprocessed_images = keras.applications.vgg16.preprocess_input(images)
        features = conv_base.predict(preprocessed_images)
        all_features.append(features)
        all_labels.append(labels)
    return np.concatenate(all_features), np.concatenate(all_labels)
```

```
train_features, train_labels = get_features_and_labels(train_dataset)
val_features, val_labels = get_features_and_labels(validation_dataset)
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```

- We **extract the features** from the convolutional base of the VGG16 model for the **train and validation dataset**.
- We **don't need** to extract **the features from the test dataset** because we will use the full model to predict it.

1.0.1 Saving the features and labels

[6]:
```
np.save('../features/05_model_t_tl_feat_ext_rmsprop_train_features.npy',␣
 ↪train_features)
np.save('../features/05_model_t_tl_feat_ext_rmsprop_train_labels.npy',␣
 ↪train_labels)
np.save('../features/05_model_t_tl_feat_ext_rmsprop_val_features.npy',␣
 ↪val_features)
np.save('../features/05_model_t_tl_feat_ext_rmsprop_val_labels.npy', val_labels)
```

1.0.2 Loading the features and labels

[7]:
```
# train_features = np.load('../features/
 ↪05_model_t_tl_feat_ext_rmsprop_train_features.npy')
# train_labels = np.load('../features/
 ↪05_model_t_tl_feat_ext_rmsprop_train_labels.npy')
```

```
# val_features = np.load('../features/
↪05_model_t_tl_feat_ext_rmsprop_val_features.npy')
# val_labels = np.load('../features/05_model_t_tl_feat_ext_rmsprop_val_labels.
↪npy')
```

Classifier Arquitecture

[8]:
```
inputs = keras.Input(shape=(4, 4, 512))
x = layers.Flatten()(inputs)
x = layers.Dropout(0.5)(x)
x = layers.Dense(512, activation="relu", kernel_regularizer=regularizers.
↪L2(1e-4))(x)
x = layers.Dropout(0.5)(x)
outputs = layers.Dense(NUM_CLASSES, activation="softmax",␣
↪kernel_regularizer=regularizers.L2(1e-4))(x)
classifier = keras.Model(inputs, outputs)
classifier.summary()
```

```
Model: "model"

_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_2 (InputLayer)        [(None, 4, 4, 512)]       0

 flatten (Flatten)           (None, 8192)              0

 dropout (Dropout)           (None, 8192)              0

 dense (Dense)               (None, 512)               4194816

 dropout_1 (Dropout)         (None, 512)               0

 dense_1 (Dense)             (None, 10)                5130

=================================================================
Total params: 4199946 (16.02 MB)
Trainable params: 4199946 (16.02 MB)
Non-trainable params: 0 (0.00 Byte)
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```

Model Compilation

[9]:
```
initial_learning_rate = 0.001
optimizer = optimizers.RMSprop(learning_rate=initial_learning_rate)
loss_function = keras.losses.SparseCategoricalCrossentropy()
```

```
lr_scheduler = callbacks.ReduceLROnPlateau(monitor='val_loss', factor=0.1,␣
 ↪patience=3, verbose=1)
early_stopping = callbacks.EarlyStopping(monitor='val_loss', patience=6,␣
 ↪restore_best_weights=True, verbose=1)
save_best_model = callbacks.ModelCheckpoint(filepath='../models/
 ↪05_model_t_tl_feat_ext_rmsprop_classifier.h5', save_best_only=True,␣
 ↪monitor='val_loss', verbose=1)

callbacks = [lr_scheduler, early_stopping, save_best_model]

classifier.compile(optimizer=optimizer,
                   loss=loss_function,
                   metrics=['accuracy'])
```

Model Training

[10]:
```
history = classifier.fit(
    train_features, train_labels,
    epochs=30,
    validation_data=(val_features, val_labels),
    callbacks=callbacks)
```

```
Epoch 1/30
1249/1250 [============================>.] - ETA: 0s - loss: 2.0882 - accuracy:
0.7210
Epoch 1: val_loss improved from inf to 0.69868, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 25s 20ms/step - loss: 2.0876 -
accuracy: 0.7211 - val_loss: 0.6987 - val_accuracy: 0.8348 - lr: 0.0010
Epoch 2/30
   7/1250 […] - ETA: 23s - loss: 1.3775 - accuracy:
0.7455
```

```
/usr/local/lib/python3.9/dist-packages/keras/src/engine/training.py:3103:
UserWarning: You are saving your model as an HDF5 file via `model.save()`. This
file format is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')`.
  saving_api.save_model(
```

```
1249/1250 [============================>.] - ETA: 0s - loss: 1.1691 - accuracy:
0.7922
Epoch 2: val_loss improved from 0.69868 to 0.65767, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 1.1695 -
accuracy: 0.7921 - val_loss: 0.6577 - val_accuracy: 0.8536 - lr: 0.0010
Epoch 3/30
```

```
1249/1250 [============================>.] - ETA: 0s - loss: 1.0680 - accuracy:
0.8083
Epoch 3: val_loss improved from 0.65767 to 0.64178, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 1.0682 -
accuracy: 0.8083 - val_loss: 0.6418 - val_accuracy: 0.8589 - lr: 0.0010
Epoch 4/30
1249/1250 [============================>.] - ETA: 0s - loss: 1.0201 - accuracy:
0.8153
Epoch 4: val_loss did not improve from 0.64178
1250/1250 [==============================] - 24s 19ms/step - loss: 1.0200 -
accuracy: 0.8154 - val_loss: 0.6591 - val_accuracy: 0.8540 - lr: 0.0010
Epoch 5/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.9945 - accuracy:
0.8241
Epoch 5: val_loss did not improve from 0.64178
1250/1250 [==============================] - 23s 19ms/step - loss: 0.9945 -
accuracy: 0.8241 - val_loss: 0.6654 - val_accuracy: 0.8655 - lr: 0.0010
Epoch 6/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.9914 - accuracy:
0.8252
Epoch 6: ReduceLROnPlateau reducing learning rate to 0.00010000000474974513.

Epoch 6: val_loss did not improve from 0.64178
1250/1250 [==============================] - 24s 19ms/step - loss: 0.9913 -
accuracy: 0.8253 - val_loss: 0.6751 - val_accuracy: 0.8596 - lr: 0.0010
Epoch 7/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.7153 - accuracy:
0.8567
Epoch 7: val_loss improved from 0.64178 to 0.60073, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.7160 -
accuracy: 0.8567 - val_loss: 0.6007 - val_accuracy: 0.8780 - lr: 1.0000e-04
Epoch 8/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.6890 - accuracy:
0.8693
Epoch 8: val_loss improved from 0.60073 to 0.59749, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 0.6887 -
accuracy: 0.8694 - val_loss: 0.5975 - val_accuracy: 0.8820 - lr: 1.0000e-04
Epoch 9/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.6423 - accuracy:
0.8773
Epoch 9: val_loss improved from 0.59749 to 0.58528, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 0.6427 -
accuracy: 0.8773 - val_loss: 0.5853 - val_accuracy: 0.8840 - lr: 1.0000e-04
Epoch 10/30
```

```
1249/1250 [============================>.] - ETA: 0s - loss: 0.6051 - accuracy:
0.8843
Epoch 10: val_loss improved from 0.58528 to 0.58060, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.6049 -
accuracy: 0.8843 - val_loss: 0.5806 - val_accuracy: 0.8882 - lr: 1.0000e-04
Epoch 11/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.5881 - accuracy:
0.8877
Epoch 11: val_loss improved from 0.58060 to 0.57706, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 0.5879 -
accuracy: 0.8877 - val_loss: 0.5771 - val_accuracy: 0.8866 - lr: 1.0000e-04
Epoch 12/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.5687 - accuracy:
0.8927
Epoch 12: val_loss improved from 0.57706 to 0.57455, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.5687 -
accuracy: 0.8927 - val_loss: 0.5746 - val_accuracy: 0.8886 - lr: 1.0000e-04
Epoch 13/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.5586 - accuracy:
0.8910
Epoch 13: val_loss improved from 0.57455 to 0.57241, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.5583 -
accuracy: 0.8910 - val_loss: 0.5724 - val_accuracy: 0.8926 - lr: 1.0000e-04
Epoch 14/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.5354 - accuracy:
0.8969
Epoch 14: val_loss improved from 0.57241 to 0.56496, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.5353 -
accuracy: 0.8970 - val_loss: 0.5650 - val_accuracy: 0.8893 - lr: 1.0000e-04
Epoch 15/30
1248/1250 [============================>.] - ETA: 0s - loss: 0.5137 - accuracy:
0.8961
Epoch 15: val_loss improved from 0.56496 to 0.55465, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 20ms/step - loss: 0.5140 -
accuracy: 0.8961 - val_loss: 0.5546 - val_accuracy: 0.8932 - lr: 1.0000e-04
Epoch 16/30
1250/1250 [==============================] - ETA: 0s - loss: 0.4910 - accuracy:
0.9011
Epoch 16: val_loss did not improve from 0.55465
1250/1250 [==============================] - 24s 19ms/step - loss: 0.4910 -
accuracy: 0.9011 - val_loss: 0.5557 - val_accuracy: 0.8919 - lr: 1.0000e-04
Epoch 17/30
```

```
1249/1250 [============================>.] - ETA: 0s - loss: 0.4817 - accuracy:
0.9028
Epoch 17: val_loss improved from 0.55465 to 0.54566, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 24s 19ms/step - loss: 0.4818 -
accuracy: 0.9028 - val_loss: 0.5457 - val_accuracy: 0.8945 - lr: 1.0000e-04
Epoch 18/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4604 - accuracy:
0.9072
Epoch 18: val_loss did not improve from 0.54566
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4605 -
accuracy: 0.9071 - val_loss: 0.5500 - val_accuracy: 0.8946 - lr: 1.0000e-04
Epoch 19/30
1248/1250 [============================>.] - ETA: 0s - loss: 0.4589 - accuracy:
0.9078
Epoch 19: val_loss improved from 0.54566 to 0.54361, saving model to
../models/05_model_t_tl_feat_ext_rmsprop_classifier.h5
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4596 -
accuracy: 0.9078 - val_loss: 0.5436 - val_accuracy: 0.8923 - lr: 1.0000e-04
Epoch 20/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4455 - accuracy:
0.9092
Epoch 20: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 18ms/step - loss: 0.4453 -
accuracy: 0.9092 - val_loss: 0.5539 - val_accuracy: 0.8930 - lr: 1.0000e-04
Epoch 21/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4454 - accuracy:
0.9116
Epoch 21: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4455 -
accuracy: 0.9116 - val_loss: 0.5487 - val_accuracy: 0.8948 - lr: 1.0000e-04
Epoch 22/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4343 - accuracy:
0.9141
Epoch 22: ReduceLROnPlateau reducing learning rate to 1.0000000474974514e-05.

Epoch 22: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4342 -
accuracy: 0.9141 - val_loss: 0.5552 - val_accuracy: 0.8945 - lr: 1.0000e-04
Epoch 23/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4082 - accuracy:
0.9195
Epoch 23: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4087 -
accuracy: 0.9194 - val_loss: 0.5511 - val_accuracy: 0.8964 - lr: 1.0000e-05
Epoch 24/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4066 - accuracy:
0.9208
```

```
Epoch 24: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4070 -
accuracy: 0.9207 - val_loss: 0.5491 - val_accuracy: 0.8974 - lr: 1.0000e-05
Epoch 25/30
1249/1250 [============================>.] - ETA: 0s - loss: 0.4017 - accuracy:
0.9206
Epoch 25: ReduceLROnPlateau reducing learning rate to 1.0000000656873453e-06.
Restoring model weights from the end of the best epoch: 19.

Epoch 25: val_loss did not improve from 0.54361
1250/1250 [==============================] - 23s 19ms/step - loss: 0.4018 -
accuracy: 0.9205 - val_loss: 0.5497 - val_accuracy: 0.8970 - lr: 1.0000e-05
Epoch 25: early stopping
```

Save Model History

[11]:
```
with open("../history/05_model_t_tl_feat_ext_rmsprop_classifier.pkl", "wb") as␣
↪file:
    pickle.dump(history.history, file)
```

Classifier Evaluation

[12]:
```
val_loss, val_acc = classifier.evaluate(val_features, val_labels)
print(f'Classifier Validation Loss: {val_loss:.2f}')
print(f'Classifier Validation Accuracy: {val_acc:.2%}')
```

```
313/313 [==============================] - 1s 2ms/step - loss: 0.5436 -
accuracy: 0.8923
Classifier Validation Loss: 0.54
Classifier Validation Accuracy: 89.23%
```

Classifier Training Visualization

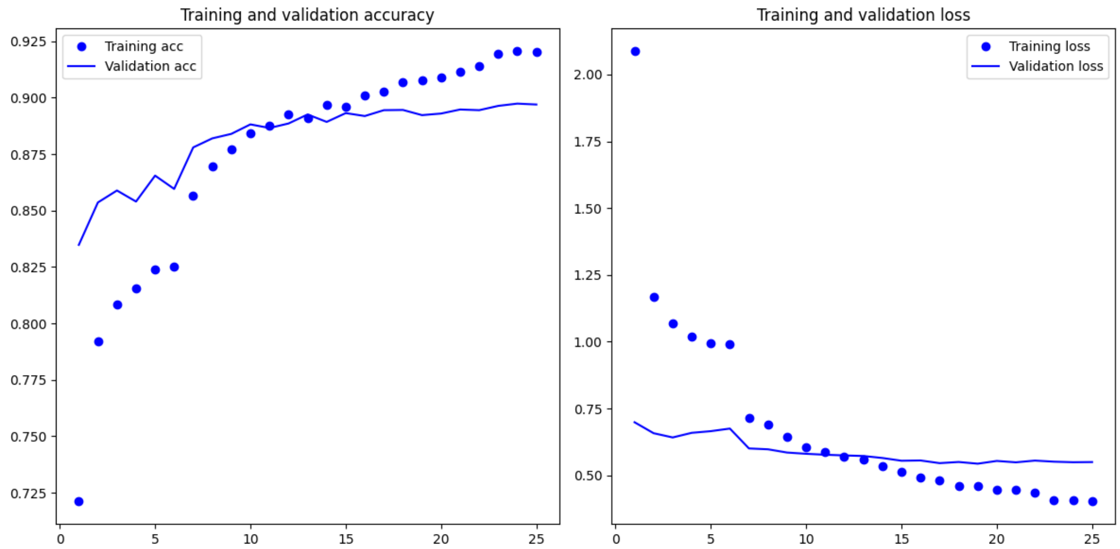
[13]:
```
acc = history.history['accuracy']
val_acc = history.history['val_accuracy']
loss = history.history['loss']
val_loss = history.history['val_loss']
epochs = range(1, len(acc) + 1)

plt.figure(figsize=(12, 6))
plt.subplot(1, 2, 1)
plt.plot(epochs, acc, 'bo', label='Training acc')
plt.plot(epochs, val_acc, 'b', label='Validation acc')
plt.title('Training and validation accuracy')
```

```
plt.legend()

plt.subplot(1, 2, 2)
plt.plot(epochs, loss, 'bo', label='Training loss')
plt.plot(epochs, val_loss, 'b', label='Validation loss')
plt.title('Training and validation loss')
plt.legend()

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



- Analyzing the training and validation, accuracy and loss over the epochs:
  - We see that the model begins overfitting slightly after the **16th** epoch.
  - The validation accuracy stops improving significantly after the **17th** epoch while the training accuracy keeps improving.
  - The validation loss stops improving significantly after the **17th** epoch while the training loss keeps improving.
  - The best model, based on validation loss, is saved on the **19th** epoch.
  - The training stops after the **25th** epoch because of the **Early Stopping** callback.

Building the Full Model with the VGG16 Convolutional Base and the Classifier

[14]:
```
inputs = keras.Input(shape=(IMG_SIZE, IMG_SIZE, 3))
x = keras.applications.vgg16.preprocess_input(inputs)
x = conv_base(x)
outputs = classifier(x)
model = keras.Model(inputs, outputs)
```

```python
model.compile(
    loss=loss_function,
    optimizer=optimizer,
    metrics=["accuracy"])

model.save('../models/05_model_t_tl_feat_ext_rmsprop_model.h5')
model.summary()
```

```
Model: "model_1"

_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_3 (InputLayer)        [(None, 128, 128, 3)]     0

 tf.__operators__.getitem (  (None, 128, 128, 3)       0
 SlicingOpLambda)

 tf.nn.bias_add (TFOpLambda  (None, 128, 128, 3)       0
 )

 vgg16 (Functional)          (None, 4, 4, 512)         14714688

 model (Functional)          (None, 10)                4199946

=================================================================
Total params: 18914634 (72.15 MB)
Trainable params: 4199946 (16.02 MB)
Non-trainable params: 14714688 (56.13 MB)
_________________________________________________________________
```

Model Testing

[15]:
```python
test_labels = []
test_predictions = []
test_probabilities = []

for images, labels in test_dataset:
    test_labels.extend(labels.numpy())
    predictions = model.predict(images)
    test_predictions.extend(np.argmax(predictions, axis=-1))
    test_probabilities.extend(predictions)

test_labels = np.array(test_labels)
test_predictions = np.array(test_predictions)
test_probabilities = np.array(test_probabilities)
```

```
2/2 [==============================] - 1s 623ms/step
```

```
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```
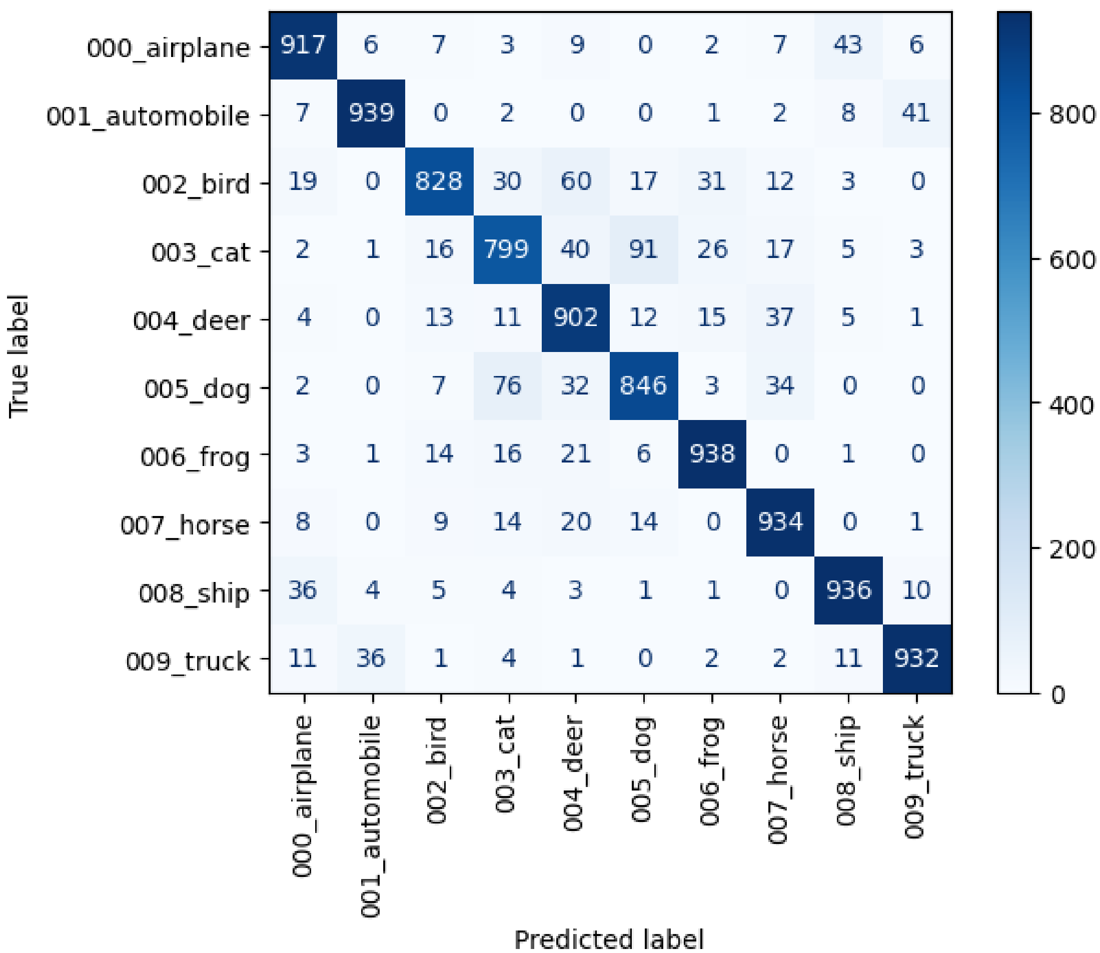

Confusion Matrix

[16]:
```python
cm = confusion_matrix(test_labels, test_predictions)
disp = ConfusionMatrixDisplay(confusion_matrix=cm, display_labels=class_names)
disp.plot(cmap=plt.cm.Blues, xticks_rotation=90)
plt.show()
```

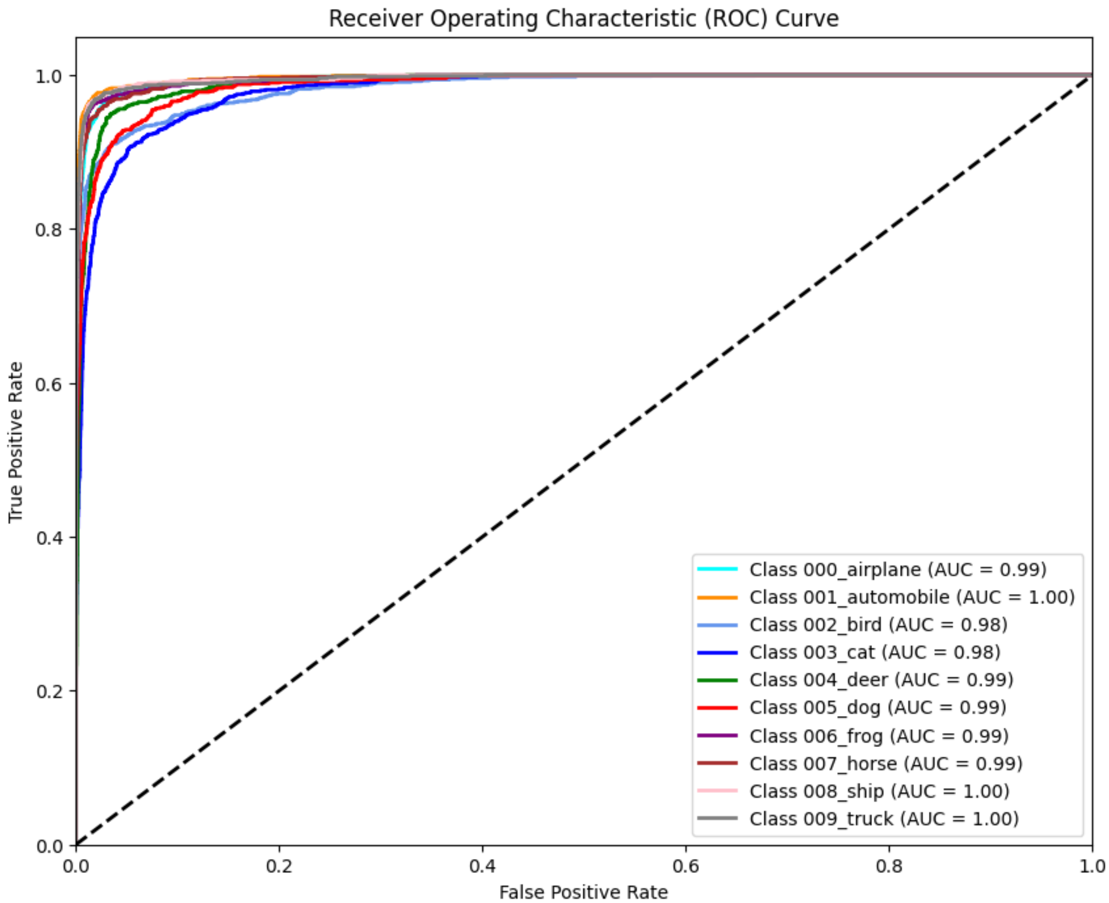


- Looking at the confusion matrix, we see that:
  - The model has a hard time distinguishing the categories 003_cat and 005_dog.
  - The model has a very low performance on the category 003_cat.
  - The model performs better on the vehicle categories than on the animal categories.
  - The model has a below average performance on the categories 005_dog and 002_bird, in which we see a very high false positive rate.
  - The model also has a hard time distinguishing between some other categories but the deviation is not as significant.

  - The model has an above average performance on the categories 000_airplane, 001_automobile, 006_frog, 008_ship and 009_truck.
  - **Basically, the model has the same error distribution but with higher accuracy**.

ROC Curve Analysis

[17]:
```
test_labels_bin = label_binarize(test_labels, classes=range(NUM_CLASSES))

false_positive_rate = dict()
true_positive_rate = dict()
roc_auc = dict()

for i in range(NUM_CLASSES):
    false_positive_rate[i], true_positive_rate[i], _ = roc_curve(test_labels_bin[:, i], test_probabilities[:, i])
    roc_auc[i] = auc(false_positive_rate[i], true_positive_rate[i])

plt.figure(figsize=(10, 8))
colors = cycle(['aqua', 'darkorange', 'cornflowerblue', 'blue', 'green', 'red', 'purple', 'brown', 'pink', 'grey'])
for i, color in zip(range(NUM_CLASSES), colors):
    plt.plot(false_positive_rate[i], true_positive_rate[i], color=color, lw=2, label=f'Class {class_names[i]} (AUC = {roc_auc[i]:.2f})')

plt.plot([0, 1], [0, 1], 'k--', lw=2)
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.05])
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('Receiver Operating Characteristic (ROC) Curve')
plt.legend(loc="lower right")
plt.show()
```



- Looking at the ROC curve:
  - We see that the model has a good performance on the ROC curve for most categories.
  - The categories 003_cat and 002_bird have the worst AUC (Area Under Curve) performance.
  - The other categories have the same performance but with higher AUC.
  - The category 001_automobile, 008_ship and 009_truck has the best AUC performance.
  - The overall AUC performance increases as the false positive rate decreases and the true positive rate increases.
  - **A perfect AUC of 1.0 would mean that the model classifies all images either true positives or true negatives**.

Performance Metrics

- **Accuracy** is the proportion of correctly predicted instances out of the total instances.
- **Precision** is the ratio of true positive predictions to the total predicted positives. Macro precision calculates this for each class independently and then averages them.

- **Weighted precision** calculates the precision for each class, then averages them, weighted by the number of true instances for each class.

- **Recall** is the ratio of true positive predictions to the total actual positives. Macro recall calculates this for each class independently and then averages them.

- **Weighted recall** calculates the recall for each class, then averages them, weighted by the number of true instances for each class.

- The **F1-score** is the harmonic mean of precision and recall. Macro F1-score calculates this for each class independently and then averages them.

- **Weighted F1-score** calculates the F1-score for each class, then averages them, weighted by the number of true instances for each class.

[18]:
```
acc = accuracy_score(y_true =  test_labels, y_pred = test_predictions)
print(f'Accuracy : {np.round(acc*100,2)}%')
precision = precision_score(y_true =  test_labels, y_pred = test_predictions,␣
 ↪average='macro')
print(f'Precision - Macro: {np.round(precision*100,2)}%')
recall = recall_score(y_true =  test_labels, y_pred = test_predictions,␣
 ↪average='macro')
print(f'Recall - Macro: {np.round(recall*100,2)}%')
f1 = f1_score(y_true =  test_labels, y_pred = test_predictions, average='macro')
print(f'F1-score - Macro: {np.round(f1*100,2)}%')
precision = precision_score(y_true =  test_labels, y_pred = test_predictions,␣
 ↪average='weighted')
print(f'Precision - Weighted: {np.round(precision*100,2)}%')
recall = recall_score(y_true =  test_labels, y_pred = test_predictions,␣
 ↪average='weighted')
print(f'Recall - Weighted: {np.round(recall*100,2)}%')
f1 = f1_score(y_true =  test_labels, y_pred = test_predictions,␣
 ↪average='weighted')
print(f'F1-score - Weighted: {np.round(f1*100,2)}%')
```

```
Accuracy : 89.71%
Precision - Macro: 89.76%
Recall - Macro: 89.71%
F1-score - Macro: 89.69%
Precision - Weighted: 89.76%
Recall - Weighted: 89.71%
F1-score - Weighted: 89.69%
```

- **Since the dataset is balanced, the** MACRO** average is a good metric to evaluate the model.**

2 Conclusion

2.0.1 Summary

- Before this notebook:
  - We resized our images to be the 128 x 128 x 3.
  - Our reasoning was up scaling by a factor of 4.
- In this notebook:
  - We extracted feature maps from our train and validation datasets using the convolutional base of the VGG16.
  - We trained a classifier with those extracted features:
    * We used the Root Mean Squared Propagation (RMSProp) optimizer with an initial learning rate of 0.001.
    * We kept the same 30 epochs with a batch size of 64.
  - We evaluated the classifier on the validation dataset:
    * Overfitting was observed after **16 epochs**, but the best classifier was saved at the **19th epoch**.
    * Training was intended for 30 epochs but stopped early due to the **Early Stopping** callback.
  - We then joined the VGG16 Convolutional Base with our Classifier
  - We tested the resulting model on the test set:
    * We evaluated the model using a confusion matrix to analyze its performance on each category.
    * We evaluated the model using ROC curves for a deeper performance analysis.
    * The model achieved an accuracy of 89.71% on the test set, which was a good improvement.

2.0.2 Future Work

- In the next notebook:
  - Implement and train a transfer learning model with the VGG16 convolutional base frozen and a new classifier.
  - Experiment with **custom** data augmentation to improve classifier generalization
  - We will use 50 Epochs with a batch size of 64.
  - Test the model performance.