Tomato Leaf Health Dataset

The data analysis and modeling will be done for the tomato leaf health dataset, which can be found here Tomato Leaf Health Data.

Introduction

My intention for this project is to demonstrate a methodology for generating an accurate model for problem. In this case taking images of tomato leaves and classifying them into one of eleven buckets; one healthy and the rest diseased in various ways. I will start with a small convolutional neural network (CNN), see how it performs, and add data augmentation to see if that improves its accuracy. Afterwards, I will use pretrained image classification models with transfer learning and fine-tuning to see if I can get a model that is substantially more accurate than the original CNN. Finally, after obtaining a better accuracy model from the transfer learning approach I will revisit the CNN and try training using knowledge distillation where the transfer learning model will work as the teacher, and the CNN will function as the student. Hopefully this will result in a much smaller model with improved accuracy. The purpose of doing this is to try and find a model that is small enough for offline edge devices to use that is also accurate enough to be useful.

Exploratory Data Analysis

In [14]:
```
import collections
import os

import keras.losses
from PIL import Image
from keras import backend
from keras import models
from keras import layers
from keras import optimizers
from keras.utils import to_categorical
import numpy as np
import matplotlib.pyplot as plt
from keras import regularizers
from keras.layers import BatchNormalization
from keras.callbacks import EarlyStopping
from sklearn.model_selection import train_test_split
from keras.utils import to_categorical
from PIL import Image
from keras.preprocessing.image import ImageDataGenerator
from keras.preprocessing import image
import os, shutil
np.random.seed(1)
```

In [15]:
```
# Data Details for EDA
def describe_data():
```

```
    train_path = "../data/train"
    test_path = "../data/valid"
    img_shapes = []
    training_files = get_file_count(train_path, img_shapes)
    print(f'Train Count: {training_files}')  # 69h X 130w
    test_files = get_file_count(test_path, img_shapes)
    print(f'Test Count: {test_files}')  # 100h X 150w

    test_x, test_y = img_shapes[0]
    print(f'{test_x}x{test_y}')
    x_avg, x_min, x_max = 0, 10000, 0
    y_avg, y_min, y_max = 0, 10000, 0

    x_s = []
    y_s = []

    for x, y in img_shapes:
        x_s.append(x)
        x_avg += x
        x_min = min(x_min, x)
        x_max = max(x_max, x)
        y_s.append(y)
        y_avg += y
        y_min = min(y_min, y)
        y_max = max(y_max, y)

    x_mode = collections.Counter(x_s).most_common()[0][0]
    y_mode = collections.Counter(y_s).most_common()[0][0]

    x_avg = x_avg // len(img_shapes)
    y_avg = y_avg // len(img_shapes)

    print(f'Avg: {x_avg}x{y_avg}')
    print(f'Mode: {x_mode}x{y_mode}')
    print(f'Min: {x_min}x{y_min}')
    print(f'Max: {x_max}x{y_max}')
```

In [16]:
```
def get_file_count(directory, shapes):
    count = 0
    for path in os.listdir(directory):
        if os.path.isfile(os.path.join(directory, path)):
            im = Image.open(os.path.join(directory, path))
            shapes.append(im.size)
            count += 1
        if os.path.isdir(os.path.join(directory, path)):
            add = get_file_count(os.path.join(directory, path), shapes)
            count += add
    return count
```

In [17]:
```
describe_data()
```

```
Train Count: 25848
Test Count: 6683
256x256
Avg: 292x303
Mode: 256x256
Min: 130x69
Max: 6000x6000
```

Looks like our training set is over 25k images, and that the most common image size is 256 by 256. I will start using that as my input shape, and we can adjust if needed.

In [27]:
```
categories = ['Bacterial_spot', 'Early_blight', 'healthy', 'Late_blight', 'Leaf_Mold',
              'powdery_mildew', 'Septoria_leaf_spot', 'Spider_mites Two-spotted_spider_m
              'Target_Spot', 'Tomato_mosaic_virus', 'Tomato_Yellow_Leaf_Curl_Virus']
train_dir = "../data/train"
test_dir = "../data/valid"
val_dir = "../data/val"
```

In [21]:
```
# Only run once
for category in categories:
  os.makedirs(val_dir + category)
  print(os.listdir(val_dir + category))
  files = os.listdir(train_dir + category)
  np.random.shuffle(files)
  num_val_samples = int(0.2*len(files))
  val_files = files[-num_val_samples:]
  for fname in val_files:
    shutil.move("../data/train/" + category + "/" + fname,
                "../data/val/" + category + "/" + fname)
```

```
---------------------------------------------------------------------------
FileExistsError                           Traceback (most recent call last)
Cell In [21], line 2
      1 for category in categories:
----> 2   os.makedirs("../data/val/" + category)
      3   print(os.listdir("../data/val/" + category))
      4   files = os.listdir("../data/train/" + category)

File ~\anaconda3\envs\deep-learning-cv\lib\os.py:225, in makedirs(name, mode, exist_o
k)
    223         return
    224 try:
--> 225     mkdir(name, mode)
    226 except OSError:
    227     # Cannot rely on checking for EEXIST, since the operating system
    228     # could give priority to other errors like EACCES or EROFS
    229     if not exist_ok or not path.isdir(name):

FileExistsError: [WinError 183] Cannot create a file when that file already exists:
'../data/val/Bacterial_spot'
```

In [23]:
```
# Build Category Size Display Function
def describe_categories(cats, directory):
    for cat in cats:
        full_dir = os.path.join(directory, cat)
        print(len(os.listdir(full_dir)))
```

In [24]:
```
# Checking the number of files in each class directory
describe_categories(categories, train_dir)
```

```
2261
1964
2441
2491
2204
804
2306
1398
1462
1723
1629
```

In [28]:
```python
describe_categories(categories, val_dir)
```

```
565
491
610
622
550
200
576
349
365
430
407
```

In [26]:
```python
describe_categories(categories, test_dir)
```

```
732
643
805
792
739
252
746
435
457
584
498
```

The distribution of the data appears to be fairly consistent, with a small outlier for the powdery mildew class. It likely isn't enough to cause problems, but if we find ourselves unable to classify correctly we should revisit.

In [29]:
```python
train_datagen = ImageDataGenerator(rescale=1./255)
test_datagen = ImageDataGenerator(rescale=1./255)
```

In [30]:
```python
train_generator = train_datagen.flow_from_directory(
    train_dir,
    target_size=(256, 256), # Choosing our mode image values
    batch_size=20,
    class_mode='categorical') # Since we have 11 classes as output

val_generator = train_datagen.flow_from_directory(
    val_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')
```

```
test_generator = test_datagen.flow_from_directory(
    test_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')
```

```
Found 20683 images belonging to 11 classes.
Found 5165 images belonging to 11 classes.
Found 6683 images belonging to 11 classes.
```

Now we have a validation set, and all 11 classes are represented. We will want to make sure that our neural network that we design has a softmax activation function, and 11 outputs.

In [40]:

```
# Build a plotting function
def plot_history(history):
  history_dict = history.history
  loss_values = history_dict['loss'] or history_dict['student_loss']
  val_loss_values = history_dict['val_loss'] or history_dict['val_student_loss']
  acc_values = history_dict['accuracy'] or history_dict['categorical_accuracy']
  val_acc_values = history_dict['val_accuracy'] or history_dict['val_categorical_accur
  epochs = range(1, len(history_dict['accuracy']) + 1)

  plt.plot(epochs, loss_values, 'bo', label = 'Training loss')
  plt.plot(epochs, val_loss_values, 'b', label = 'Validation loss')
  plt.title('Training and validation loss')
  plt.xlabel('Epochs')
  plt.ylabel('Loss')
  plt.legend()
  plt.show()

  plt.plot(epochs, acc_values, 'bo', label = 'Training accuracy')
  plt.plot(epochs, val_acc_values, 'b', label = 'Validation accuracy')
  plt.title('Training and validation accuracy')
  plt.xlabel('Epochs')
  plt.ylabel('Accuracy')
  plt.legend()
  return plt.show()
```

Deep Learning Model

I will be going down the path of experimenting with deep learning models, as they tend to work well on computer vision problems. I will start with a fairly classic architecture for my model with a sequential model using convolutional layers, max pooling, batch normalization into a top that flattens into dense layers with dropout to our softmax classifier. I will be using the Adam optimizer for scheduling, categorical crossentropy for loss, and accuracy for our metric. We could tune these hyperparameters but the proof of concept that I am looking for is taking a fairly small and inaccurate model and through knowledge distillation increasing its accuracy while keeping it small.

In [41]:

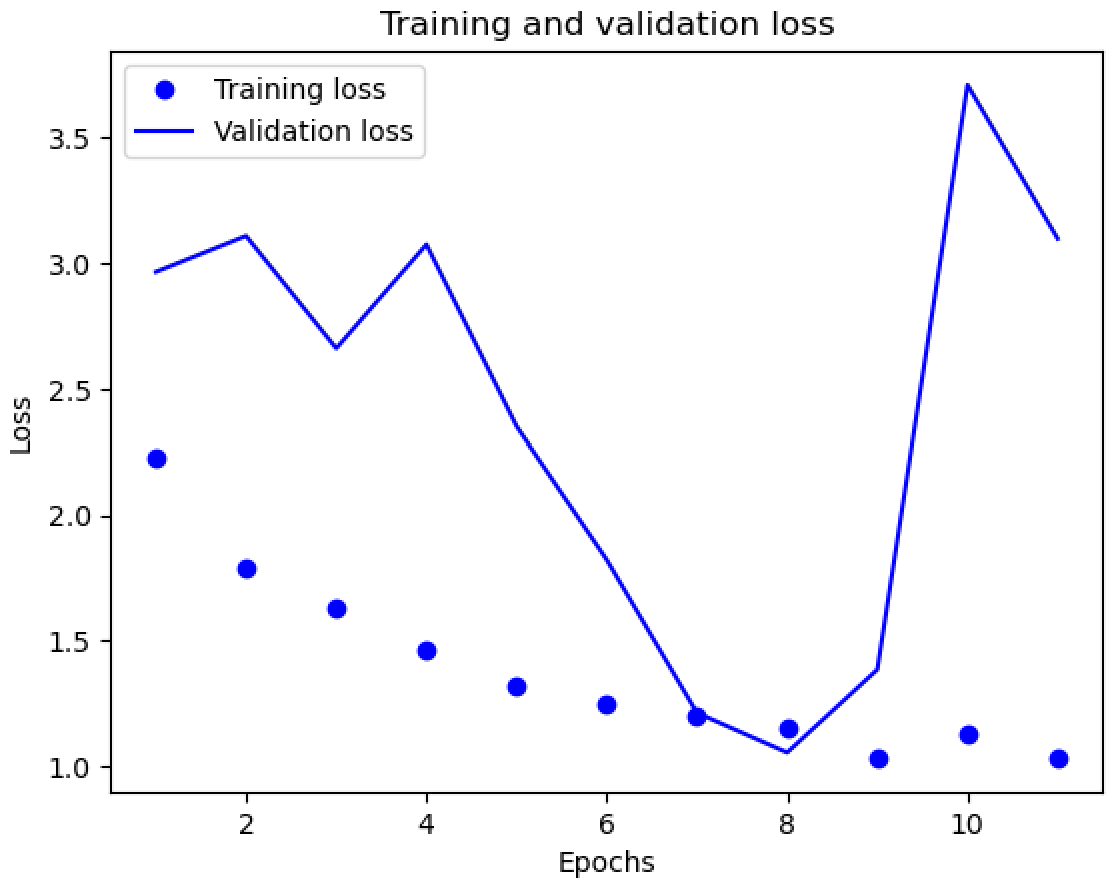
```
# Build a model
def Base_CNN():
  backend.clear_session()
  model = models.Sequential()
```

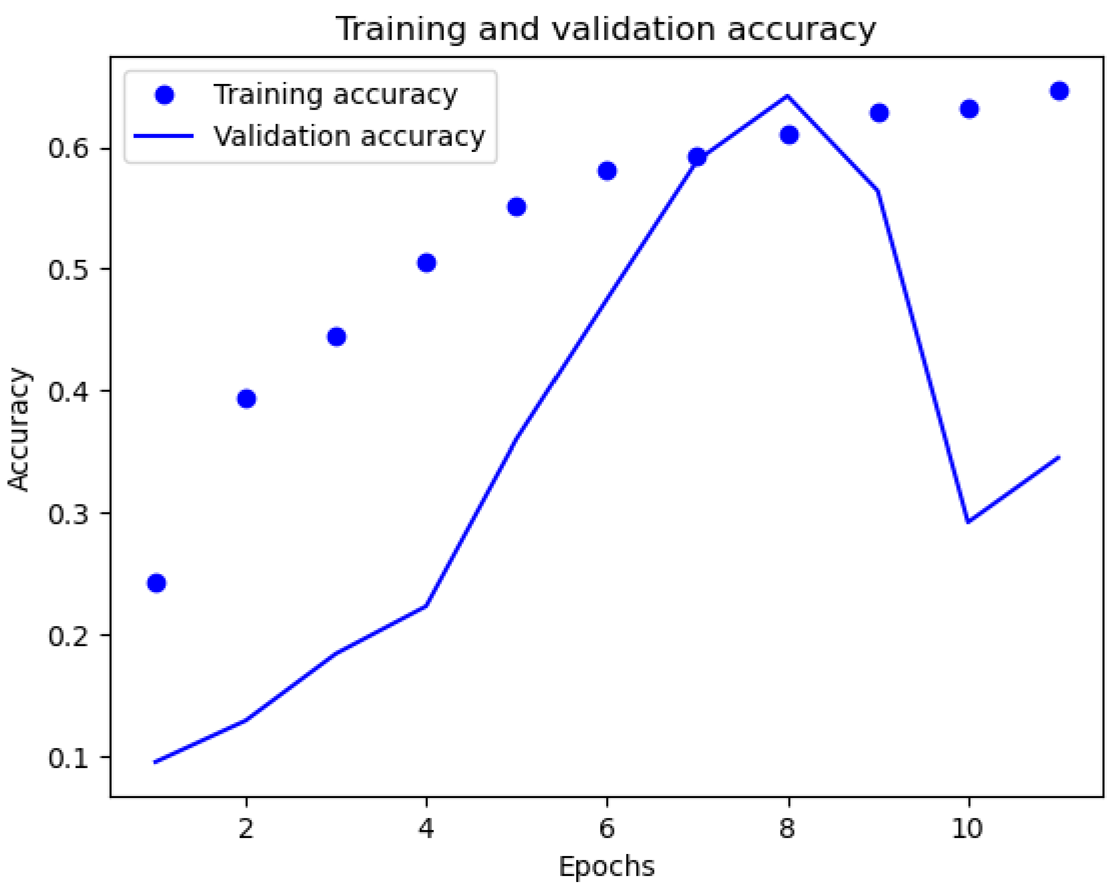
```
    model.add(layers.Conv2D(32, (3,3), activation = 'relu', input_shape = (256, 256, 3))
    model.add(layers.MaxPool2D((2,2)))
    model.add(BatchNormalization())

    model.add(layers.Conv2D(32, (3,3), activation = 'relu'))
    model.add(layers.MaxPool2D((2,2)))
    model.add(BatchNormalization())

    model.add(layers.Conv2D(32, (3,3), activation = 'relu'))
    model.add(layers.MaxPool2D((2,2)))
    model.add(BatchNormalization())

    model.add(layers.Conv2D(32, (3,3), activation = 'relu'))
    model.add(layers.MaxPool2D((2,2)))
    model.add(BatchNormalization())

    model.add(layers.Flatten())
    model.add(layers.Dense(64, activation='relu'))
    model.add(layers.Dense(64, activation='relu'))
    model.add(layers.Dense(64, activation='relu'))
    model.add(layers.Dropout(0.5))

    model.add(layers.Dense(11, activation='softmax'))

    model.compile(optimizer = 'adam',
                  loss = 'categorical_crossentropy',
                  metrics = ['accuracy'])
    return model
```

In [42]:
```
model = Base_CNN()
```

In [43]:
```
history = model.fit( # The image data must come from the image generator that takes th
    train_generator,
    steps_per_epoch=100,
    epochs=100,
    validation_data=val_generator,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_accuracy', patience=5, restore_best_weights

plot_history(history) # Use our plot function to plot the loss and accuracy.

test_loss, test_acc =model.evaluate(test_generator, steps = 100)

print('test_acc:', test_acc)
```

```
Epoch 1/100
100/100 [==============================] - 23s 221ms/step - loss: 2.2259 - accuracy:
0.2430 - val_loss: 2.9652 - val_accuracy: 0.0950
Epoch 2/100
100/100 [==============================] - 22s 220ms/step - loss: 1.7937 - accuracy:
0.3940 - val_loss: 3.1084 - val_accuracy: 0.1290
Epoch 3/100
100/100 [==============================] - 22s 219ms/step - loss: 1.6326 - accuracy:
0.4450 - val_loss: 2.6607 - val_accuracy: 0.1840
Epoch 4/100
100/100 [==============================] - 23s 228ms/step - loss: 1.4627 - accuracy:
0.5050 - val_loss: 3.0743 - val_accuracy: 0.2230
Epoch 5/100
100/100 [==============================] - 22s 218ms/step - loss: 1.3240 - accuracy:
0.5510 - val_loss: 2.3513 - val_accuracy: 0.3600
Epoch 6/100
100/100 [==============================] - 22s 219ms/step - loss: 1.2499 - accuracy:
0.5810 - val_loss: 1.8223 - val_accuracy: 0.4750
Epoch 7/100
100/100 [==============================] - 22s 218ms/step - loss: 1.1999 - accuracy:
0.5930 - val_loss: 1.2130 - val_accuracy: 0.5890
Epoch 8/100
100/100 [==============================] - 21s 213ms/step - loss: 1.1554 - accuracy:
0.6105 - val_loss: 1.0553 - val_accuracy: 0.6420
Epoch 9/100
100/100 [==============================] - 23s 228ms/step - loss: 1.0341 - accuracy:
0.6295 - val_loss: 1.3857 - val_accuracy: 0.5640
Epoch 10/100
100/100 [==============================] - 22s 220ms/step - loss: 1.1286 - accuracy:
0.6315 - val_loss: 3.7098 - val_accuracy: 0.2920
Epoch 11/100
100/100 [==============================] - 22s 222ms/step - loss: 1.0355 - accuracy:
0.6470 - val_loss: 3.0973 - val_accuracy: 0.3450
```






```
100/100 [==============================] - 8s 84ms/step - loss: 1.0379 - accuracy: 0.
6475
test_acc: 0.6474999785423279
```

Looks like our accuracy peaked at almost 65% and quickly fell off. We could extend the patience for a few more epochs to see if it recovers but we can move on to trying some data augmentation first.

In [51]:
```
model_path = 'tomato_leaf_classifier_base_cnn.h5'
model.save(model_path)
```

In [52]:
```
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d (Conv2D)             (None, 254, 254, 32)      896       
                                                                 
 max_pooling2d (MaxPooling2D  (None, 127, 127, 32)     0         
 )                                                               
                                                                 
 batch_normalization (BatchN  (None, 127, 127, 32)     128       
 ormalization)                                                   
                                                                 
 conv2d_1 (Conv2D)           (None, 125, 125, 32)      9248      
                                                                 
 max_pooling2d_1 (MaxPooling  (None, 62, 62, 32)       0         
 2D)                                                             
                                                                 
 batch_normalization_1 (Batc  (None, 62, 62, 32)       128       
 hNormalization)                                                 
                                                                 
 conv2d_2 (Conv2D)           (None, 60, 60, 32)        9248      
                                                                 
 max_pooling2d_2 (MaxPooling  (None, 30, 30, 32)       0         
 2D)                                                             
                                                                 
 batch_normalization_2 (Batc  (None, 30, 30, 32)       128       
 hNormalization)                                                 
                                                                 
 conv2d_3 (Conv2D)           (None, 28, 28, 32)        9248      
                                                                 
 max_pooling2d_3 (MaxPooling  (None, 14, 14, 32)       0         
 2D)                                                             
                                                                 
 batch_normalization_3 (Batc  (None, 14, 14, 32)       128       
 hNormalization)                                                 
                                                                 
 flatten (Flatten)           (None, 6272)              0         
                                                                 
 dense (Dense)               (None, 64)                401472    
                                                                 
 dense_1 (Dense)             (None, 64)                4160      
                                                                 
 dense_2 (Dense)             (None, 64)                4160      
                                                                 
 dropout (Dropout)           (None, 64)                0         
                                                                 
 dense_3 (Dense)             (None, 11)                715       
                                                                 
=================================================================
Total params: 439,659
Trainable params: 439,403
Non-trainable params: 256
_________________________________________________________________
```

In [55]:

```python
# Size the h5 files, we can also change data type to make it smaller before inference
def model_size(path):
    size = os.path.getsize(path) / 1000000
    print(f'Model is approx {size} MB')
```

In [56]:
```
model_size(model_path)
```

```
Model is approx 5.387932 MB
```

Adding Data Augmentation

We likely have enough images that it won't change our accuracy much using data augmentation, but perhaps we can improve our fit, lets continue training our model on the augmented dataset and see if it does anything.

In [58]:
```
datagen = ImageDataGenerator(
    rotation_range=40,
    width_shift_range=0.2,
    height_shift_range=0.2,
    shear_range=0.2,
    zoom_range=0.2,
    horizontal_flip=True,
    fill_mode='nearest')
```

First lets take a look at the data augmentation results for making additional images for classification.

In [ ]:
```
from tensorflow.keras.preprocessing import image
example_dir = os.path.join(train_dir, categories[0])
img = image.load_img(os.path.join(example_dir, os.listdir(example_dir)[1]), target_siz
x = image.img_to_array(img)
x = x.reshape((1,) + x.shape)
i = 0
for batch in datagen.flow(x, batch_size=1):
    plt.figure(i)
    imgplot = plt.imshow(image.array_to_img(batch[0]))
    i += 1
    if i % 4 == 0:
        break
plt.show()
```

This should give us a good range of rotations and leaf locations, so it should at least give us more variety to train on.

In [64]:
```
# Apply the data augmentation to our data.
train_datagen2 = ImageDataGenerator(
    rescale=1./255,
    rotation_range=40,
    width_shift_range=0.2,
    height_shift_range=0.2,
    shear_range=0.2,
    zoom_range=0.2,
    horizontal_flip=True)

test_datagen2 = ImageDataGenerator(rescale=1./255) #Never apply data augmentation to t

train_generator2 = train_datagen2.flow_from_directory(
    train_dir,
    target_size=(256, 256),
    batch_size=20,
```

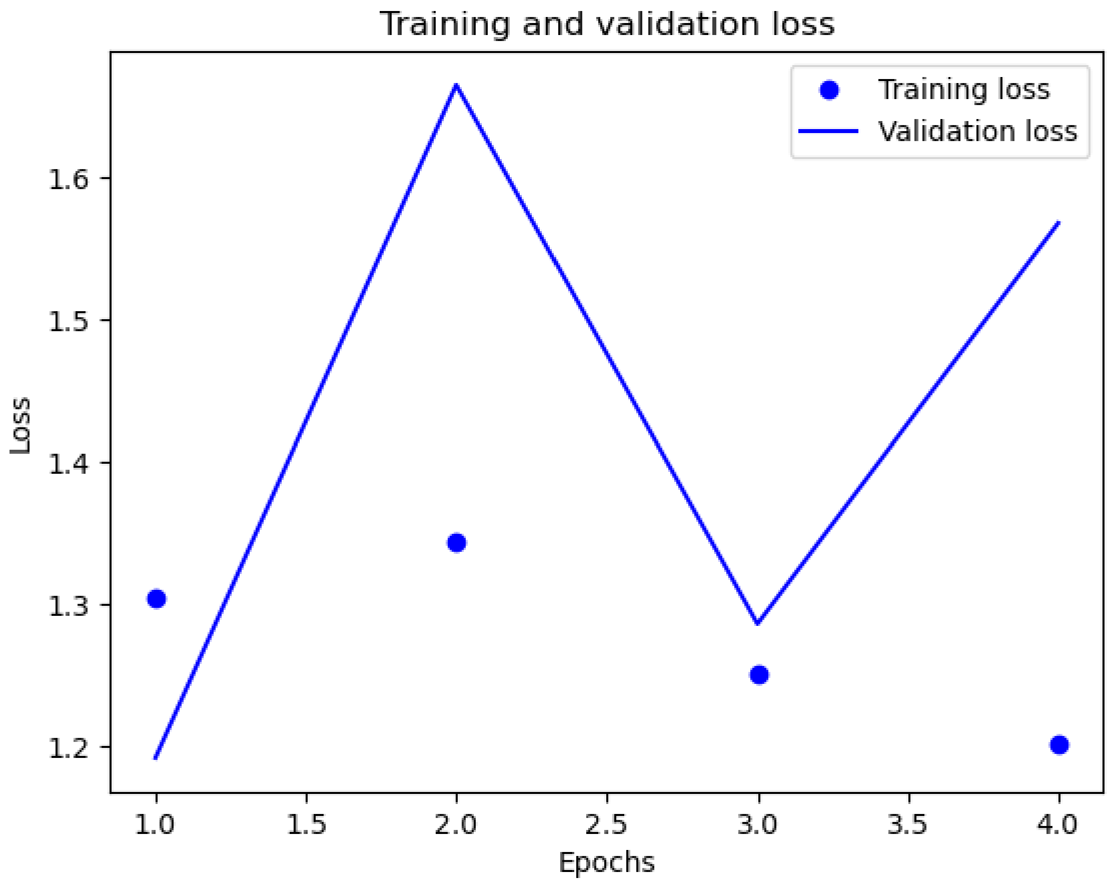
```
    class_mode='categorical')

validation_generator2 = train_datagen2.flow_from_directory(
    val_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')

test_generator2 = test_datagen2.flow_from_directory( # Resize test data
    test_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')
```

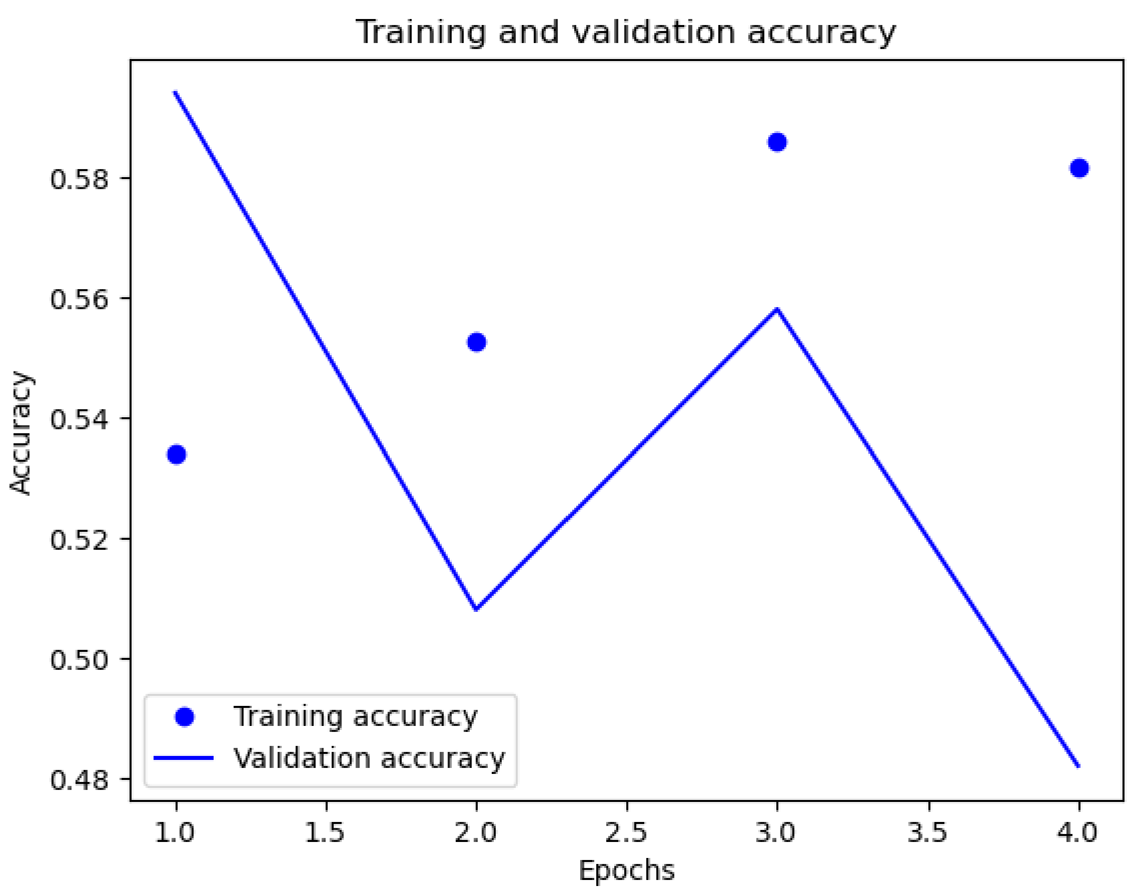
```
Found 20683 images belonging to 11 classes.
Found 5165 images belonging to 11 classes.
Found 6683 images belonging to 11 classes.
```

In [66]:

```
history = model.fit(
    train_generator2,
    steps_per_epoch=100,
    epochs=100,
    validation_data=validation_generator2,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_accuracy', patience=5, restore_best_weights


plot_history(history)

test_loss, test_acc = model.evaluate(test_generator2, steps = 100)
print('test_acc:', test_acc)
model_path = "tomato_leaf_classifier_augmented_cnn.h5"
model.save(model_path)
```

```
Epoch 1/100
100/100 [==============================] - 55s 553ms/step - loss: 1.3046 - accuracy:
0.5340 - val_loss: 1.1921 - val_accuracy: 0.5940
Epoch 2/100
100/100 [==============================] - 55s 555ms/step - loss: 1.3434 - accuracy:
0.5525 - val_loss: 1.6648 - val_accuracy: 0.5080
Epoch 3/100
100/100 [==============================] - 55s 554ms/step - loss: 1.2509 - accuracy:
0.5860 - val_loss: 1.2862 - val_accuracy: 0.5580
Epoch 4/100
100/100 [==============================] - 55s 548ms/step - loss: 1.2020 - accuracy:
0.5815 - val_loss: 1.5677 - val_accuracy: 0.4820
```






```
100/100 [==============================] - 9s 88ms/step - loss: 1.0232 - accuracy: 0.
6445
test_acc: 0.6445000171661377
```

Our network immediately exited out from patience, so it does not look like we will be getting an improvement by using data augmentation. Next I will make next size up version of our CNN, which we can use for testing our knowledge distillation methods at the end. We won't go through testing it now as it is meant as something we can scale up to later if our small model cannot get us the desired accuracy.

In [151...

```
def Next_CNN():
  backend.clear_session()
  model = models.Sequential()

  model.add(layers.Conv2D(64, (3,3), activation = 'relu', input_shape = (256, 256, 3))
  model.add(layers.MaxPool2D((2,2)))
  model.add(BatchNormalization())

  model.add(layers.Conv2D(64, (3,3), activation = 'relu'))
  model.add(layers.MaxPool2D((2,2)))
  model.add(BatchNormalization())

  model.add(layers.Conv2D(64, (3,3), activation = 'relu'))
  model.add(layers.MaxPool2D((2,2)))
  model.add(BatchNormalization())

  model.add(layers.Conv2D(64, (3,3), activation = 'relu'))
  model.add(layers.MaxPool2D((2,2)))
  model.add(BatchNormalization())

  model.add(layers.Flatten())
  model.add(layers.Dense(128, activation='relu'))
  model.add(layers.Dense(128, activation='relu'))
  model.add(layers.Dense(128, activation='relu'))
  model.add(layers.Dropout(0.5))

  model.add(layers.Dense(11, activation='softmax'))

  model.compile(optimizer = 'adam',
                loss = 'categorical_crossentropy',
                metrics = ['accuracy'])
  return model
```

Transfer Learning Models

Here we will try using a few different pretrained models fine-tuned to our specific problem. The problem involves a lot more nuanced detail differences of leaves for the same plant. Hopefully that is not too narrow for this approach to work. My plan is to try our a few different sizes and types of pretrained image classifiers: ResNet, EfficientNet, and DenseNet in particular to try and get a higher accuracy prediction since our classic CNN only gave us 64% accuracy.

In [120...

```
from keras.applications import VGG16 # Tested and dropped due to accuracy
from keras.applications import ResNet152V2
from keras.applications import ResNet50 # Tested and dropped due to accuracy
from keras.applications import EfficientNetB0
from keras.applications import EfficientNetB7 # Tested and dropped due to accuracy
from keras.applications import DenseNet201
```

In [91]:
```
# Apply the data augmentation to our data for transfer learning case, again these are
train_datagen3 = ImageDataGenerator(
    rescale=1./255,
    rotation_range=10,
    width_shift_range=0.2,
    height_shift_range=0.2,
    shear_range=0.02,
    zoom_range=0.1,
    horizontal_flip=True,
    vertical_flip=True)

test_datagen3 = ImageDataGenerator(rescale=1./255)

train_generator3 = train_datagen3.flow_from_directory(
    train_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')

validation_generator3 = train_datagen3.flow_from_directory(
    val_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')

test_generator3 = test_datagen3.flow_from_directory(
    test_dir,
    target_size=(256, 256),
    batch_size=20,
    class_mode='categorical')
```

```
Found 20683 images belonging to 11 classes.
Found 5165 images belonging to 11 classes.
Found 6683 images belonging to 11 classes.
```

In [74]:
```
# Now we can freeze all the resnet weights except the last few, and train those before
backend.clear_session()
resnet_base = ResNet152V2(weights = 'imagenet', include_top = False, input_shape = (25

# Here we freeze all the layers except the last 4.
for layer in resnet_base.layers[:-4]:
  layer.trainable = False
for layer in resnet_base.layers:
  print(layer, layer.trainable)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-applications/re
snet/resnet152v2_weights_tf_dim_ordering_tf_kernels_notop.h5
234545216/234545216 [==============================] - 4s 0us/step
<keras.engine.input_layer.InputLayer object at 0x000001CFC4D7B8E0> False
<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001CFCB90B6D0> Fa
lse
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCB90BA90> False
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<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001CFCFA66CE0> Fa
lse
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFB19C60> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
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<keras.layers.pooling.max_pooling2d.MaxPooling2D object at 0x000001CFCFB1B1F0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFAE2290> False
```

```
<keras.layers.merging.add.Add object at 0x000001CFCFAFEB60> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFAC4F70> False
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<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001CFCFB3F220> Fa
lse
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CFCFB5EC80> False
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<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFB5ECB0> False
<keras.layers.merging.add.Add object at 0x000001CFCFB5D930> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFB75510> False
<keras.layers.core.activation.Activation object at 0x000001CFCFB3EAD0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFB77790> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFB77580> False
<keras.layers.core.activation.Activation object at 0x000001CFCFB77CA0> False
<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001CFCFB91BA0> Fa
lse
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFB91E70> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFB93CD0> False
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<keras.layers.merging.add.Add object at 0x000001CFCFAA1210> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFB3E5F0> False
<keras.layers.core.activation.Activation object at 0x000001CFCFB77FA0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFA87AC0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
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<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001CFCFAFF640> Fa
lse
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFB911E0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFB5CAF0> False
<keras.layers.core.activation.Activation object at 0x000001CFCFB19CF0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001CFCFBBF0D0> True
<keras.layers.merging.add.Add object at 0x000001CFCFBBE380> True
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
CFCFBBCA00> True
<keras.layers.core.activation.Activation object at 0x000001CFCFB5CDF0> True
```

We have brought in a trained ResNet model and made the last few layers trainable for fine-tuning.

In [118…

```
def model_transfer_train(model_base):
  backend.clear_session()
  X = models.Sequential()
  X.add(model_base)
  X.add(layers.Flatten())
```

```
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(11, activation = 'softmax'))

  X.compile('adam',
    loss = 'categorical_crossentropy',
    metrics = ['accuracy'])

  return X
```

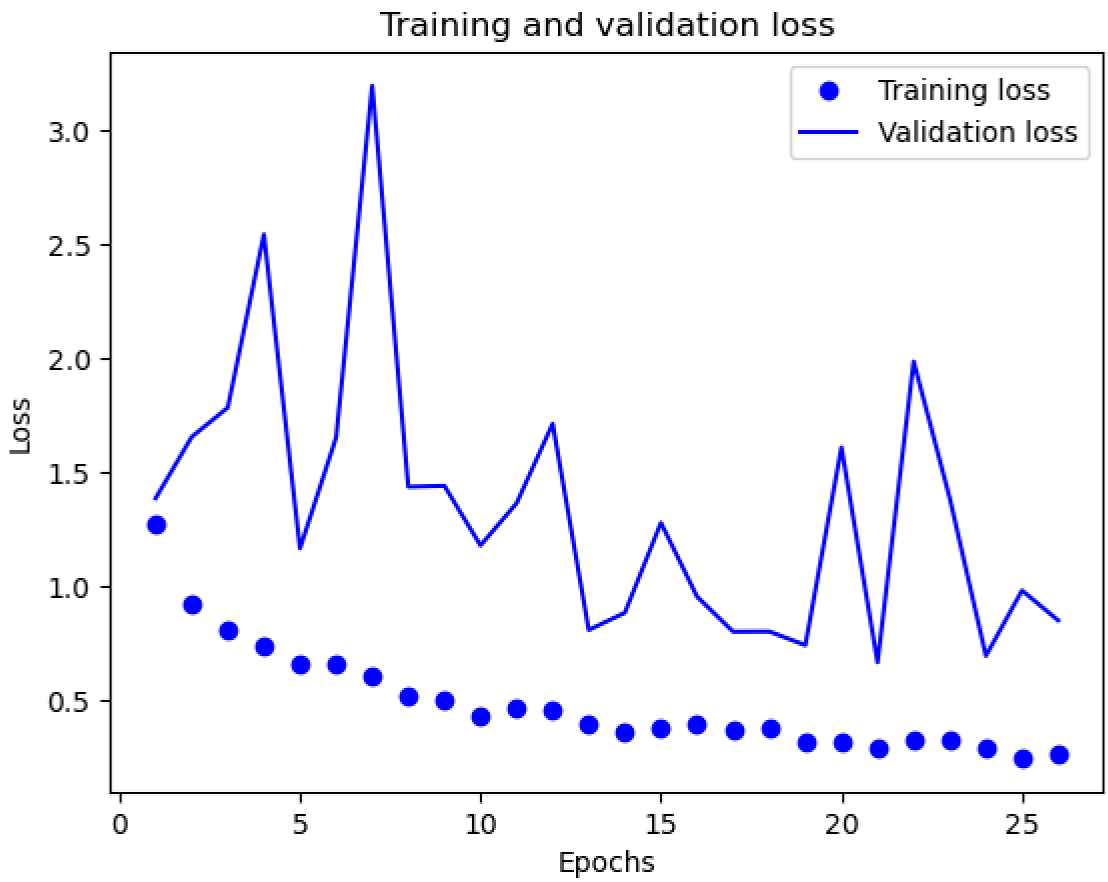
Finishing the model we add our own top to act as the classifier for our 11 leaf health classes.

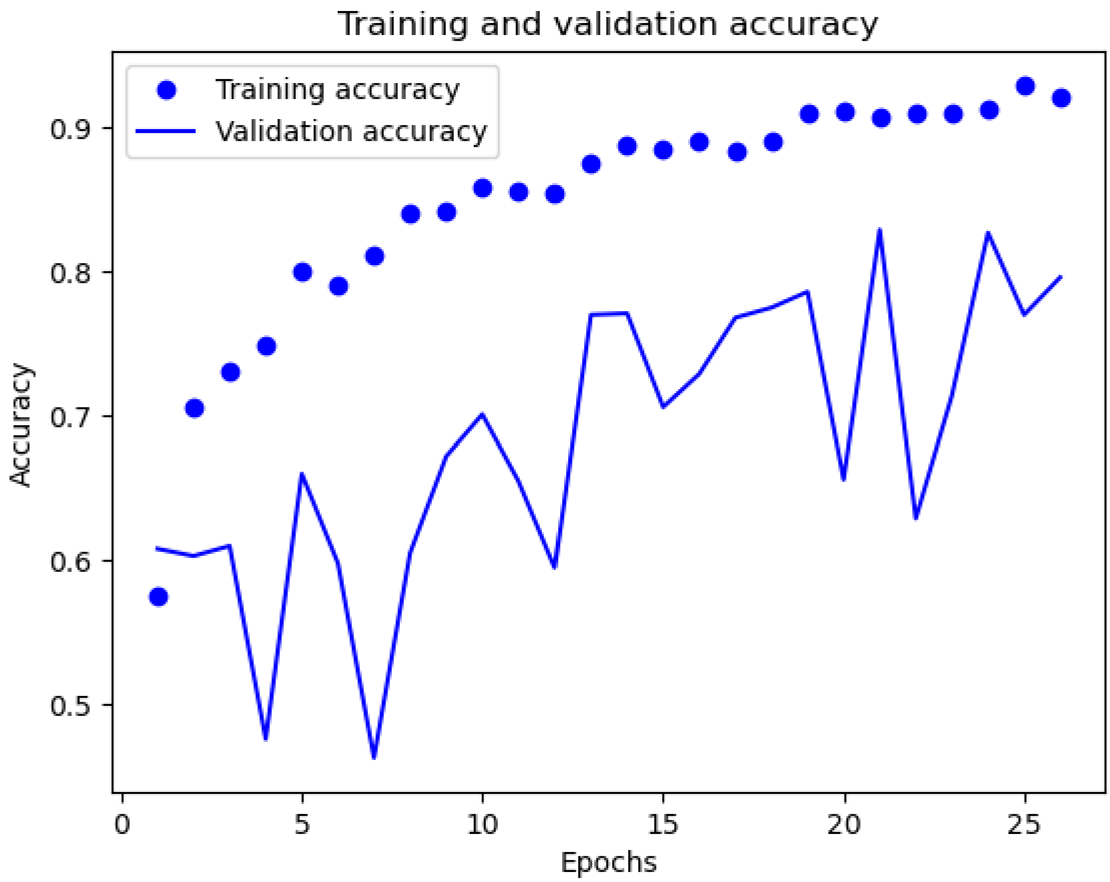
In [76]:
```
model = model_transfer_train(resnet_base)
```

In [78]:
```
history = model.fit(
    train_generator,
    steps_per_epoch=100,
    epochs=100,
    validation_data=val_generator,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_accuracy', patience=5, restore_best_weights


plot_history(history)

test_loss, test_acc = model.evaluate(test_generator, steps = 100)
print('test_acc:', test_acc)
model_path = "tomato_leaf_classifier_transfer_resnet152v2.h5"
model.save(model_path)
```

```
Epoch 1/100
100/100 [==============================] - 190s 2s/step - loss: 1.2708 - accuracy: 0.
5755 - val_loss: 1.3864 - val_accuracy: 0.6080
Epoch 2/100
100/100 [==============================] - 186s 2s/step - loss: 0.9243 - accuracy: 0.
7055 - val_loss: 1.6565 - val_accuracy: 0.6030
Epoch 3/100
100/100 [==============================] - 186s 2s/step - loss: 0.8125 - accuracy: 0.
7315 - val_loss: 1.7855 - val_accuracy: 0.6100
Epoch 4/100
100/100 [==============================] - 184s 2s/step - loss: 0.7418 - accuracy: 0.
7494 - val_loss: 2.5459 - val_accuracy: 0.4760
Epoch 5/100
100/100 [==============================] - 190s 2s/step - loss: 0.6594 - accuracy: 0.
8008 - val_loss: 1.1666 - val_accuracy: 0.6600
Epoch 6/100
100/100 [==============================] - 187s 2s/step - loss: 0.6575 - accuracy: 0.
7900 - val_loss: 1.6536 - val_accuracy: 0.5980
Epoch 7/100
100/100 [==============================] - 188s 2s/step - loss: 0.6052 - accuracy: 0.
8110 - val_loss: 3.1982 - val_accuracy: 0.4630
Epoch 8/100
100/100 [==============================] - 187s 2s/step - loss: 0.5165 - accuracy: 0.
8410 - val_loss: 1.4373 - val_accuracy: 0.6050
Epoch 9/100
100/100 [==============================] - 200s 2s/step - loss: 0.5052 - accuracy: 0.
8415 - val_loss: 1.4416 - val_accuracy: 0.6720
Epoch 10/100
100/100 [==============================] - 199s 2s/step - loss: 0.4331 - accuracy: 0.
8580 - val_loss: 1.1798 - val_accuracy: 0.7010
Epoch 11/100
100/100 [==============================] - 193s 2s/step - loss: 0.4640 - accuracy: 0.
8565 - val_loss: 1.3652 - val_accuracy: 0.6550
Epoch 12/100
100/100 [==============================] - 187s 2s/step - loss: 0.4571 - accuracy: 0.
8550 - val_loss: 1.7144 - val_accuracy: 0.5950
Epoch 13/100
100/100 [==============================] - 188s 2s/step - loss: 0.3972 - accuracy: 0.
8750 - val_loss: 0.8088 - val_accuracy: 0.7700
Epoch 14/100
100/100 [==============================] - 190s 2s/step - loss: 0.3648 - accuracy: 0.
8880 - val_loss: 0.8842 - val_accuracy: 0.7710
Epoch 15/100
100/100 [==============================] - 187s 2s/step - loss: 0.3807 - accuracy: 0.
8845 - val_loss: 1.2795 - val_accuracy: 0.7060
Epoch 16/100
100/100 [==============================] - 187s 2s/step - loss: 0.3978 - accuracy: 0.
8905 - val_loss: 0.9551 - val_accuracy: 0.7290
Epoch 17/100
100/100 [==============================] - 190s 2s/step - loss: 0.3719 - accuracy: 0.
8840 - val_loss: 0.8012 - val_accuracy: 0.7680
Epoch 18/100
100/100 [==============================] - 188s 2s/step - loss: 0.3806 - accuracy: 0.
8905 - val_loss: 0.8020 - val_accuracy: 0.7750
Epoch 19/100
100/100 [==============================] - 217s 2s/step - loss: 0.3206 - accuracy: 0.
9095 - val_loss: 0.7418 - val_accuracy: 0.7860
Epoch 20/100
100/100 [==============================] - 238s 2s/step - loss: 0.3133 - accuracy: 0.
9120 - val_loss: 1.6108 - val_accuracy: 0.6560
```

```
Epoch 21/100
100/100 [==============================] - 240s 2s/step - loss: 0.2914 - accuracy: 0.
9070 - val_loss: 0.6660 - val_accuracy: 0.8290
Epoch 22/100
100/100 [==============================] - 236s 2s/step - loss: 0.3252 - accuracy: 0.
9097 - val_loss: 1.9882 - val_accuracy: 0.6290
Epoch 23/100
100/100 [==============================] - 240s 2s/step - loss: 0.3224 - accuracy: 0.
9105 - val_loss: 1.3868 - val_accuracy: 0.7140
Epoch 24/100
100/100 [==============================] - 246s 2s/step - loss: 0.2930 - accuracy: 0.
9125 - val_loss: 0.6948 - val_accuracy: 0.8270
Epoch 25/100
100/100 [==============================] - 233s 2s/step - loss: 0.2473 - accuracy: 0.
9295 - val_loss: 0.9821 - val_accuracy: 0.7700
Epoch 26/100
100/100 [==============================] - 238s 2s/step - loss: 0.2600 - accuracy: 0.
9205 - val_loss: 0.8507 - val_accuracy: 0.7960
```






```
100/100 [==============================] - 144s 1s/step - loss: 0.6345 - accuracy: 0.
8435
test_acc: 0.843500018119812
```

In [79]:
```
model_size(model_path)
```

```
Model is approx 1054.418624 MB
```

Our first transfer learning model is 84% accurate but also over 1 GB in size. Let's try a few more transfer learning models before we move on to other alternatives.

In [106…
```
backend.clear_session()
effnet_base = EfficientNetB0(weights = 'imagenet', include_top = False, input_shape =

effnet_base.trainable = False # I tried doing fine tuning with this model as well but
```

In [107…
```
def model_efficient_net_train(base):
  backend.clear_session()
  X = models.Sequential()
  X.add(base)
  X.add(layers.Flatten())
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(512, activation = 'relu'))
  X.add(layers.Dense(11, activation = 'softmax'))

  X.compile('adam',
    loss = 'categorical_crossentropy',
    metrics = ['accuracy'])

  return X
```

In [108…

```
model = model_efficient_net_train(effnet_base)
```

In [109…

```
history = model.fit(
    train_generator,
    steps_per_epoch=100,
    epochs=100,
    validation_data=val_generator,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_accuracy', patience=4, restore_best_weights


plot_history(history)

test_loss, test_acc = model.evaluate(test_generator, steps = 100)
print('test_acc:', test_acc)
model_path = "tomato_leaf_classifier_transfer_effnetB0.h5"
model.save(model_path)
```

```
Epoch 1/100
100/100 [==============================] - 292s 3s/step - loss: 15.2926 - accuracy: 0.1120 - val_loss: 2.3949 - val_accuracy: 0.1020
Epoch 2/100
100/100 [==============================] - 265s 3s/step - loss: 2.5077 - accuracy: 0.1070 - val_loss: 2.3673 - val_accuracy: 0.1000
Epoch 3/100
100/100 [==============================] - 260s 3s/step - loss: 2.4231 - accuracy: 0.1180 - val_loss: 2.3676 - val_accuracy: 0.1060
Epoch 4/100
 86/100 [========================>.....] - ETA: 26s - loss: 2.4793 - accuracy: 0.1122
```

```
---------------------------------------------------------------------------
KeyboardInterrupt                         Traceback (most recent call last)
Cell In [109], line 1
----> 1 history = model.fit(
      2     train_generator3,
      3     steps_per_epoch=100,
      4     epochs=100,
      5     validation_data=validation_generator3,
      6     validation_steps=50,
      7     verbose = 1,
      8     callbacks=[EarlyStopping(monitor='val_accuracy', patience=4, restore_best
_weights = True)])
     11 plot_history(history)
     13 test_loss, test_acc = model.evaluate(test_generator3, steps = 100)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\keras\utils\traceback_utils.
py:64, in filter_traceback.<locals>.error_handler(*args, **kwargs)
     62 filtered_tb = None
     63 try:
---> 64   return fn(*args, **kwargs)
     65 except Exception as e:  # pylint: disable=broad-except
     66   filtered_tb = _process_traceback_frames(e.__traceback__)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\keras\engine\training.py:140
9, in Model.fit(self, x, y, batch_size, epochs, verbose, callbacks, validation_split,
validation_data, shuffle, class_weight, sample_weight, initial_epoch, steps_per_epoc
h, validation_steps, validation_batch_size, validation_freq, max_queue_size, workers,
use_multiprocessing)
   1402 with tf.profiler.experimental.Trace(
   1403     'train',
   1404     epoch_num=epoch,
   1405     step_num=step,
   1406     batch_size=batch_size,
   1407     _r=1):
   1408   callbacks.on_train_batch_begin(step)
-> 1409   tmp_logs = self.train_function(iterator)
   1410   if data_handler.should_sync:
   1411     context.async_wait()

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\util\trace
back_utils.py:150, in filter_traceback.<locals>.error_handler(*args, **kwargs)
    148 filtered_tb = None
    149 try:
--> 150   return fn(*args, **kwargs)
    151 except Exception as e:
    152   filtered_tb = _process_traceback_frames(e.__traceback__)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\def_
function.py:915, in Function.__call__(self, *args, **kwds)
    912 compiler = "xla" if self._jit_compile else "nonXla"
    914 with OptionalXlaContext(self._jit_compile):
--> 915   result = self._call(*args, **kwds)
    917 new_tracing_count = self.experimental_get_tracing_count()
    918 without_tracing = (tracing_count == new_tracing_count)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\def_
function.py:947, in Function._call(self, *args, **kwds)
    944   self._lock.release()
    945   # In this case we have created variables on the first call, so we run the
    946   # defunned version which is guaranteed to never create variables.
```

```
--> 947   return self._stateless_fn(*args, **kwds)  # pylint: disable=not-callable
    948 elif self._stateful_fn is not None:
    949   # Release the lock early so that multiple threads can perform the call
    950   # in parallel.
    951   self._lock.release()

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\function.py:2453, in Function.__call__(self, *args, **kwargs)
   2450 with self._lock:
   2451   (graph_function,
   2452    filtered_flat_args) = self._maybe_define_function(args, kwargs)
-> 2453 return graph_function._call_flat(
   2454     filtered_flat_args, captured_inputs=graph_function.captured_inputs)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\function.py:1860, in ConcreteFunction._call_flat(self, args, captured_inputs, cancellation_manager)
   1856 possible_gradient_type = gradients_util.PossibleTapeGradientTypes(args)
   1857 if (possible_gradient_type == gradients_util.POSSIBLE_GRADIENT_TYPES_NONE
   1858     and executing_eagerly):
   1859   # No tape is watching; skip to running the function.
-> 1860   return self._build_call_outputs(self._inference_function.call(
   1861       ctx, args, cancellation_manager=cancellation_manager))
   1862 forward_backward = self._select_forward_and_backward_functions(
   1863     args,
   1864     possible_gradient_type,
   1865     executing_eagerly)
   1866 forward_function, args_with_tangents = forward_backward.forward()

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\function.py:497, in _EagerDefinedFunction.call(self, ctx, args, cancellation_manager)
    495 with _InterpolateFunctionError(self):
    496   if cancellation_manager is None:
--> 497     outputs = execute.execute(
    498         str(self.signature.name),
    499         num_outputs=self._num_outputs,
    500         inputs=args,
    501         attrs=attrs,
    502         ctx=ctx)
    503   else:
    504     outputs = execute.execute_with_cancellation(
    505         str(self.signature.name),
    506         num_outputs=self._num_outputs,
   (...)
    509         ctx=ctx,
    510         cancellation_manager=cancellation_manager)

File ~\anaconda3\envs\deep-learning-cv\lib\site-packages\tensorflow\python\eager\execute.py:54, in quick_execute(op_name, num_outputs, inputs, attrs, ctx, name)
     52 try:
     53   ctx.ensure_initialized()
---> 54   tensors = pywrap_tfe.TFE_Py_Execute(ctx._handle, device_name, op_name,
     55                                       inputs, attrs, num_outputs)
     56 except core._NotOkStatusException as e:
     57   if name is not None:

KeyboardInterrupt:
```

In [99]:

```
model_size(model_path)
```

```
Model is approx 529.615288 MB
```

Unfortunately we didn't get a good result from this one with an accuracy never making it out of the 40%'s, and a model size of 530 MB. This is a little concerning because my plan was to train a smaller model using a good transfer learning model as a teacher, and with this being half the size of our previous transfer learner but unable to compete on accuracy I am worried.

In [121…

```
# Now we can freeze all the resnet weights except the last few, and train those before
backend.clear_session()
base = DenseNet201(weights = 'imagenet', include_top = False, input_shape = (256, 256,

# Here we freeze all the layers except the last 4.
for layer in base.layers[:-4]:
    layer.trainable = False
for layer in base.layers:
    print(layer, layer.trainable)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-applications/de
nsenet/densenet201_weights_tf_dim_ordering_tf_kernels_notop.h5
74836368/74836368 [==============================] - 2s 0us/step
<keras.engine.input_layer.InputLayer object at 0x000001D169596A40> False
<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001D169A18490> Fa
lse
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A181F0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A19450> False
<keras.layers.core.activation.Activation object at 0x000001D169A18E50> False
<keras.layers.reshaping.zero_padding2d.ZeroPadding2D object at 0x000001D1694FFEE0> Fa
lse
<keras.layers.pooling.max_pooling2d.MaxPooling2D object at 0x000001CFA0123460> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D16954F2B0> False
<keras.layers.core.activation.Activation object at 0x000001D16954EF80> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A1A560> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A1AF20> False
<keras.layers.core.activation.Activation object at 0x000001D16A4BBBB0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A4D8A0> False
<keras.layers.merging.concatenate.Concatenate object at 0x000001D169A1B100> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A4F7C0> False
<keras.layers.core.activation.Activation object at 0x000001CFF1838040> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A4F280> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A5F5E0> False
<keras.layers.core.activation.Activation object at 0x000001D169A5DB40> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A5C250> False
<keras.layers.merging.concatenate.Concatenate object at 0x000001D169A5DF30> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A5E230> False
<keras.layers.core.activation.Activation object at 0x000001D169A1A980> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A1B1F0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D16C4251B0> False
<keras.layers.core.activation.Activation object at 0x000001D16A4B82B0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A196F0> False
<keras.layers.merging.concatenate.Concatenate object at 0x000001D169A5D1B0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A7C370> False
<keras.layers.core.activation.Activation object at 0x000001D169A4EA10> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D16A4D9CC0> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D16A4DA6B0> False
<keras.layers.core.activation.Activation object at 0x000001D169A5D630> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A7C550> False
<keras.layers.merging.concatenate.Concatenate object at 0x000001D169A7DB10> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A8A8C0> False
<keras.layers.core.activation.Activation object at 0x000001D169A7DC30> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A89090> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169A89C00> False
<keras.layers.core.activation.Activation object at 0x000001D169A7F2B0> False
<keras.layers.convolutional.conv2d.Conv2D object at 0x000001D169A88BE0> False
<keras.layers.merging.concatenate.Concatenate object at 0x000001D169A8AE00> False
<keras.layers.normalization.batch_normalization.BatchNormalization object at 0x000001
D169AA3430> False
```

```
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```

In [122…

```
model = model_transfer_train(base)
```

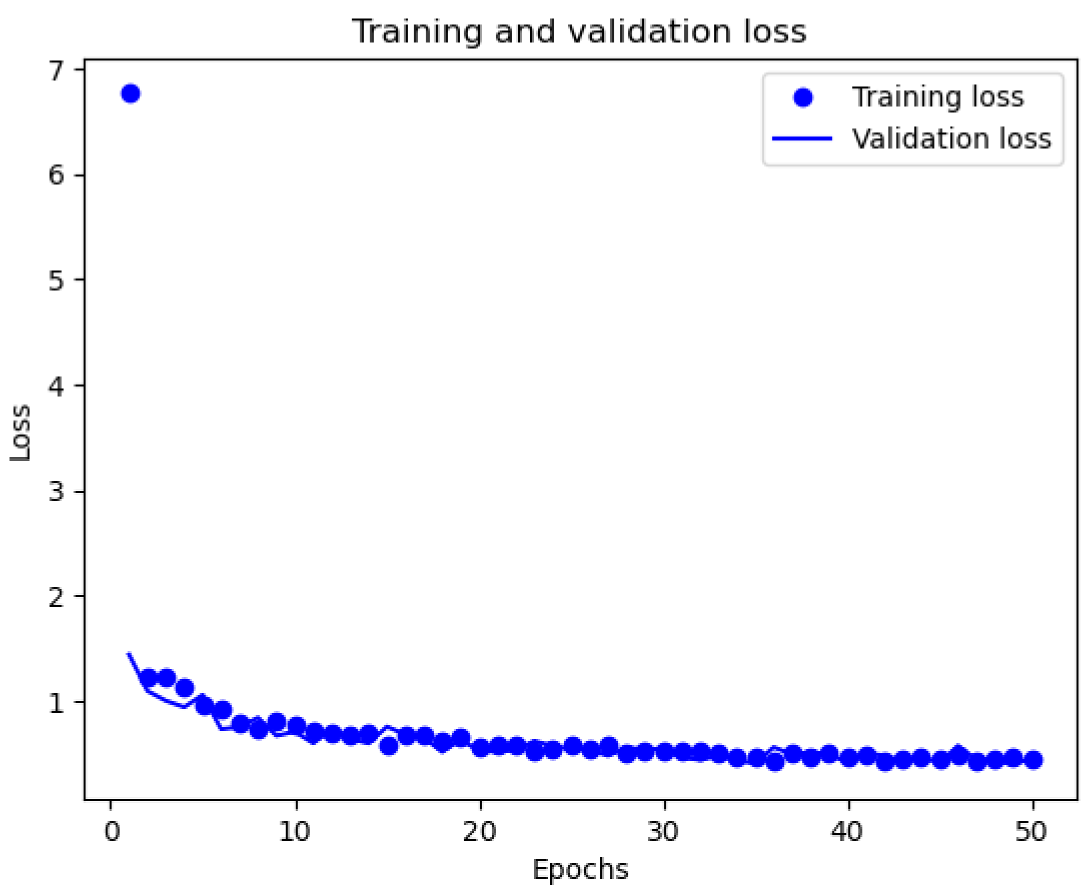
In [123…

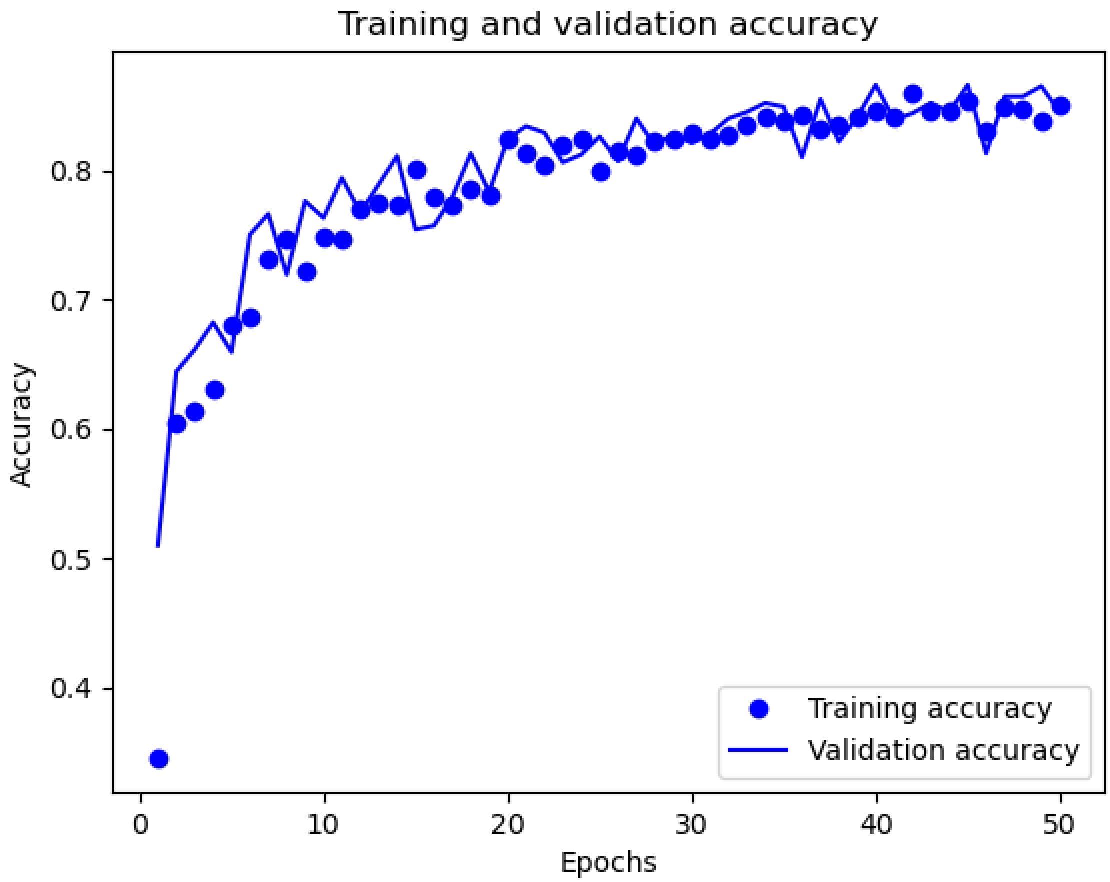
```
history = model.fit(
    train_generator3,
    steps_per_epoch=100,
    epochs=100,
    validation_data=validation_generator3,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_accuracy', patience=10, restore_best_weights


plot_history(history)

test_loss, test_acc = model.evaluate(test_generator3, steps = 100)
print('test_acc:', test_acc)
model_path = "tomato_leaf_classifier_densenet.h5"
model.save(model_path)
```

```
Epoch 1/100
100/100 [==============================] - 174s 2s/step - loss: 6.7753 - accuracy: 0.
3455 - val_loss: 1.4400 - val_accuracy: 0.5100
Epoch 2/100
100/100 [==============================] - 155s 2s/step - loss: 1.2224 - accuracy: 0.
6040 - val_loss: 1.0930 - val_accuracy: 0.6440
Epoch 3/100
100/100 [==============================] - 154s 2s/step - loss: 1.2217 - accuracy: 0.
6132 - val_loss: 0.9998 - val_accuracy: 0.6610
Epoch 4/100
100/100 [==============================] - 155s 2s/step - loss: 1.1315 - accuracy: 0.
6305 - val_loss: 0.9390 - val_accuracy: 0.6820
Epoch 5/100
100/100 [==============================] - 154s 2s/step - loss: 0.9586 - accuracy: 0.
6800 - val_loss: 1.0561 - val_accuracy: 0.6590
Epoch 6/100
100/100 [==============================] - 155s 2s/step - loss: 0.9241 - accuracy: 0.
6855 - val_loss: 0.7305 - val_accuracy: 0.7500
Epoch 7/100
100/100 [==============================] - 155s 2s/step - loss: 0.7963 - accuracy: 0.
7310 - val_loss: 0.7508 - val_accuracy: 0.7660
Epoch 8/100
100/100 [==============================] - 155s 2s/step - loss: 0.7379 - accuracy: 0.
7470 - val_loss: 0.8399 - val_accuracy: 0.7190
Epoch 9/100
100/100 [==============================] - 152s 2s/step - loss: 0.8057 - accuracy: 0.
7211 - val_loss: 0.6672 - val_accuracy: 0.7760
Epoch 10/100
100/100 [==============================] - 154s 2s/step - loss: 0.7778 - accuracy: 0.
7475 - val_loss: 0.7065 - val_accuracy: 0.7630
Epoch 11/100
100/100 [==============================] - 155s 2s/step - loss: 0.7156 - accuracy: 0.
7465 - val_loss: 0.5963 - val_accuracy: 0.7940
Epoch 12/100
100/100 [==============================] - 154s 2s/step - loss: 0.6917 - accuracy: 0.
7700 - val_loss: 0.7306 - val_accuracy: 0.7670
Epoch 13/100
100/100 [==============================] - 155s 2s/step - loss: 0.6718 - accuracy: 0.
7750 - val_loss: 0.6385 - val_accuracy: 0.7890
Epoch 14/100
100/100 [==============================] - 155s 2s/step - loss: 0.6869 - accuracy: 0.
7735 - val_loss: 0.5952 - val_accuracy: 0.8110
Epoch 15/100
100/100 [==============================] - 156s 2s/step - loss: 0.5788 - accuracy: 0.
8005 - val_loss: 0.7539 - val_accuracy: 0.7540
Epoch 16/100
100/100 [==============================] - 156s 2s/step - loss: 0.6711 - accuracy: 0.
7795 - val_loss: 0.6793 - val_accuracy: 0.7570
Epoch 17/100
100/100 [==============================] - 156s 2s/step - loss: 0.6700 - accuracy: 0.
7730 - val_loss: 0.6496 - val_accuracy: 0.7790
Epoch 18/100
100/100 [==============================] - 156s 2s/step - loss: 0.6264 - accuracy: 0.
7855 - val_loss: 0.5133 - val_accuracy: 0.8130
Epoch 19/100
100/100 [==============================] - 156s 2s/step - loss: 0.6513 - accuracy: 0.
7800 - val_loss: 0.6316 - val_accuracy: 0.7830
Epoch 20/100
100/100 [==============================] - 155s 2s/step - loss: 0.5560 - accuracy: 0.
8245 - val_loss: 0.5229 - val_accuracy: 0.8240
```

```
Epoch 21/100
100/100 [==============================] - 156s 2s/step - loss: 0.5707 - accuracy: 0.
8125 - val_loss: 0.5162 - val_accuracy: 0.8340
Epoch 22/100
100/100 [==============================] - 156s 2s/step - loss: 0.5713 - accuracy: 0.
8035 - val_loss: 0.5311 - val_accuracy: 0.8290
Epoch 23/100
100/100 [==============================] - 155s 2s/step - loss: 0.5307 - accuracy: 0.
8200 - val_loss: 0.6176 - val_accuracy: 0.8060
Epoch 24/100
100/100 [==============================] - 155s 2s/step - loss: 0.5495 - accuracy: 0.
8245 - val_loss: 0.5702 - val_accuracy: 0.8120
Epoch 25/100
100/100 [==============================] - 156s 2s/step - loss: 0.5855 - accuracy: 0.
8000 - val_loss: 0.5380 - val_accuracy: 0.8260
Epoch 26/100
100/100 [==============================] - 155s 2s/step - loss: 0.5444 - accuracy: 0.
8155 - val_loss: 0.5355 - val_accuracy: 0.8070
Epoch 27/100
100/100 [==============================] - 156s 2s/step - loss: 0.5751 - accuracy: 0.
8120 - val_loss: 0.4770 - val_accuracy: 0.8400
Epoch 28/100
100/100 [==============================] - 156s 2s/step - loss: 0.5027 - accuracy: 0.
8220 - val_loss: 0.5517 - val_accuracy: 0.8190
Epoch 29/100
100/100 [==============================] - 156s 2s/step - loss: 0.5214 - accuracy: 0.
8240 - val_loss: 0.5392 - val_accuracy: 0.8280
Epoch 30/100
100/100 [==============================] - 156s 2s/step - loss: 0.5201 - accuracy: 0.
8290 - val_loss: 0.5441 - val_accuracy: 0.8210
Epoch 31/100
100/100 [==============================] - 156s 2s/step - loss: 0.5236 - accuracy: 0.
8240 - val_loss: 0.4606 - val_accuracy: 0.8280
Epoch 32/100
100/100 [==============================] - 156s 2s/step - loss: 0.5208 - accuracy: 0.
8275 - val_loss: 0.4377 - val_accuracy: 0.8400
Epoch 33/100
100/100 [==============================] - 156s 2s/step - loss: 0.5030 - accuracy: 0.
8350 - val_loss: 0.4767 - val_accuracy: 0.8450
Epoch 34/100
100/100 [==============================] - 156s 2s/step - loss: 0.4724 - accuracy: 0.
8405 - val_loss: 0.4291 - val_accuracy: 0.8520
Epoch 35/100
100/100 [==============================] - 155s 2s/step - loss: 0.4576 - accuracy: 0.
8380 - val_loss: 0.4069 - val_accuracy: 0.8490
Epoch 36/100
100/100 [==============================] - 156s 2s/step - loss: 0.4315 - accuracy: 0.
8430 - val_loss: 0.5582 - val_accuracy: 0.8100
Epoch 37/100
100/100 [==============================] - 156s 2s/step - loss: 0.4959 - accuracy: 0.
8320 - val_loss: 0.4903 - val_accuracy: 0.8550
Epoch 38/100
100/100 [==============================] - 154s 2s/step - loss: 0.4712 - accuracy: 0.
8345 - val_loss: 0.5126 - val_accuracy: 0.8220
Epoch 39/100
100/100 [==============================] - 155s 2s/step - loss: 0.5037 - accuracy: 0.
8415 - val_loss: 0.4934 - val_accuracy: 0.8410
Epoch 40/100
100/100 [==============================] - 156s 2s/step - loss: 0.4670 - accuracy: 0.
8460 - val_loss: 0.4108 - val_accuracy: 0.8660
```

```
Epoch 41/100
100/100 [==============================] - 155s 2s/step - loss: 0.4773 - accuracy: 0.
8410 - val_loss: 0.5005 - val_accuracy: 0.8390
Epoch 42/100
100/100 [==============================] - 155s 2s/step - loss: 0.4315 - accuracy: 0.
8590 - val_loss: 0.4816 - val_accuracy: 0.8440
Epoch 43/100
100/100 [==============================] - 156s 2s/step - loss: 0.4441 - accuracy: 0.
8450 - val_loss: 0.4184 - val_accuracy: 0.8520
Epoch 44/100
100/100 [==============================] - 155s 2s/step - loss: 0.4739 - accuracy: 0.
8465 - val_loss: 0.4714 - val_accuracy: 0.8450
Epoch 45/100
100/100 [==============================] - 155s 2s/step - loss: 0.4384 - accuracy: 0.
8530 - val_loss: 0.4059 - val_accuracy: 0.8660
Epoch 46/100
100/100 [==============================] - 155s 2s/step - loss: 0.4911 - accuracy: 0.
8310 - val_loss: 0.5731 - val_accuracy: 0.8130
Epoch 47/100
100/100 [==============================] - 155s 2s/step - loss: 0.4226 - accuracy: 0.
8485 - val_loss: 0.4403 - val_accuracy: 0.8570
Epoch 48/100
100/100 [==============================] - 155s 2s/step - loss: 0.4422 - accuracy: 0.
8472 - val_loss: 0.4379 - val_accuracy: 0.8570
Epoch 49/100
100/100 [==============================] - 156s 2s/step - loss: 0.4629 - accuracy: 0.
8385 - val_loss: 0.3908 - val_accuracy: 0.8650
Epoch 50/100
100/100 [==============================] - 155s 2s/step - loss: 0.4522 - accuracy: 0.
8510 - val_loss: 0.4558 - val_accuracy: 0.8450
```






```
100/100 [==============================] - 92s 916ms/step - loss: 0.3740 - accuracy: 0.8710
test_acc: 0.8709999918937683
```

In [124…

```
model_size(model_path)
```

```
Model is approx 836.169824 MB
```

The best model that we have so far is the DenseNet 201 transfer model, with a trained model size of 836 MB, which is likely too big for our offline edge devices. We have an accuracy of 87% for our best model. My hope is that by doing some knowledge distillation we can get something under 32 MB that gets close to 80% accuracy. I don't know the specific constraints for the problem, but I think that this is both achievable and realistic for this kind of problem.

Knowledge Distillation

The process of knowledge distillation is a setup where we have a trained teacher model that acts as second avenue of feedback to a much smaller student model. The student model is given both the input and the teacher information for its training backpropagation. For our purposes we will be using our DenseNet trained model as our teacher model, and we will start with the Base CNN as our first student. We will then step up in size until we get close to 80% accuracy (+/-2%) which would be a 15% increase in accuracy for our small models.

In [128…

```
from utils import Distiller # KD class adapted from the keras library examples
import keras
```

In [133…

```
student = Base_CNN()
distiller = Distiller(student=student, teacher=model) # Takes both models for KD proce
distiller.compile(
    optimizer = keras.optimizers.Adam(),
    student_loss_fn = keras.losses.CategoricalCrossentropy(),
    distillation_loss_fn = keras.losses.KLDivergence(),
    metrics = [keras.metrics.CategoricalAccuracy()],
    alpha = 0.1,
    temperature = 10
)
```

In [135…

```
history = distiller.fit(
    train_generator3,
    steps_per_epoch=100,
    epochs=100,
    validation_data=validation_generator3,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_categorical_accuracy', patience=10, restore_
```

```
Epoch 1/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.292
5 - student_loss: 2.0479 - distillation_loss: 0.0307 - val_categorical_accuracy: 0.08
60 - val_student_loss: 2.4433
Epoch 2/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.336
5 - student_loss: 1.8855 - distillation_loss: 0.0290 - val_categorical_accuracy: 0.16
20 - val_student_loss: 3.3626
Epoch 3/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.407
0 - student_loss: 1.7353 - distillation_loss: 0.0269 - val_categorical_accuracy: 0.22
10 - val_student_loss: 2.5427
Epoch 4/100
100/100 [==============================] - 132s 1s/step - categorical_accuracy: 0.419
5 - student_loss: 1.6798 - distillation_loss: 0.0257 - val_categorical_accuracy: 0.23
60 - val_student_loss: 2.8907
Epoch 5/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.421
5 - student_loss: 1.7337 - distillation_loss: 0.0262 - val_categorical_accuracy: 0.21
20 - val_student_loss: 2.6056
Epoch 6/100
100/100 [==============================] - 134s 1s/step - categorical_accuracy: 0.461
0 - student_loss: 1.5556 - distillation_loss: 0.0239 - val_categorical_accuracy: 0.26
90 - val_student_loss: 2.0648
Epoch 7/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.487
5 - student_loss: 1.5113 - distillation_loss: 0.0233 - val_categorical_accuracy: 0.48
60 - val_student_loss: 1.5689
Epoch 8/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.485
0 - student_loss: 1.4685 - distillation_loss: 0.0227 - val_categorical_accuracy: 0.42
70 - val_student_loss: 2.0517
Epoch 9/100
100/100 [==============================] - 134s 1s/step - categorical_accuracy: 0.523
0 - student_loss: 1.3843 - distillation_loss: 0.0216 - val_categorical_accuracy: 0.41
80 - val_student_loss: 2.5555
Epoch 10/100
100/100 [==============================] - 133s 1s/step - categorical_accuracy: 0.548
5 - student_loss: 1.3164 - distillation_loss: 0.0212 - val_categorical_accuracy: 0.31
90 - val_student_loss: 3.5153
Epoch 11/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.551
5 - student_loss: 1.3258 - distillation_loss: 0.0208 - val_categorical_accuracy: 0.44
40 - val_student_loss: 1.7940
Epoch 12/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.551
5 - student_loss: 1.2858 - distillation_loss: 0.0208 - val_categorical_accuracy: 0.50
60 - val_student_loss: 1.2782
Epoch 13/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.530
5 - student_loss: 1.3889 - distillation_loss: 0.0217 - val_categorical_accuracy: 0.27
00 - val_student_loss: 4.2867
Epoch 14/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.559
5 - student_loss: 1.2750 - distillation_loss: 0.0204 - val_categorical_accuracy: 0.45
90 - val_student_loss: 2.4101
Epoch 15/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.592
0 - student_loss: 1.2123 - distillation_loss: 0.0196 - val_categorical_accuracy: 0.55
70 - val_student_loss: 0.8901
```

```
Epoch 16/100
100/100 [==============================] - 129s 1s/step - categorical_accuracy: 0.599
5 - student_loss: 1.1913 - distillation_loss: 0.0191 - val_categorical_accuracy: 0.59
80 - val_student_loss: 1.0555
Epoch 17/100
100/100 [==============================] - 134s 1s/step - categorical_accuracy: 0.574
5 - student_loss: 1.2758 - distillation_loss: 0.0202 - val_categorical_accuracy: 0.61
30 - val_student_loss: 2.0561
Epoch 18/100
100/100 [==============================] - 133s 1s/step - categorical_accuracy: 0.571
5 - student_loss: 1.2376 - distillation_loss: 0.0194 - val_categorical_accuracy: 0.59
70 - val_student_loss: 0.8585
Epoch 19/100
100/100 [==============================] - 132s 1s/step - categorical_accuracy: 0.586
5 - student_loss: 1.2207 - distillation_loss: 0.0199 - val_categorical_accuracy: 0.26
90 - val_student_loss: 2.6003
Epoch 20/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.599
5 - student_loss: 1.1387 - distillation_loss: 0.0181 - val_categorical_accuracy: 0.58
40 - val_student_loss: 1.4591
Epoch 21/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.585
0 - student_loss: 1.2081 - distillation_loss: 0.0189 - val_categorical_accuracy: 0.61
60 - val_student_loss: 0.7015
Epoch 22/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.589
5 - student_loss: 1.2028 - distillation_loss: 0.0190 - val_categorical_accuracy: 0.59
00 - val_student_loss: 1.9274
Epoch 23/100
100/100 [==============================] - 129s 1s/step - categorical_accuracy: 0.589
5 - student_loss: 1.1733 - distillation_loss: 0.0185 - val_categorical_accuracy: 0.57
30 - val_student_loss: 1.3579
Epoch 24/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.602
0 - student_loss: 1.1517 - distillation_loss: 0.0179 - val_categorical_accuracy: 0.37
20 - val_student_loss: 1.4832
Epoch 25/100
100/100 [==============================] - 129s 1s/step - categorical_accuracy: 0.615
2 - student_loss: 1.1451 - distillation_loss: 0.0186 - val_categorical_accuracy: 0.66
80 - val_student_loss: 1.2212
Epoch 26/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.639
0 - student_loss: 1.0726 - distillation_loss: 0.0171 - val_categorical_accuracy: 0.58
50 - val_student_loss: 1.9295
Epoch 27/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.636
0 - student_loss: 1.0916 - distillation_loss: 0.0171 - val_categorical_accuracy: 0.44
60 - val_student_loss: 2.0436
Epoch 28/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.614
5 - student_loss: 1.1554 - distillation_loss: 0.0181 - val_categorical_accuracy: 0.51
50 - val_student_loss: 1.4140
Epoch 29/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.634
0 - student_loss: 1.0612 - distillation_loss: 0.0169 - val_categorical_accuracy: 0.37
20 - val_student_loss: 2.7720
Epoch 30/100
100/100 [==============================] - 129s 1s/step - categorical_accuracy: 0.638
4 - student_loss: 1.0655 - distillation_loss: 0.0174 - val_categorical_accuracy: 0.47
20 - val_student_loss: 1.0632
```

```
Epoch 31/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.610
0 - student_loss: 1.1651 - distillation_loss: 0.0183 - val_categorical_accuracy: 0.37
40 - val_student_loss: 2.0020
Epoch 32/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.625
5 - student_loss: 1.0857 - distillation_loss: 0.0177 - val_categorical_accuracy: 0.34
40 - val_student_loss: 2.8150
Epoch 33/100
100/100 [==============================] - 128s 1s/step - categorical_accuracy: 0.651
5 - student_loss: 1.0193 - distillation_loss: 0.0169 - val_categorical_accuracy: 0.51
50 - val_student_loss: 1.4228
Epoch 34/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.646
0 - student_loss: 1.0587 - distillation_loss: 0.0166 - val_categorical_accuracy: 0.67
80 - val_student_loss: 1.2373
Epoch 35/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.652
5 - student_loss: 1.0264 - distillation_loss: 0.0161 - val_categorical_accuracy: 0.55
30 - val_student_loss: 1.5131
Epoch 36/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.620
0 - student_loss: 1.1236 - distillation_loss: 0.0176 - val_categorical_accuracy: 0.70
10 - val_student_loss: 0.8184
Epoch 37/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.665
0 - student_loss: 1.0083 - distillation_loss: 0.0164 - val_categorical_accuracy: 0.53
20 - val_student_loss: 1.4865
Epoch 38/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.658
5 - student_loss: 0.9936 - distillation_loss: 0.0157 - val_categorical_accuracy: 0.47
40 - val_student_loss: 2.6707
Epoch 39/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.661
1 - student_loss: 1.0048 - distillation_loss: 0.0161 - val_categorical_accuracy: 0.65
60 - val_student_loss: 1.2406
Epoch 40/100
100/100 [==============================] - 132s 1s/step - categorical_accuracy: 0.676
0 - student_loss: 0.9581 - distillation_loss: 0.0152 - val_categorical_accuracy: 0.42
40 - val_student_loss: 1.9443
Epoch 41/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.640
0 - student_loss: 1.0966 - distillation_loss: 0.0168 - val_categorical_accuracy: 0.50
50 - val_student_loss: 2.3205
Epoch 42/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.676
5 - student_loss: 0.9639 - distillation_loss: 0.0155 - val_categorical_accuracy: 0.66
40 - val_student_loss: 0.8544
Epoch 43/100
100/100 [==============================] - 130s 1s/step - categorical_accuracy: 0.673
0 - student_loss: 1.0147 - distillation_loss: 0.0163 - val_categorical_accuracy: 0.68
40 - val_student_loss: 1.4043
Epoch 44/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.677
0 - student_loss: 0.9464 - distillation_loss: 0.0152 - val_categorical_accuracy: 0.60
40 - val_student_loss: 0.9938
Epoch 45/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.689
0 - student_loss: 0.9440 - distillation_loss: 0.0150 - val_categorical_accuracy: 0.47
50 - val_student_loss: 1.7083
```

```
Epoch 46/100
100/100 [==============================] - 131s 1s/step - categorical_accuracy: 0.679
5 - student_loss: 0.9480 - distillation_loss: 0.0152 - val_categorical_accuracy: 0.66
00 - val_student_loss: 0.9039
```

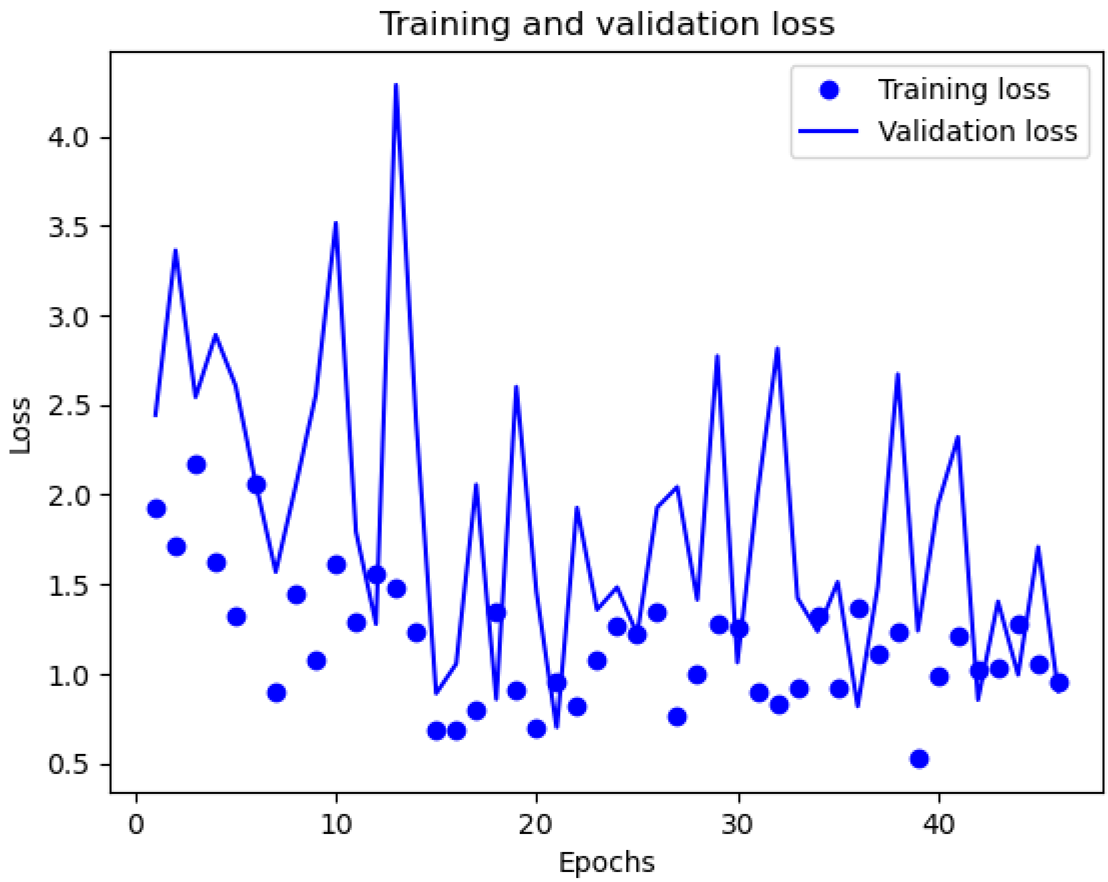
```
---------------------------------------------------------------------------
KeyError                                  Traceback (most recent call last)
Cell In [135], line 11
      1 history = distiller.fit(
      2     train_generator3,
      3     steps_per_epoch=100,
   (...)
      7     verbose = 1,
      8     callbacks=[EarlyStopping(monitor='val_categorical_accuracy', patience=10,
restore_best_weights = True)])
---> 11 plot_history(history)
     13 test_loss, test_acc = model.evaluate(test_generator3, steps = 100)
     14 print('test_acc:', test_acc)

Cell In [40], line 4, in plot_history(history)
      2 def plot_history(history):
      3   history_dict = history.history
----> 4   loss_values = history_dict['loss']
      5   val_loss_values = history_dict['val_loss']
      6   acc_values = history_dict['accuracy']

KeyError: 'loss'
```

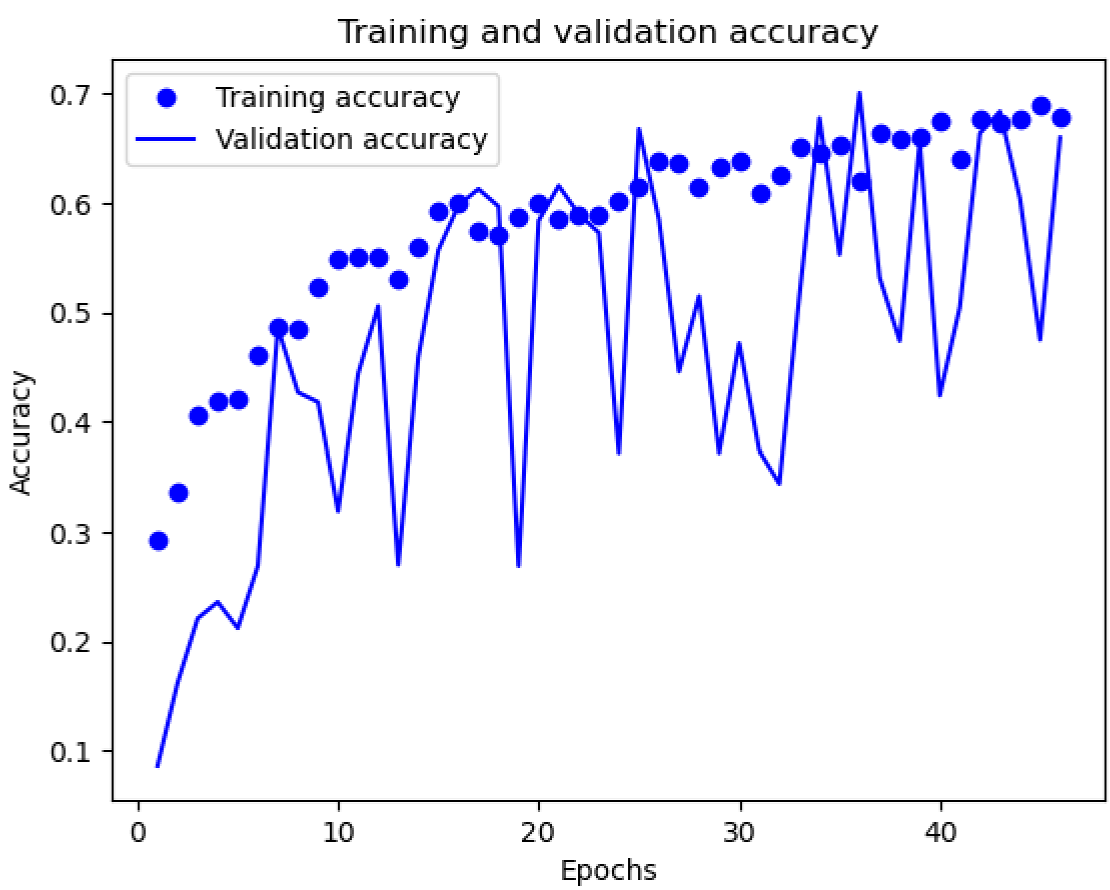
In [148…

```python
# Build a plotting function
def distiller_plot_history(history):
  history_dict = history.history
  loss_values = history_dict['student_loss']
  val_loss_values = history_dict['val_student_loss']
  acc_values =  history_dict['categorical_accuracy']
  val_acc_values = history_dict['val_categorical_accuracy']
  epochs = range(1, len(history_dict['categorical_accuracy']) + 1)

  plt.plot(epochs, loss_values, 'bo', label = 'Training loss')
  plt.plot(epochs, val_loss_values, 'b', label = 'Validation loss')
  plt.title('Training and validation loss')
  plt.xlabel('Epochs')
  plt.ylabel('Loss')
  plt.legend()
  plt.show()

  plt.plot(epochs, acc_values, 'bo', label = 'Training accuracy')
  plt.plot(epochs, val_acc_values, 'b', label = 'Validation accuracy')
  plt.title('Training and validation accuracy')
  plt.xlabel('Epochs')
  plt.ylabel('Accuracy')
  plt.legend()
  return plt.show()
```

In [149…

```python
distiller_plot_history(history)
```


Training and validation loss
Training loss
Validation loss
Loss
Epochs
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40


Training and validation accuracy
Training accuracy
Validation accuracy
Accuracy
Epochs
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40

These graphs clearly illustrate the problem that could arise with small patience windows, where our accuracy could spike and dip for several epochs in a row.

In [143…
```
student.evaluate(test_generator3, steps = 100)
```

```
100/100 [==============================] - 11s 100ms/step - loss: 0.9002 - accuracy: 0.7115
```

Out[143]:
```
[0.9001874327659607, 0.7114999890327454]
```

In [144…
```
model_path = "tomato_leaf_classifier_kd.h5"
student.save(model_path)
```

In [145…
```
model_size(model_path)
```

```
Model is approx 1.816936 MB
```

Improved Base_CNN accuracy from 64.75% to 71.15% and at a size of just 1.82 MB. With our best model giving us near 87% accuracy lets see if we can get a smaller model closer to that value.

In [154…
```
student = Next_CNN()
distiller = Distiller(student=student, teacher=model)
distiller.compile(
    optimizer = keras.optimizers.Adam(),
    student_loss_fn = keras.losses.CategoricalCrossentropy(),
    distillation_loss_fn = keras.losses.KLDivergence(),
    metrics = [keras.metrics.CategoricalAccuracy()],
    alpha = 0.1,
    temperature = 10
)
```

In [155…
```
history = distiller.fit(
    train_generator3,
    steps_per_epoch=100,
    epochs=100,
    validation_data=validation_generator3,
    validation_steps=50,
    verbose = 1,
    callbacks=[EarlyStopping(monitor='val_categorical_accuracy', patience=10, restore_
```

```
Epoch 1/100
100/100 [==============================] - 162s 2s/step - categorical_accuracy: 0.305
0 - student_loss: 2.1138 - distillation_loss: 0.0328 - val_categorical_accuracy: 0.12
40 - val_student_loss: 3.0044
Epoch 2/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.417
5 - student_loss: 1.7190 - distillation_loss: 0.0271 - val_categorical_accuracy: 0.12
60 - val_student_loss: 5.5132
Epoch 3/100
100/100 [==============================] - 153s 2s/step - categorical_accuracy: 0.481
1 - student_loss: 1.5569 - distillation_loss: 0.0247 - val_categorical_accuracy: 0.12
40 - val_student_loss: 5.0516
Epoch 4/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.503
5 - student_loss: 1.3985 - distillation_loss: 0.0233 - val_categorical_accuracy: 0.12
00 - val_student_loss: 5.2131
Epoch 5/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.569
5 - student_loss: 1.2544 - distillation_loss: 0.0212 - val_categorical_accuracy: 0.23
30 - val_student_loss: 2.6008
Epoch 6/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.576
0 - student_loss: 1.2267 - distillation_loss: 0.0198 - val_categorical_accuracy: 0.33
30 - val_student_loss: 2.1153
Epoch 7/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.577
5 - student_loss: 1.2149 - distillation_loss: 0.0197 - val_categorical_accuracy: 0.40
40 - val_student_loss: 2.8616
Epoch 8/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.606
5 - student_loss: 1.1304 - distillation_loss: 0.0187 - val_categorical_accuracy: 0.36
10 - val_student_loss: 2.2302
Epoch 9/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.610
5 - student_loss: 1.1182 - distillation_loss: 0.0184 - val_categorical_accuracy: 0.50
20 - val_student_loss: 1.9881
Epoch 10/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.640
4 - student_loss: 1.0506 - distillation_loss: 0.0178 - val_categorical_accuracy: 0.53
50 - val_student_loss: 1.2556
Epoch 11/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.635
5 - student_loss: 1.0424 - distillation_loss: 0.0174 - val_categorical_accuracy: 0.22
40 - val_student_loss: 4.2424
Epoch 12/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.643
0 - student_loss: 1.0228 - distillation_loss: 0.0169 - val_categorical_accuracy: 0.54
80 - val_student_loss: 1.5999
Epoch 13/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.658
5 - student_loss: 0.9725 - distillation_loss: 0.0163 - val_categorical_accuracy: 0.60
60 - val_student_loss: 0.9686
Epoch 14/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.678
0 - student_loss: 0.9144 - distillation_loss: 0.0158 - val_categorical_accuracy: 0.47
00 - val_student_loss: 1.6537
Epoch 15/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.669
0 - student_loss: 0.9235 - distillation_loss: 0.0157 - val_categorical_accuracy: 0.43
50 - val_student_loss: 1.8233
```

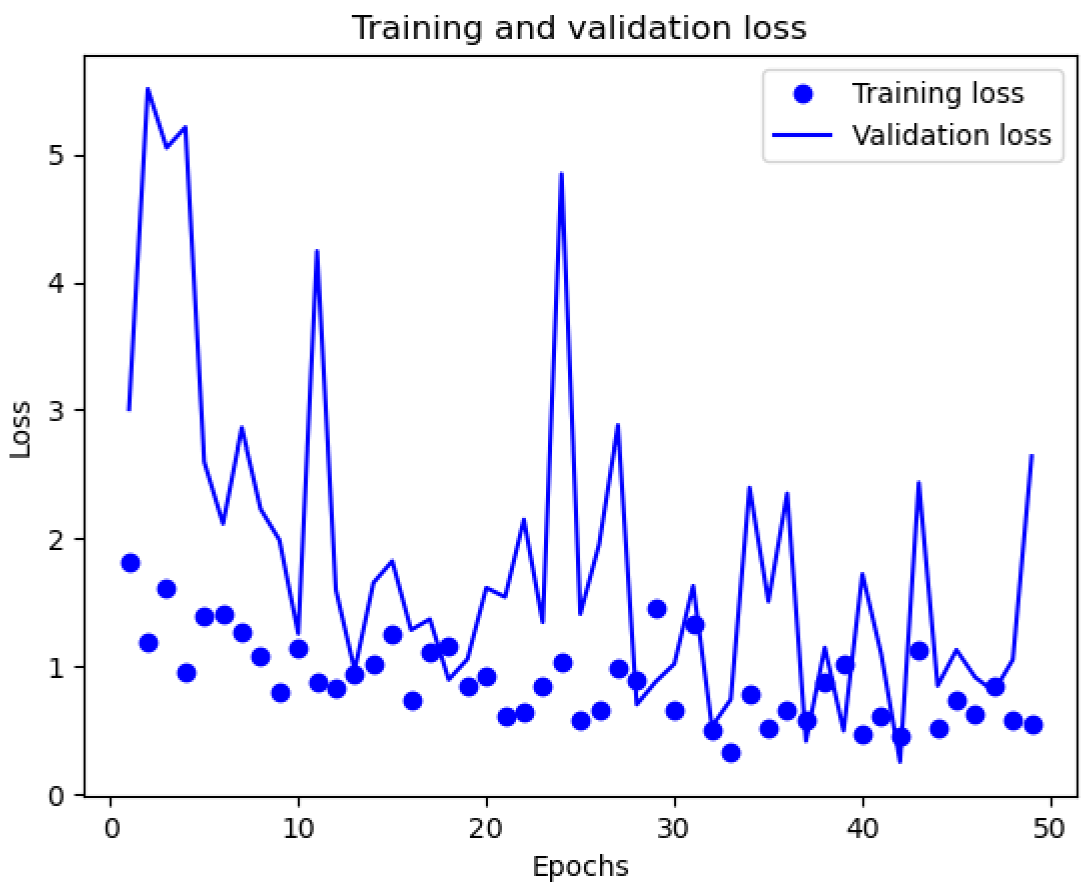
```
Epoch 16/100
100/100 [==============================] - 157s 2s/step - categorical_accuracy: 0.669
5 - student_loss: 0.9191 - distillation_loss: 0.0156 - val_categorical_accuracy: 0.60
30 - val_student_loss: 1.2839
Epoch 17/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.690
0 - student_loss: 0.8691 - distillation_loss: 0.0147 - val_categorical_accuracy: 0.53
50 - val_student_loss: 1.3689
Epoch 18/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.671
5 - student_loss: 0.9317 - distillation_loss: 0.0155 - val_categorical_accuracy: 0.61
80 - val_student_loss: 0.8948
Epoch 19/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.708
5 - student_loss: 0.8288 - distillation_loss: 0.0148 - val_categorical_accuracy: 0.60
20 - val_student_loss: 1.0560
Epoch 20/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.704
5 - student_loss: 0.8263 - distillation_loss: 0.0135 - val_categorical_accuracy: 0.59
60 - val_student_loss: 1.6140
Epoch 21/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.711
0 - student_loss: 0.8324 - distillation_loss: 0.0150 - val_categorical_accuracy: 0.47
90 - val_student_loss: 1.5424
Epoch 22/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.713
5 - student_loss: 0.8117 - distillation_loss: 0.0138 - val_categorical_accuracy: 0.46
00 - val_student_loss: 2.1488
Epoch 23/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.726
5 - student_loss: 0.7792 - distillation_loss: 0.0137 - val_categorical_accuracy: 0.49
60 - val_student_loss: 1.3453
Epoch 24/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.721
0 - student_loss: 0.8004 - distillation_loss: 0.0135 - val_categorical_accuracy: 0.28
80 - val_student_loss: 4.8470
Epoch 25/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.733
0 - student_loss: 0.7978 - distillation_loss: 0.0137 - val_categorical_accuracy: 0.63
20 - val_student_loss: 1.4095
Epoch 26/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.720
5 - student_loss: 0.7721 - distillation_loss: 0.0136 - val_categorical_accuracy: 0.50
70 - val_student_loss: 1.9551
Epoch 27/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.709
5 - student_loss: 0.8407 - distillation_loss: 0.0140 - val_categorical_accuracy: 0.35
30 - val_student_loss: 2.8799
Epoch 28/100
100/100 [==============================] - 153s 2s/step - categorical_accuracy: 0.709
5 - student_loss: 0.7994 - distillation_loss: 0.0139 - val_categorical_accuracy: 0.62
50 - val_student_loss: 0.7002
Epoch 29/100
100/100 [==============================] - 153s 2s/step - categorical_accuracy: 0.752
4 - student_loss: 0.7292 - distillation_loss: 0.0130 - val_categorical_accuracy: 0.67
40 - val_student_loss: 0.8773
Epoch 30/100
100/100 [==============================] - 156s 2s/step - categorical_accuracy: 0.739
5 - student_loss: 0.7576 - distillation_loss: 0.0128 - val_categorical_accuracy: 0.72
50 - val_student_loss: 1.0186
```

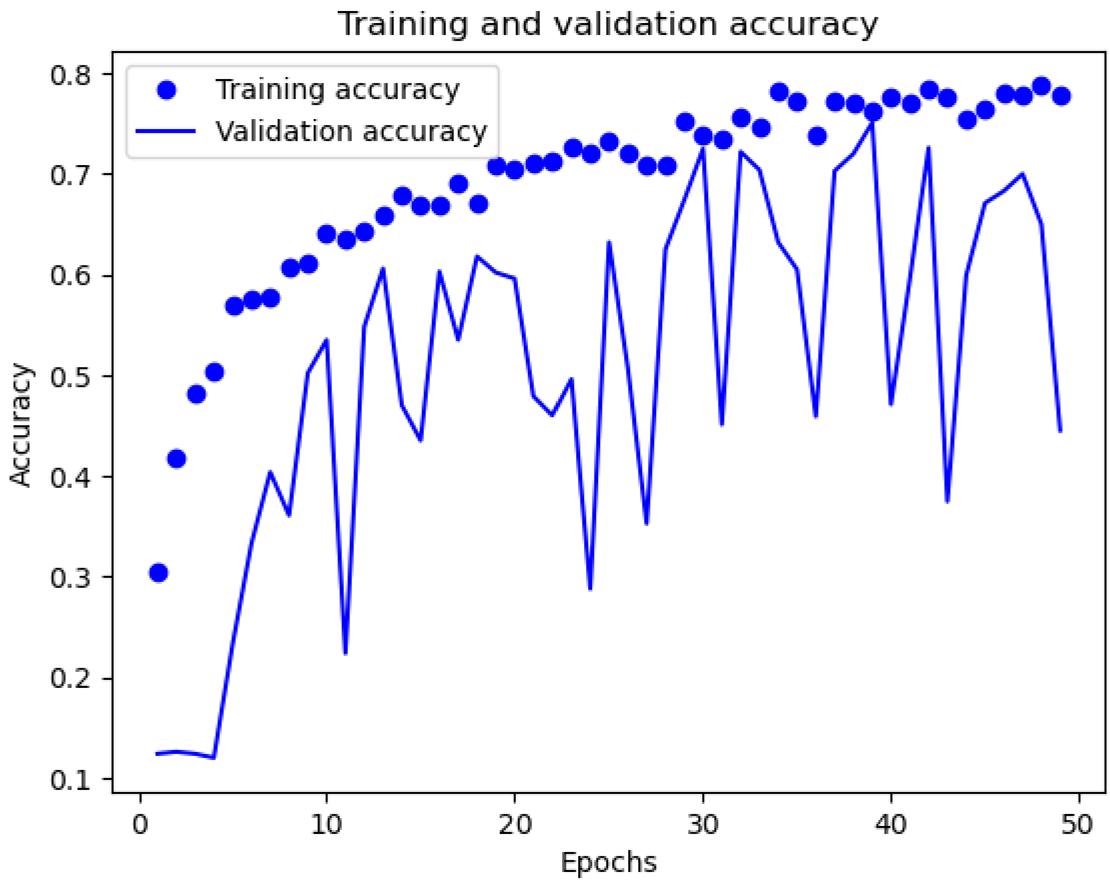
```
Epoch 31/100
100/100 [==============================] - 156s 2s/step - categorical_accuracy: 0.735
5 - student_loss: 0.7803 - distillation_loss: 0.0134 - val_categorical_accuracy: 0.45
10 - val_student_loss: 1.6294
Epoch 32/100
100/100 [==============================] - 157s 2s/step - categorical_accuracy: 0.756
5 - student_loss: 0.6868 - distillation_loss: 0.0120 - val_categorical_accuracy: 0.72
20 - val_student_loss: 0.5273
Epoch 33/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.746
0 - student_loss: 0.7159 - distillation_loss: 0.0128 - val_categorical_accuracy: 0.70
40 - val_student_loss: 0.7404
Epoch 34/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.782
0 - student_loss: 0.6611 - distillation_loss: 0.0115 - val_categorical_accuracy: 0.63
20 - val_student_loss: 2.3984
Epoch 35/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.772
0 - student_loss: 0.6479 - distillation_loss: 0.0117 - val_categorical_accuracy: 0.60
50 - val_student_loss: 1.5078
Epoch 36/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.738
0 - student_loss: 0.7037 - distillation_loss: 0.0131 - val_categorical_accuracy: 0.45
90 - val_student_loss: 2.3524
Epoch 37/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.773
0 - student_loss: 0.6373 - distillation_loss: 0.0122 - val_categorical_accuracy: 0.70
30 - val_student_loss: 0.4144
Epoch 38/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.769
5 - student_loss: 0.6720 - distillation_loss: 0.0124 - val_categorical_accuracy: 0.72
00 - val_student_loss: 1.1460
Epoch 39/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.762
0 - student_loss: 0.6715 - distillation_loss: 0.0120 - val_categorical_accuracy: 0.75
10 - val_student_loss: 0.4947
Epoch 40/100
100/100 [==============================] - 153s 2s/step - categorical_accuracy: 0.776
0 - student_loss: 0.6558 - distillation_loss: 0.0118 - val_categorical_accuracy: 0.47
10 - val_student_loss: 1.7218
Epoch 41/100
100/100 [==============================] - 156s 2s/step - categorical_accuracy: 0.769
5 - student_loss: 0.6387 - distillation_loss: 0.0119 - val_categorical_accuracy: 0.59
50 - val_student_loss: 1.0955
Epoch 42/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.784
0 - student_loss: 0.6123 - distillation_loss: 0.0112 - val_categorical_accuracy: 0.72
60 - val_student_loss: 0.2513
Epoch 43/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.777
0 - student_loss: 0.6633 - distillation_loss: 0.0119 - val_categorical_accuracy: 0.37
50 - val_student_loss: 2.4370
Epoch 44/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.754
5 - student_loss: 0.6864 - distillation_loss: 0.0125 - val_categorical_accuracy: 0.59
90 - val_student_loss: 0.8470
Epoch 45/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.763
5 - student_loss: 0.6771 - distillation_loss: 0.0117 - val_categorical_accuracy: 0.67
10 - val_student_loss: 1.1282
```

```
Epoch 46/100
100/100 [==============================] - 154s 2s/step - categorical_accuracy: 0.780
5 - student_loss: 0.6148 - distillation_loss: 0.0111 - val_categorical_accuracy: 0.68
30 - val_student_loss: 0.9128
Epoch 47/100
100/100 [==============================] - 155s 2s/step - categorical_accuracy: 0.778
0 - student_loss: 0.6671 - distillation_loss: 0.0116 - val_categorical_accuracy: 0.70
00 - val_student_loss: 0.8023
Epoch 48/100
100/100 [==============================] - 156s 2s/step - categorical_accuracy: 0.788
5 - student_loss: 0.6042 - distillation_loss: 0.0106 - val_categorical_accuracy: 0.65
00 - val_student_loss: 1.0522
Epoch 49/100
100/100 [==============================] - 162s 2s/step - categorical_accuracy: 0.778
5 - student_loss: 0.6217 - distillation_loss: 0.0112 - val_categorical_accuracy: 0.44
50 - val_student_loss: 2.6440
```

In [156…

```
distiller_plot_history(history)
```





In [157…

```
student.evaluate(test_generator3, steps = 100)
```

```
100/100 [==============================] - 21s 204ms/step - loss: 0.6120 - accuracy:
0.7865
```

Out[157]:

```
[0.6120110154151917, 0.7864999771118164]
```

In [158…

```
model_path = "tomato_leaf_classifier_kd2.h5"
student.save(model_path)
```

In [159…

```
model_size(model_path)
```

```
Model is approx 7.073504 MB
```

We now have a knowledge distillation model that is 79% accurate at just 7.07 MB. This fits within my original goal of under 32 MB, albeit slightly lower accuracy than I had hoped for. I bet with experimentation we should be able to find something above 80% while staying below my memory target, but I am happy with where this is at for a proof of concept.

Conclusion

The process of generating a CNN, finding a superior transfer learning model, and using knowledge distillation to create an improved small CNN for edge device use appears to be possible for this problem. Starting with a CNN with 64.75% accuracy, we were able to improve its accuracy to 71.15% while having a memory footprint of just 1.82 MB. Increasing the CNN's size and continuing with the same knowledge distillation technique we were able to create a

7.07 MB model with 78.65% accuracy. I was not able to find a combination that satisfied my goal of 80% accuracy and under 32 MB, but I do believe that continued experimentation can get us there. Additionally, we should that data augmentation was not needed with the number of examples available, but that it also did appear to make the models more resistant to over-fitting. This process for creating a small and accurate model appears to be viable for the problem, and additional compression techniques could be used as well. I believe that future experimentation could use the smallest available DenseNet for transfer learning, use it as the student model, and then apply pruning, quantization, and half precision data types for an inference version with nearly the same accuracy as our best large model but at just 64 MB.