

CNN_Lab

May 31, 2025

1 CNN Image Classification Laboration

Images used in this laboration are from [CIFAR10](#). The CIFAR10 dataset contains 60,000 32x32 color images in 10 different classes. The 10 different classes represent airplanes, cars, birds, cats, deer, dogs, frogs, horses, ships, and trucks. There are 6,000 images of each class.

Your task is to make a classifier, using a convolutional neural network, that can correctly classify each image into the correct class.

Complete the code flagged throughout the elaboration and **answer all the questions in the notebook**.

```
[1]: # Setups
      # Automatically reload modules when changed
      %reload_ext autoreload
      %autoreload 2
```

2 Part 1: Convolutions

In the next sections you will familiarize yourself with 2D convolutions.

2.1 1.1 What is a convolution?

To understand a bit more about convolutions, we will first test the convolution function in `scipy` using a number of classical filters.

Convolve the image with Gaussian filter, a Sobel X filter, and a Sobel Y filter, using the function `convolve2d` in `signal` from `scipy` (see the [documentation](#) for more details).

In a CNN, many filters are applied in each layer, and the filter coefficients are learned through back propagation (which is in contrast to traditional image processing, where the filters are designed by an expert).

Run the cell below to define a Gaussian filter and a Sobel X and Y filters.

```
[2]: from scipy import signal
      import numpy as np

      # Get a test image
      from scipy import datasets
      image = datasets.ascent()
```

```

# Define a help function for creating a Gaussian filter
def matlab_style_gauss2D(shape=(3,3),sigma=0.5):
    """
    2D gaussian mask - should give the same result as MATLAB's
    fspecial('gaussian',[shape],[sigma])
    """
    m,n = [(ss-1.)//2. for ss in shape]
    y,x = np.ogrid[-m:m+1,-n:n+1]
    h = np.exp( -(x*x + y*y) / (2.*sigma*sigma) )
    h[ h < np.finfo(h.dtype).eps*h.max() ] = 0
    sumh = h.sum()
    if sumh != 0:
        h /= sumh
    return h

# Create Gaussian filter with certain size and standard deviation
gaussFilter = matlab_style_gauss2D((15,15),4)

# Define filter kernels for SobelX and Sobely
sobelX = np.array([[ 1, 0, -1],
                    [2, 0, -2],
                    [1, 0, -1]])

sobelY = np.array([[ 1, 2, 1],
                    [0, 0, 0],
                    [-1, -2, -1]])

```

```

[3]: from scipy.signal import convolve2d

# Perform convolution using the function 'convolve2d' for the different filters
filterResponseGauss = convolve2d(image, gaussFilter, mode='same',
    ↪boundary='symm')
filterResponseSobelX = convolve2d(image, sobelX, mode='same', boundary='symm')
filterResponseSobelY = convolve2d(image, sobelY, mode='same', boundary='symm')

# =====

```

```

[4]: import matplotlib.pyplot as plt

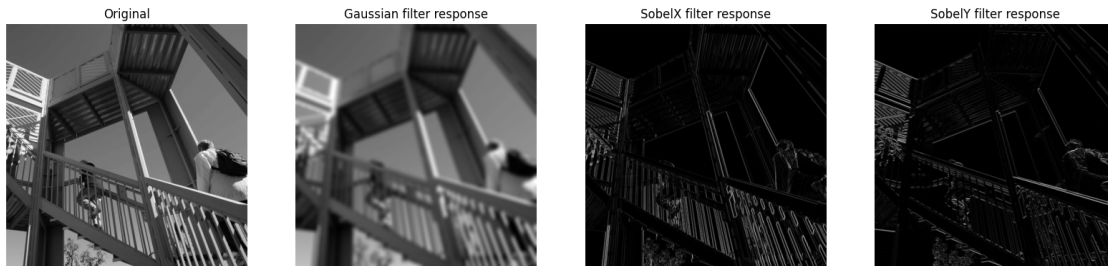
# Show filter responses
fig, (ax_orig, ax_filt1, ax_filt2, ax_filt3) = plt.subplots(1, 4, figsize=(20,
    ↪6))
ax_orig.imshow(image, cmap='gray')
ax_orig.set_title('Original')
ax_orig.set_axis_off()
ax_filt1.imshow(np.absolute(filterResponseGauss), cmap='gray')

```

```

ax_filt1.set_title('Gaussian filter response')
ax_filt1.set_axis_off()
ax_filt2.imshow(np.absolute(filterResponseSobelX), cmap='gray')
ax_filt2.set_title('SobelX filter response')
ax_filt2.set_axis_off()
ax_filt3.imshow(np.absolute(filterResponseSobelY), cmap='gray')
ax_filt3.set_title('SobelY filter response')
ax_filt3.set_axis_off()

```



2.2 1.2 Understanding convolutions

Questions

1. What do the 3 different filters (Gaussian, SobelX, SobelY) do to the original image?
2. What is the size of the original image? How many channels does it have? How many channels does a color image normally have?
3. What is the size of the different filters?
4. What is the size of the filter response if mode 'same' is used for the convolution ?
5. What is the size of the filter response if mode 'valid' is used for the convolution? How does the size of the valid filter response depend on the size of the filter?
6. Why are 'valid' convolutions a problem for CNNs with many layers?

Answers [Your answer here] 1. Gaussian Filter: Blurs the image, reducing noise and smoothing edges. SobelX Filter: Detects vertical edges by highlighting changes in intensity along the X-axis. SobelY Filter: Detects horizontal edges by highlighting changes in intensity along the Y-axis. 2. The size of the original image is 512x512 pixels. It has 1 channel (grayscale). A normal color image has 3 channels (Red, Green, Blue - RGB). 3. Gaussian Filter: 15x15, SobelX Filter: 3x3 and SobelY Filter: 3x3 4. The output image size is the same as the input image (512x512). 5. When mode='valid' is used, the size of the filter response is reduced. The output size is calculated as: Output Size=(Image Size–Filter Size+1) For a 3x3 filter, output size = $(512-3+1) \times (512-3+1) = 510 \times 510$. For a 15x15 filter, output size = $(512-15+1) \times (512-15+1) = 498 \times 498$. 6. Valid convolutions reduce the size of the feature map at every layer. This is why padding (like in 'same' mode) is often used in CNNs to maintain the spatial dimensions of the feature map.

```
[5]: # Check the size of the original image
print("Original image size:", image.shape)

# Check the size of the Gaussian filter
print("Gaussian filter size:", gaussFilter.shape)

# Check the size of the SobelX filter
print("SobelX filter size:", sobelX.shape)

# Check the size of the SobelY filter
print("SobelY filter size:", sobelY.shape)

# Check the size of the filter responses with mode='same'
print("Gaussian filter response size (mode='same'):", filterResponseGauss.shape)
print("SobelX filter response size (mode='same'):", filterResponseSobelX.shape)
print("SobelY filter response size (mode='same'):", filterResponseSobelY.shape)

# Perform convolution with mode='valid' and check the sizes
filterResponseGauss_valid = signal.convolve2d(image, gaussFilter, mode='valid')
filterResponseSobelX_valid = signal.convolve2d(image, sobelX, mode='valid')
filterResponseSobelY_valid = signal.convolve2d(image, sobelY, mode='valid')

print("Gaussian filter response size (mode='valid'):",
      ↪filterResponseGauss_valid.shape)
print("SobelX filter response size (mode='valid'):", filterResponseSobelX_valid.
      ↪shape)
print("SobelY filter response size (mode='valid'):", filterResponseSobelY_valid.
      ↪shape)
```

```
Original image size: (512, 512)
Gaussian filter size: (15, 15)
SobelX filter size: (3, 3)
SobelY filter size: (3, 3)
Gaussian filter response size (mode='same'): (512, 512)
SobelX filter response size (mode='same'): (512, 512)
SobelY filter response size (mode='same'): (512, 512)
Gaussian filter response size (mode='valid'): (498, 498)
SobelX filter response size (mode='valid'): (510, 510)
SobelY filter response size (mode='valid'): (510, 510)
```

3 Part 2: Get a graphics card

Skip the next cell if you run on the CPU.

If your computer has a dedicated graphics card and you would like to use it, we need to make sure that our script can see the graphics card that will be used. The graphics cards will perform all the time consuming calculations in every training iteration.

```
[6]: import os
import warnings

# Ignore FutureWarning from numpy
warnings.simplefilter(action='ignore', category=FutureWarning)

import tensorflow as tf

os.environ["CUDA_DEVICE_ORDER"]="PCI_BUS_ID"

# The GPU id to use, usually either "0" or "1";
os.environ["CUDA_VISIBLE_DEVICES"]="0"

# This sets the GPU to allocate memory only as needed
physical_devices = tf.config.experimental.list_physical_devices('GPU')
if len(physical_devices) != 0:
    tf.config.experimental.set_memory_growth(physical_devices[0], True)
    print("Running on GPU")
else:
    print('No GPU available.')
```

WARNING: All log messages before absl::InitializeLog() is called are written to STDERR

E0000 00:00:1746534512.753087 736732 cuda_dnn.cc:8310] Unable to register cuDNN factory: Attempting to register factory for plugin cuDNN when one has already been registered

E0000 00:00:1746534512.755600 736732 cuda_blas.cc:1418] Unable to register cuBLAS factory: Attempting to register factory for plugin cuBLAS when one has already been registered

Running on GPU

3.1 How fast is the graphics card?

Questions

7. Why are the filters used for a color image of size 7 x 7 x 3, and not 7 x 7 ?
8. What operation is performed by the 'Conv2D' layer? Is it a standard 2D convolution, as performed by the function `signal.convolve2d` we just tested?
9. Pretend that everyone is using an Nvidia RTX 3090 graphics card, how many CUDA cores does it have? How much memory does the graphics card have?
10. How much memory does the graphics card have?
11. What is stored in the GPU memory while training a CNN?
12. Do you think that a graphics card, compared to the CPU, is equally faster for convolving a batch of 1,000 images, compared to convolving a batch of 3 images? Motivate your answer.

Answers [Your answer here]

7. A color image has 3 channels (Red, Green, and Blue). Therefore, a filter used for a color image must account for all 3 channels. A $7 \times 7 \times 3$ filter means that the convolution operation is applied across all 3 channels of the image simultaneously. If a 7×7 filter were used, it would only apply to a single channel (grayscale image), not capturing the color relationships between channels.
8. The Conv2D layer performs a 2D convolution, but it is more general than the `signal.convolve2d` function: It supports multiple filters (kernels) in a single layer, allowing the extraction of multiple features. It works with batches of images (e.g., 32 images at once) and multiple input channels (e.g., 3 for RGB images). It includes bias terms and activation functions (e.g., ReLU) as part of the operation. But, `signal.convolve2d` is a simpler function that performs a single 2D convolution on a single 2D input.
9. Nvidia RTX 3090 has 10,496 CUDA cores and 24 GB of GDDR6X memory.
10. Nvidia RTX 3090 has 24 GB of GDDR6X memory.
11. The GPU memory stores: Model parameters: Weights and biases of each layer. Input data: The batch of images being processed. Intermediate activations: Feature maps from each layer. Gradients: Needed for backpropagation. Optimizer states: Momentum, learning rates, etc.
12. A GPU is faster for convolving a batch of 1,000 images compared to a batch of 3 images, and it outperforms a CPU in both cases. GPUs are optimized for parallel processing, which means they are highly efficient for processing large batches of data simultaneously. For a batch of 1,000 images, the GPU can utilize its numerous cores to process many images in parallel, achieving significantly faster performance compared to the CPU. For a batch of 3 images, the workload is much smaller, and the parallelization advantage of the GPU is not fully utilized. In this case, the GPU's performance advantage over the CPU is less pronounced.

4 Part 3: Dataset

In the following section you will load the CIFAR10 dataset, check few samples, perform some preprocessing on the images and the labels, and split the data into training, validation and testing.

4.1 3.1 Load the dataset

Run the following section to load the CIFAR10 data, take a total of 10.000 training/validation samples and 2000 testing samples.

```
[7]: from keras.datasets import cifar10
import numpy as np

classes = ['plane', 'car', 'bird', 'cat', 'deer', 'dog', 'frog', 'horse', '
↪ 'ship', 'truck']

# Download CIFAR train and test data
(X, Y), (Xtest, Ytest) = cifar10.load_data()

print("Training/validation images have size {} and labels have size {}".
↪ format(X.shape, Y.shape))
```

```

print("Test images have size {} and labels have size {} \n ".format(Xtest.
    ↪shape, Ytest.shape))

# Reduce the number of images for training/validation and testing to 10000 and
    ↪2000 respectively,
# to reduce processing time for this elaboration.
X = X[0:10000]
Y = Y[0:10000]

Xtest = Xtest[0:2000]
Ytest = Ytest[0:2000]

Ytestint = Ytest

print("Reduced training/validation images have size %s and labels have size %s
    ↪" % (X.shape, Y.shape))
print("Reduced test images have size %s and labels have size %s \n" % (Xtest.
    ↪shape, Ytest.shape))

# Check that we have some training examples from each class
for i in range(10):
    print("Number of training/validation examples for class {} is {}".
        ↪format(i,np.sum(Y == i)))

```

Training/validation images have size (50000, 32, 32, 3) and labels have size (50000, 1)

Test images have size (10000, 32, 32, 3) and labels have size (10000, 1)

Reduced training/validation images have size (10000, 32, 32, 3) and labels have size (10000, 1)

Reduced test images have size (2000, 32, 32, 3) and labels have size (2000, 1)

```

Number of training/validation examples for class 0 is 1005
Number of training/validation examples for class 1 is 974
Number of training/validation examples for class 2 is 1032
Number of training/validation examples for class 3 is 1016
Number of training/validation examples for class 4 is 999
Number of training/validation examples for class 5 is 937
Number of training/validation examples for class 6 is 1030
Number of training/validation examples for class 7 is 1001
Number of training/validation examples for class 8 is 1025
Number of training/validation examples for class 9 is 981

```

Lets look at some of the training examples, this cell is already finished. You will see different examples every time you run the cell.

```
[8]: import matplotlib.pyplot as plt

plt.figure(figsize=(12,4))
for i in range(18):
    idx = np.random.randint(7500)
    label = Y[idx,0]

    plt.subplot(3,6,i+1)
    plt.tight_layout()
    plt.imshow(X[idx])
    plt.title("Class: {} ({}).format(label, classes[label]))
    plt.axis('off')
plt.show()
```



4.2 3.2 Split data into training, validation and testing

Split your data (X, Y) into training (Xtrain, Ytrain) and validation (Xval, Yval), so that we have training, validation and test datasets (as in the previous laboration).

We use the `train_test_split` function from scikit learn (see the [documentation](#) for more details) to obtain 25% validation set.

```
[9]: from sklearn.model_selection import train_test_split

# Split the original dataset into 75% Training and 25% Validation
Xtrain, Xval, Ytrain, Yval = train_test_split(X, Y, test_size=0.25,
    random_state=42)

# Print the size of training data, validation data, and test data
print("Training images have size:", Xtrain.shape)
print("Training labels have size:", Ytrain.shape)
print("Validation images have size:", Xval.shape)
print("Validation labels have size:", Yval.shape)
print("Test images have size:", Xtest.shape)
```



```
print("Test labels have size:", Ytest.shape)
```

```
Training images have size: (7500, 32, 32, 3)
Training labels have size: (7500, 1)
Validation images have size: (2500, 32, 32, 3)
Validation labels have size: (2500, 1)
Test images have size: (2000, 32, 32, 3)
Test labels have size: (2000, 1)
```

4.3 3.3 Image Preprocessing

Lets perform some preprocessing. The images are stored as uint8, i.e. 8 bit unsigned integers, but need to be converted to 32 bit floats. We also make sure that the range is -1 to 1, instead of 0 - 255.

```
[10]: # Convert datatype for Xtrain, Xval, Xtest, to float32
Xtrain = Xtrain.astype('float32')
Xval = Xval.astype('float32')
Xtest = Xtest.astype('float32')

# Change range of pixel values to [-1,1]
Xtrain = Xtrain / 127.5 - 1
Xval = Xval / 127.5 - 1
Xtest = Xtest / 127.5 - 1
```

4.4 3.4 Label preprocessing

The labels (Y) need to be converted from e.g. '4' to "hot encoded", i.e. to a vector of type [0, 0, 0, 1, 0, 0, 0, 0, 0, 0] . We use the `to_categorical` function in Keras (see the [documentation](#) for details on how to use it)

```
[11]: from tensorflow.keras.utils import to_categorical

# Print shapes before converting the labels
print('Ytrain has size {}'.format(Ytrain.shape))
print('Yval has size {}'.format(Yval.shape))
print('Ytest has size {}'.format(Ytest.shape))

# Your code for converting Ytrain, Yval, Ytest to categorical
Ytrain = to_categorical(Ytrain, num_classes=10)
Yval = to_categorical(Yval, num_classes=10)
Ytest = to_categorical(Ytest, num_classes=10)

# Print shapes after converting the labels
print('Ytrain has size {}'.format(Ytrain.shape))
print('Yval has size {}'.format(Yval.shape))
print('Ytest has size {}'.format(Ytest.shape))
```

Ytrain has size (7500, 1).
Yval has size (2500, 1).
Ytest has size (2000, 1).
Ytrain has size (7500, 10).
Yval has size (2500, 10).
Ytest has size (2000, 10).

5 Part 4: 2D CNN

In the following sections you will build a 2D CNN model and will train it to perform classification on the CIFAR10 dataset.

5.1 4.1 Build CNN model

Start by implementing the `build_CNN` function in the `utilities.py` file. Below you can find the specifications on how your `build_CNN` function should build the model: - Each convolutional layer is composed by: 2D convolution -> batch normalization -> max pooling. - The 2D convolution uses a 3 x 3 kernel size, padding='same' and a number of starting filter that is an input to the `build_CNN` function. The number of filters doubles with each convolutional layer (e.g. 32, 64, 128, etc.) - The max pooling layers should have a pool size of 2 x 2. - After the convolutional layers comes a flatten layer, followed by a number of intermediate dense layers. - The number of nodes in the intermediate dense layers before the final dense layer is an input to the `build_CNN` function. The intermediate dense layers use `relu` activation functions and each is followed by batch normalization. - The final dense layer should have 10 nodes (=the number of classes in this elaboration) and `softmax` activation.

Here are some relevant functions that you should use in `build_CNN`. For a complete list of functions and their definitions see the [keras documentation](#):

- `model.add()`, adds a layer to the network;
- `Dense()`, a dense network layer. See the [documentation](#) what are the input options and outputs of the `Dense()` function.
- `Conv2D()` performs 2D convolutions with a number of filters with a certain size (e.g. 3 x 3) (see [documentation](#)).
- `BatchNormalization()`, perform batch normalization (see [documentation](#)).
- `MaxPooling2D()`, saves the max for a given pool size, results in down sampling (see [documentation](#)).
- `Flatten()`, flatten a multi-channel tensor into a long vector (see [documentation](#)).
- `model.compile()`, compiles the model. You can set the input metrics=['accuracy'] to print the classification accuracy during the training.
- cost and loss functions: check the [documentation](#) and chose a loss function for binary classification.

To get more information in model [compile](#), [training](#) and [evaluation](#) see the relevant documentation.

Here you can start with the `Adam` optimizer when compiling the model.

Use the following cell to test your `build_CNN` utility function. Remember to import a relevant cost function for multi-class classification from [keras.losses](#) which relates to how many classes you have.

```
[12]: ## import utilities
from utilities import build_CNN

# -----
# === Your code here =====
# -----

# import a suitable loss function from keras.losses and use as input to the
# build_CNN function.
from tf_keras.losses import CategoricalCrossentropy

# Define the input shape for CIFAR10 dataset
input_shape = (32, 32, 3) # CIFAR10 images are 32x32 with 3 color channels

# Build a CNN model following the specifications above
model = build_CNN(input_shape = input_shape,
                  loss = CategoricalCrossentropy(),
                  n_conv_layers = 3,
                  n_filters = 32,
                  n_dense_layers = 2,
                  n_nodes = 128,
                  use_dropout = True,
                  learning_rate = 0.001,
                  act_fun = 'relu',
                  optimizer = 'adam',
                  print_summary = True)

# =====
```

Model: "sequential"

Layer (type)	Output Shape	Param #
conv2d (Conv2D)	(None, 32, 32, 32)	896
batch_normalization (Batch Normalization)	(None, 32, 32, 32)	128
max_pooling2d (MaxPooling2D)	(None, 16, 16, 32)	0
dropout (Dropout)	(None, 16, 16, 32)	0
conv2d_1 (Conv2D)	(None, 16, 16, 64)	18496
batch_normalization_1 (Batch Normalization)	(None, 16, 16, 64)	256

max_pooling2d_1 (MaxPoolin g2D)	(None, 8, 8, 64)	0
dropout_1 (Dropout)	(None, 8, 8, 64)	0
conv2d_2 (Conv2D)	(None, 8, 8, 128)	73856
batch_normalization_2 (Bat chNormalization)	(None, 8, 8, 128)	512
max_pooling2d_2 (MaxPoolin g2D)	(None, 4, 4, 128)	0
dropout_2 (Dropout)	(None, 4, 4, 128)	0
flatten (Flatten)	(None, 2048)	0
dense (Dense)	(None, 128)	262272
batch_normalization_3 (Bat chNormalization)	(None, 128)	512
dropout_3 (Dropout)	(None, 128)	0
dense_1 (Dense)	(None, 128)	16512
batch_normalization_4 (Bat chNormalization)	(None, 128)	512
dropout_4 (Dropout)	(None, 128)	0
dense_2 (Dense)	(None, 10)	1290

=====

Total params: 375242 (1.43 MB)
Trainable params: 374282 (1.43 MB)
Non-trainable params: 960 (3.75 KB)

I0000 00:00:1746534589.133412 736732 gpu_device.cc:2022] Created device
/job:localhost/replica:0/task:0/device:GPU:0 with 15738 MB memory: -> device:
0, name: NVIDIA RTX 4000 Ada Generation, pci bus id: 0000:01:00.0, compute
capability: 8.9

5.2 4.2 Train 2D CNN

Time to train the CNN!

Start with a model with 2 convolutional layers where the first layer has have 16 filters, and with no intermediate dense layers.

Set the training parameters, build the model and run the training.

Use the following training parameters: - `batch_size=20` - `epochs=20` - `learning_rate=0.01`

Relevant functions: - `build_CNN`, the function that you defined in the `utilities.py` file. - `model.fit()`, train the model with some training data (see [documentation](#)). - `model.evaluate()`, apply the trained model to some test data (see [documentation](#)).

5.3 2 convolutional layers, no intermediate dense layers

```
[13]: # -----  
# === Your code here =====  
# -----  
from tf_keras.losses import CategoricalCrossentropy  
# Setup some training parameters  
batch_size = 20  
epochs = 20  
input_shape = (32,32,3)  
learning_rate = 0.01  
  
# Build model  
model1 = build_CNN(  
    input_shape = input_shape,  
    loss = CategoricalCrossentropy(),  
    n_conv_layers = 2,  
    n_filters = 16,  
    n_dense_layers = 0,  
    learning_rate = learning_rate,  
    act_fun = 'relu',  
    optimizer = 'adam',  
    print_summary = True  
)  
  
# Train the model using training data and validation data  
history1 = model1.fit(  
    Xtrain, Ytrain,  
    batch_size = batch_size,  
    epochs = epochs,  
    validation_data = (Xval, Yval)  
)  
  
# =====
```

Model: "sequential_1"

Layer (type)	Output Shape	Param #
conv2d_3 (Conv2D)	(None, 32, 32, 16)	448
batch_normalization_5 (Batch Normalization)	(None, 32, 32, 16)	64
max_pooling2d_3 (MaxPooling2D)	(None, 16, 16, 16)	0
conv2d_4 (Conv2D)	(None, 16, 16, 32)	4640
batch_normalization_6 (Batch Normalization)	(None, 16, 16, 32)	128
max_pooling2d_4 (MaxPooling2D)	(None, 8, 8, 32)	0
flatten_1 (Flatten)	(None, 2048)	0
dense_3 (Dense)	(None, 10)	20490

```

Total params: 25770 (100.66 KB)
Trainable params: 25674 (100.29 KB)
Non-trainable params: 96 (384.00 Byte)

```

Epoch 1/20

```

I0000 00:00:1746534603.298198 769793 cuda_dnn.cc:529] Loaded cuDNN version
90300
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
I0000 00:00:1746534603.508167 769793 service.cc:148] XLA service 0x7f612db80fa0
initialized for platform CUDA (this does not guarantee that XLA will be used).
Devices:
I0000 00:00:1746534603.508186 769793 service.cc:156] StreamExecutor device
(0): NVIDIA RTX 4000 Ada Generation, Compute Capability 8.9
I0000 00:00:1746534603.550089 769793 device_compiler.h:188] Compiled cluster
using XLA! This line is logged at most once for the lifetime of the process.

```

```

375/375 [=====] - 2s 2ms/step - loss: 2.4970 -
accuracy: 0.3668 - val_loss: 1.5381 - val_accuracy: 0.4404

```

Epoch 2/20

```

375/375 [=====] - 0s 1ms/step - loss: 1.3984 -
accuracy: 0.4981 - val_loss: 1.3805 - val_accuracy: 0.5028

```

Epoch 3/20

```

375/375 [=====] - 0s 1ms/step - loss: 1.2575 -
accuracy: 0.5475 - val_loss: 1.3803 - val_accuracy: 0.5220

```

Epoch 4/20
375/375 [=====] - 0s 1ms/step - loss: 1.1841 -
accuracy: 0.5827 - val_loss: 1.3149 - val_accuracy: 0.5452
Epoch 5/20
375/375 [=====] - 0s 1ms/step - loss: 1.0922 -
accuracy: 0.6235 - val_loss: 1.3142 - val_accuracy: 0.5616
Epoch 6/20
375/375 [=====] - 0s 1ms/step - loss: 1.0201 -
accuracy: 0.6461 - val_loss: 1.2762 - val_accuracy: 0.5792
Epoch 7/20
375/375 [=====] - 0s 1ms/step - loss: 0.9634 -
accuracy: 0.6660 - val_loss: 1.4775 - val_accuracy: 0.5328
Epoch 8/20
375/375 [=====] - 0s 1ms/step - loss: 0.8950 -
accuracy: 0.6867 - val_loss: 1.4480 - val_accuracy: 0.5560
Epoch 9/20
375/375 [=====] - 0s 1ms/step - loss: 0.8411 -
accuracy: 0.6995 - val_loss: 1.4890 - val_accuracy: 0.5424
Epoch 10/20
375/375 [=====] - 0s 1ms/step - loss: 0.7854 -
accuracy: 0.7264 - val_loss: 1.5340 - val_accuracy: 0.5400
Epoch 11/20
375/375 [=====] - 0s 1ms/step - loss: 0.7264 -
accuracy: 0.7448 - val_loss: 1.5716 - val_accuracy: 0.5592
Epoch 12/20
375/375 [=====] - 0s 1ms/step - loss: 0.7030 -
accuracy: 0.7579 - val_loss: 1.6927 - val_accuracy: 0.5504
Epoch 13/20
375/375 [=====] - 0s 1ms/step - loss: 0.6351 -
accuracy: 0.7797 - val_loss: 1.7298 - val_accuracy: 0.5496
Epoch 14/20
375/375 [=====] - 0s 1ms/step - loss: 0.5787 -
accuracy: 0.7956 - val_loss: 1.9390 - val_accuracy: 0.5328
Epoch 15/20
375/375 [=====] - 0s 1ms/step - loss: 0.5203 -
accuracy: 0.8155 - val_loss: 2.1548 - val_accuracy: 0.5300
Epoch 16/20
375/375 [=====] - 0s 1ms/step - loss: 0.5088 -
accuracy: 0.8212 - val_loss: 2.1388 - val_accuracy: 0.5424
Epoch 17/20
375/375 [=====] - 0s 1ms/step - loss: 0.4781 -
accuracy: 0.8335 - val_loss: 2.4250 - val_accuracy: 0.5360
Epoch 18/20
375/375 [=====] - 0s 1ms/step - loss: 0.4564 -
accuracy: 0.8424 - val_loss: 2.3928 - val_accuracy: 0.5312
Epoch 19/20
375/375 [=====] - 0s 1ms/step - loss: 0.4468 -
accuracy: 0.8475 - val_loss: 2.4428 - val_accuracy: 0.5484

Epoch 20/20

375/375 [=====] - 0s 1ms/step - loss: 0.3711 - accuracy: 0.8692 - val_loss: 2.7799 - val_accuracy: 0.5236

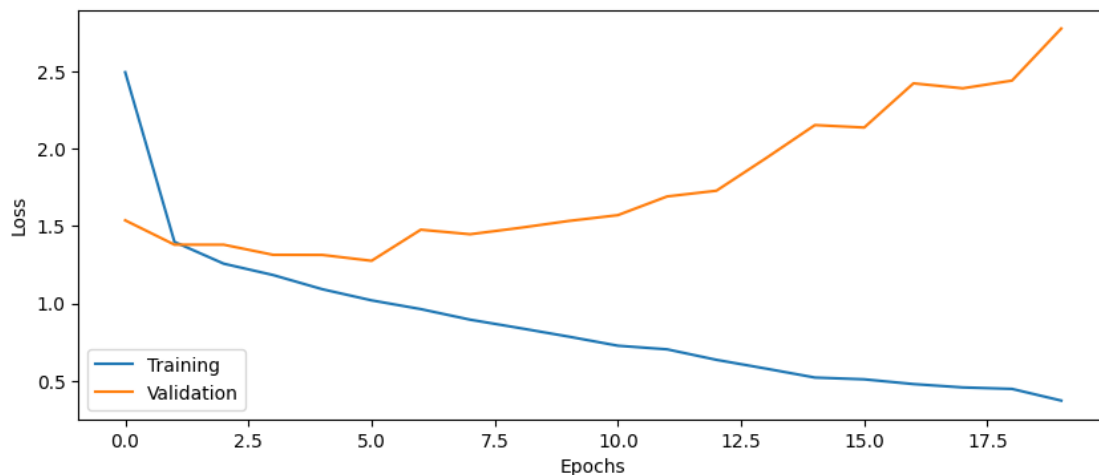
```
[14]: # -----  
# === Your code here =====  
# -----  
  
# Evaluate the trained model on test set, not used in training or validation  
score = model1.evaluate(Xtest, Ytest, verbose = 1)  
  
# =====  
  
print('Test loss: %.4f' % score[0])  
print('Test accuracy: %.4f' % score[1])
```

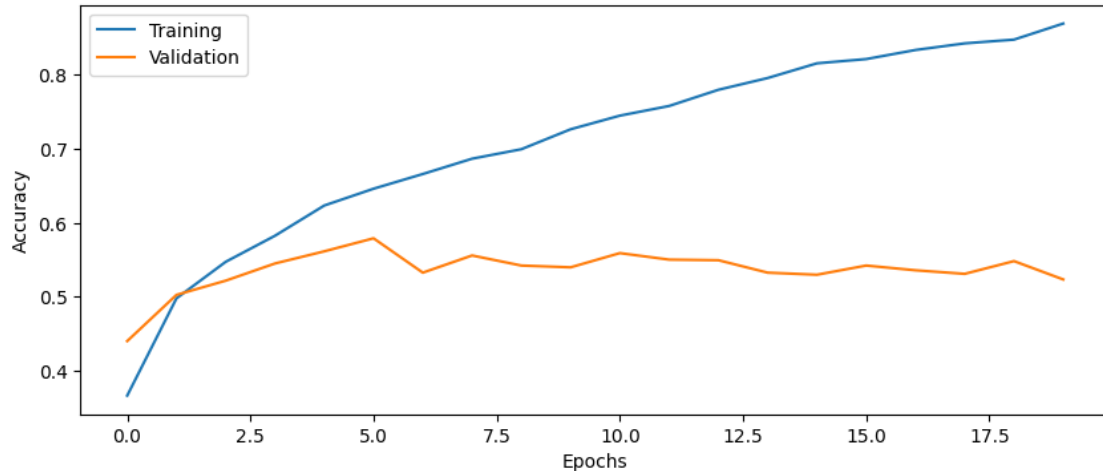
63/63 [=====] - 0s 1ms/step - loss: 2.7664 - accuracy: 0.5200

Test loss: 2.7664

Test accuracy: 0.5200

```
[15]: from utilities import plot_results  
# Plot the history from the training run  
plot_results(history1)
```





5.4 4.3 Improving model performance

Write down the test accuracy, are you satisfied with the classifier performance (random chance is 10%)?

The test accuracy is ~52% which signifies the model didn't overfit. The model needs to be improved further.

Questions

13. How big is the difference between training and test accuracy?
14. For the DNN elaboration we used a batch size of 10.000, why do we need to use a smaller batch size in this elaboration?

Answers

13. The difference between both the accuracies is huge ~2%.
14. Due to a higher number of parameters to train, it is wise to use a smaller batch size and running the model for larger amount of time. It also gives the model to update the weights more frequently and to achieve a better generalization. Another factor that we take into consideration is the memory required to store the larger amount of parameters. In this lab, as stated before the parameters number is large and them being of type 'float32' puts larger constraints on our memory.

Experiment with several model configurations in the following sections.

5.4.1 2 convolutional layers with 16 starting filters and 1 intermediate dense layer (50 nodes)

```
[17]: # -----
# === Your code here =====
# -----

# Build and train model
model1 = build_CNN(
    input_shape = (32, 32, 3),
    loss = tf.keras.losses.CategoricalCrossentropy(),
    n_conv_layers = 2,
    n_filters = 16,
    n_dense_layers = 1,
    n_nodes = 50,
    learning_rate = 0.01,
    act_fun = 'relu',
    optimizer = 'adam',
    print_summary = True
)

history1 = model1.fit(
    Xtrain, Ytrain,
    batch_size = 20,
    epochs = 20,
    validation_data = (Xval, Yval)
)

# Evaluate model on test data
score = model1.evaluate(Xtest, Ytest, verbose=1)

# =====

print('Test loss: %.4f' % score[0])
print('Test accuracy: %.4f' % score[1])

# Plot the history from the training run
plot_results(history1)
```

Model: "sequential_3"

Layer (type)	Output Shape	Param #
conv2d_7 (Conv2D)	(None, 32, 32, 16)	448
batch_normalization_9 (Batch Normalization)	(None, 32, 32, 16)	64
max_pooling2d_7 (MaxPooling2D)	(None, 16, 16, 16)	0

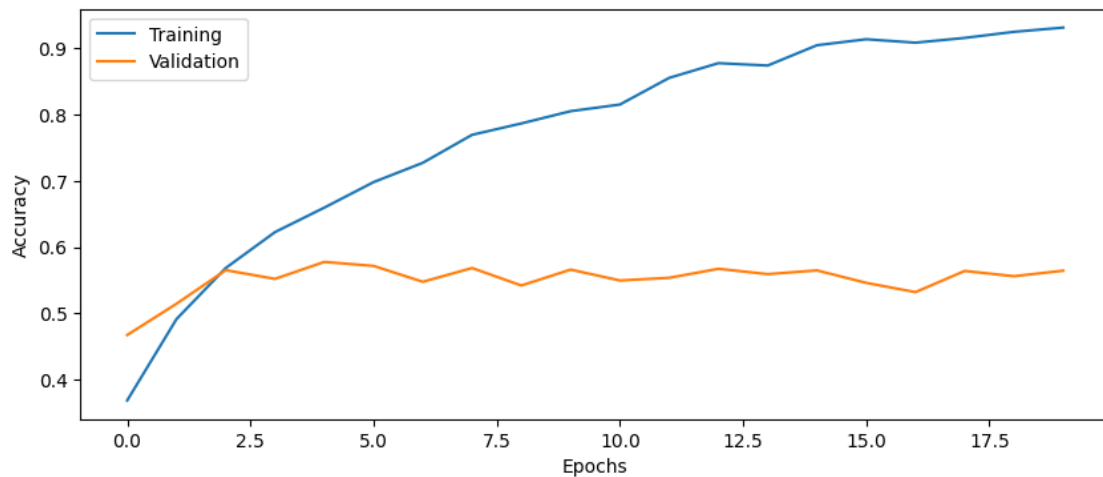
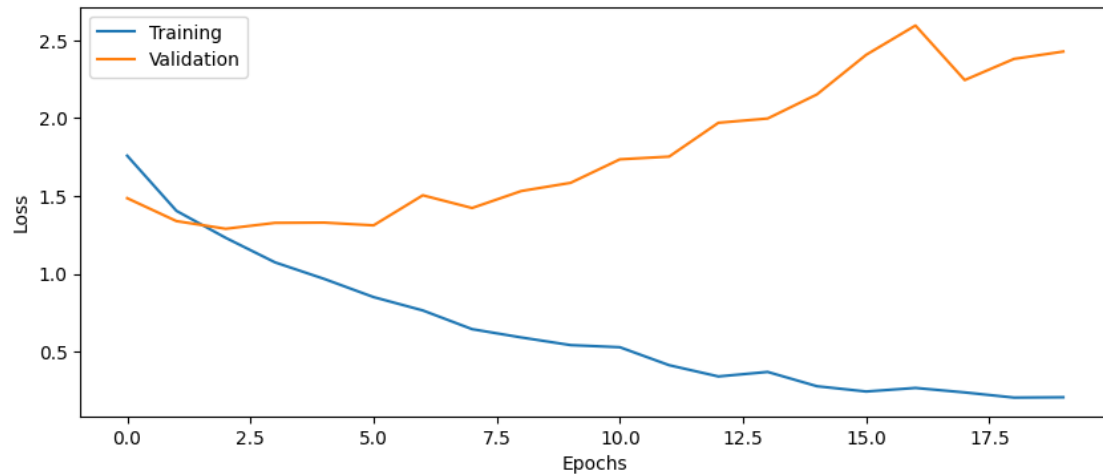
g2D)

conv2d_8 (Conv2D)	(None, 16, 16, 32)	4640
batch_normalization_10 (Batch Normalization)	(None, 16, 16, 32)	128
max_pooling2d_8 (MaxPooling2D)	(None, 8, 8, 32)	0
flatten_3 (Flatten)	(None, 2048)	0
dense_5 (Dense)	(None, 50)	102450
batch_normalization_11 (Batch Normalization)	(None, 50)	200
dense_6 (Dense)	(None, 10)	510

=====
Total params: 108440 (423.59 KB)
Trainable params: 108244 (422.83 KB)
Non-trainable params: 196 (784.00 Byte)

Epoch 1/20
375/375 [=====] - 5s 9ms/step - loss: 1.7589 - accuracy: 0.3684 - val_loss: 1.4861 - val_accuracy: 0.4672
Epoch 2/20
375/375 [=====] - 3s 7ms/step - loss: 1.4046 - accuracy: 0.4912 - val_loss: 1.3389 - val_accuracy: 0.5144
Epoch 3/20
375/375 [=====] - 3s 8ms/step - loss: 1.2314 - accuracy: 0.5684 - val_loss: 1.2896 - val_accuracy: 0.5652
Epoch 4/20
375/375 [=====] - 3s 7ms/step - loss: 1.0739 - accuracy: 0.6227 - val_loss: 1.3275 - val_accuracy: 0.5520
Epoch 5/20
375/375 [=====] - 3s 7ms/step - loss: 0.9674 - accuracy: 0.6596 - val_loss: 1.3292 - val_accuracy: 0.5776
Epoch 6/20
375/375 [=====] - 3s 7ms/step - loss: 0.8508 - accuracy: 0.6981 - val_loss: 1.3115 - val_accuracy: 0.5716
Epoch 7/20
375/375 [=====] - 3s 7ms/step - loss: 0.7650 - accuracy: 0.7273 - val_loss: 1.5047 - val_accuracy: 0.5476
Epoch 8/20
375/375 [=====] - 3s 7ms/step - loss: 0.6448 - accuracy: 0.7696 - val_loss: 1.4230 - val_accuracy: 0.5684

Epoch 9/20
375/375 [=====] - 3s 7ms/step - loss: 0.5914 -
accuracy: 0.7868 - val_loss: 1.5322 - val_accuracy: 0.5420
Epoch 10/20
375/375 [=====] - 3s 7ms/step - loss: 0.5422 -
accuracy: 0.8053 - val_loss: 1.5848 - val_accuracy: 0.5660
Epoch 11/20
375/375 [=====] - 3s 7ms/step - loss: 0.5286 -
accuracy: 0.8153 - val_loss: 1.7358 - val_accuracy: 0.5496
Epoch 12/20
375/375 [=====] - 3s 7ms/step - loss: 0.4132 -
accuracy: 0.8556 - val_loss: 1.7533 - val_accuracy: 0.5536
Epoch 13/20
375/375 [=====] - 3s 7ms/step - loss: 0.3409 -
accuracy: 0.8779 - val_loss: 1.9706 - val_accuracy: 0.5672
Epoch 14/20
375/375 [=====] - 3s 7ms/step - loss: 0.3699 -
accuracy: 0.8743 - val_loss: 1.9980 - val_accuracy: 0.5592
Epoch 15/20
375/375 [=====] - 3s 7ms/step - loss: 0.2781 -
accuracy: 0.9049 - val_loss: 2.1528 - val_accuracy: 0.5648
Epoch 16/20
375/375 [=====] - 3s 7ms/step - loss: 0.2441 -
accuracy: 0.9140 - val_loss: 2.4074 - val_accuracy: 0.5460
Epoch 17/20
375/375 [=====] - 3s 7ms/step - loss: 0.2669 -
accuracy: 0.9088 - val_loss: 2.5955 - val_accuracy: 0.5320
Epoch 18/20
375/375 [=====] - 3s 7ms/step - loss: 0.2382 -
accuracy: 0.9160 - val_loss: 2.2451 - val_accuracy: 0.5640
Epoch 19/20
375/375 [=====] - 3s 7ms/step - loss: 0.2050 -
accuracy: 0.9252 - val_loss: 2.3810 - val_accuracy: 0.5560
Epoch 20/20
375/375 [=====] - 3s 7ms/step - loss: 0.2070 -
accuracy: 0.9316 - val_loss: 2.4282 - val_accuracy: 0.5644
63/63 [=====] - 0s 4ms/step - loss: 2.4264 - accuracy:
0.5745
Test loss: 2.4264
Test accuracy: 0.5745



5.4.2 4 convolutional layers with 16 starting filters and 1 intermediate dense layer (50 nodes)

```
[18]: # -----
# === Your code here =====
# -----

# Build and train model
model2 = build_CNN(
    input_shape = (32, 32, 3),
    loss = tf.keras.losses.CategoricalCrossentropy(),
    n_conv_layers = 4,
    n_filters = 16,
```

```

    n_dense_layers = 1,
    n_nodes = 50,
    learning_rate = 0.01,
    act_fun = 'relu',
    optimizer = 'adam',
    print_summary = True
)

history2 = model2.fit(
    Xtrain, Ytrain,
    batch_size = 20,
    epochs = 20,
    validation_data = (Xval, Yval)
)

# Evaluate model on test data
score = model2.evaluate(Xtest, Ytest, verbose=1)
# =====

print('Test loss: %.4f' % score[0])
print('Test accuracy: %.4f' % score[1])

# Plot the history from the training run
plot_results(history2)

```

Model: "sequential_4"

Layer (type)	Output Shape	Param #
conv2d_9 (Conv2D)	(None, 32, 32, 16)	448
batch_normalization_12 (Batch Normalization)	(None, 32, 32, 16)	64
max_pooling2d_9 (MaxPooling2D)	(None, 16, 16, 16)	0
conv2d_10 (Conv2D)	(None, 16, 16, 32)	4640
batch_normalization_13 (Batch Normalization)	(None, 16, 16, 32)	128
max_pooling2d_10 (MaxPooling2D)	(None, 8, 8, 32)	0
conv2d_11 (Conv2D)	(None, 8, 8, 64)	18496

batch_normalization_14 (Batch Normalization)	(None, 8, 8, 64)	256
max_pooling2d_11 (MaxPooling2D)	(None, 4, 4, 64)	0
conv2d_12 (Conv2D)	(None, 4, 4, 128)	73856
batch_normalization_15 (Batch Normalization)	(None, 4, 4, 128)	512
max_pooling2d_12 (MaxPooling2D)	(None, 2, 2, 128)	0
flatten_4 (Flatten)	(None, 512)	0
dense_7 (Dense)	(None, 50)	25650
batch_normalization_16 (Batch Normalization)	(None, 50)	200
dense_8 (Dense)	(None, 10)	510

```

=====
Total params: 124760 (487.34 KB)
Trainable params: 124180 (485.08 KB)
Non-trainable params: 580 (2.27 KB)

```

```

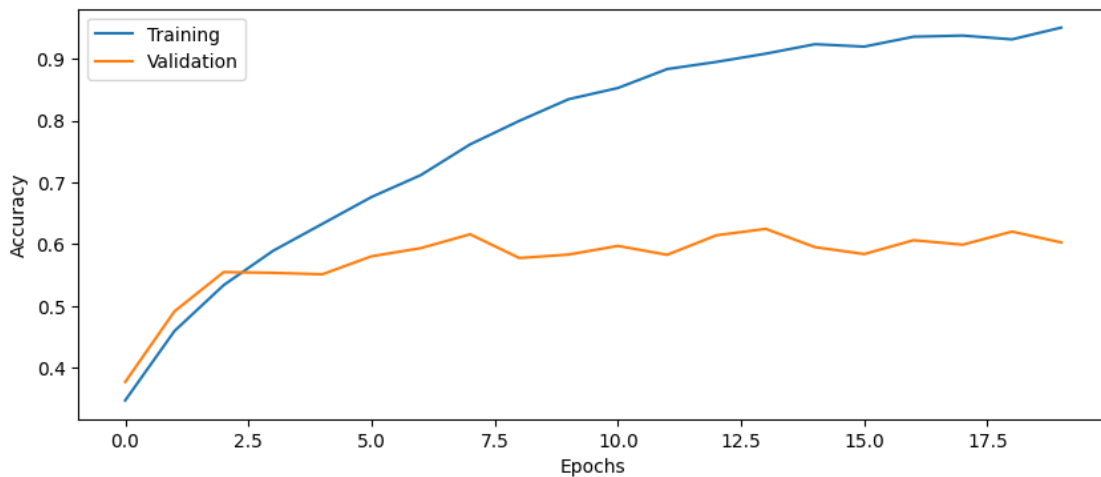
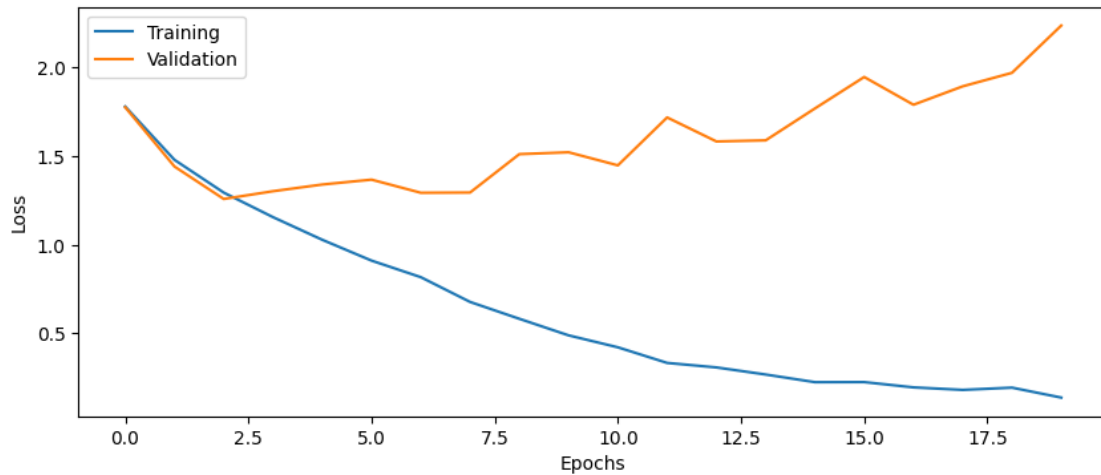
-----
Epoch 1/20
375/375 [=====] - 6s 12ms/step - loss: 1.7805 -
accuracy: 0.3469 - val_loss: 1.7767 - val_accuracy: 0.3768
Epoch 2/20
375/375 [=====] - 4s 11ms/step - loss: 1.4800 -
accuracy: 0.4593 - val_loss: 1.4424 - val_accuracy: 0.4912
Epoch 3/20
375/375 [=====] - 4s 10ms/step - loss: 1.2951 -
accuracy: 0.5337 - val_loss: 1.2592 - val_accuracy: 0.5548
Epoch 4/20
375/375 [=====] - 4s 11ms/step - loss: 1.1566 -
accuracy: 0.5892 - val_loss: 1.3030 - val_accuracy: 0.5536
Epoch 5/20
375/375 [=====] - 4s 11ms/step - loss: 1.0289 -
accuracy: 0.6328 - val_loss: 1.3408 - val_accuracy: 0.5512
Epoch 6/20
375/375 [=====] - 4s 11ms/step - loss: 0.9114 -
accuracy: 0.6764 - val_loss: 1.3683 - val_accuracy: 0.5804
Epoch 7/20
375/375 [=====] - 4s 10ms/step - loss: 0.8179 -

```

```

accuracy: 0.7119 - val_loss: 1.2942 - val_accuracy: 0.5936
Epoch 8/20
375/375 [=====] - 4s 10ms/step - loss: 0.6782 -
accuracy: 0.7616 - val_loss: 1.2955 - val_accuracy: 0.6160
Epoch 9/20
375/375 [=====] - 4s 10ms/step - loss: 0.5830 -
accuracy: 0.7997 - val_loss: 1.5122 - val_accuracy: 0.5776
Epoch 10/20
375/375 [=====] - 4s 11ms/step - loss: 0.4896 -
accuracy: 0.8348 - val_loss: 1.5227 - val_accuracy: 0.5832
Epoch 11/20
375/375 [=====] - 4s 11ms/step - loss: 0.4222 -
accuracy: 0.8529 - val_loss: 1.4488 - val_accuracy: 0.5972
Epoch 12/20
375/375 [=====] - 4s 11ms/step - loss: 0.3341 -
accuracy: 0.8836 - val_loss: 1.7192 - val_accuracy: 0.5828
Epoch 13/20
375/375 [=====] - 4s 11ms/step - loss: 0.3087 -
accuracy: 0.8952 - val_loss: 1.5839 - val_accuracy: 0.6144
Epoch 14/20
375/375 [=====] - 4s 10ms/step - loss: 0.2686 -
accuracy: 0.9085 - val_loss: 1.5900 - val_accuracy: 0.6248
Epoch 15/20
375/375 [=====] - 4s 10ms/step - loss: 0.2254 -
accuracy: 0.9239 - val_loss: 1.7700 - val_accuracy: 0.5952
Epoch 16/20
375/375 [=====] - 4s 11ms/step - loss: 0.2259 -
accuracy: 0.9200 - val_loss: 1.9475 - val_accuracy: 0.5840
Epoch 17/20
375/375 [=====] - 4s 10ms/step - loss: 0.1960 -
accuracy: 0.9360 - val_loss: 1.7909 - val_accuracy: 0.6064
Epoch 18/20
375/375 [=====] - 4s 11ms/step - loss: 0.1819 -
accuracy: 0.9379 - val_loss: 1.8948 - val_accuracy: 0.5992
Epoch 19/20
375/375 [=====] - 4s 10ms/step - loss: 0.1946 -
accuracy: 0.9317 - val_loss: 1.9711 - val_accuracy: 0.6204
Epoch 20/20
375/375 [=====] - 4s 11ms/step - loss: 0.1384 -
accuracy: 0.9508 - val_loss: 2.2380 - val_accuracy: 0.6028
63/63 [=====] - 1s 5ms/step - loss: 2.3763 - accuracy:
0.5920
Test loss: 2.3763
Test accuracy: 0.5920

```

5.5 4.4 Plot the CNN architecture and understand the internal model dimensions

To understand your network better, print the architecture using `model.summary()`

Questions

15. How many trainable parameters does your network have? Which part of the network contains most of the parameters?
16. What is the input to and output of a Conv2D layer? What are the dimensions of the input and output?
17. Is the batch size always the first dimension of each 4D tensor? Check the [documentation](#) for Conv2D.

18. If a convolutional layer that contains 128 filters is applied to an input with 32 channels, what is the number of channels in the output?
19. Why is the number of parameters in each Conv2D layer *not* equal to the number of filters times the number of filter coefficients per filter (plus biases)?
20. How does MaxPooling help in reducing the number of parameters to train?

Answers

15. The total trainable parameters are 124,180. The conv2D last layer has the most parameters and the dense layer part has the second most amount of parameters.
16. The input and output dimensions of Conv2D layer is a 4D tensor depending on the number of filters, height, width and batch_size. In our case the dimensions of input to Conv2d_9 are (None, 32, 32, 3) and output are (None, 32, 32, 16).
17. Yes, in keras and tensorflow, the first dimension is always batch_size.
18. As the number of filters in the input become the channels in the output; the number of channels in this case will be 128.
19. The number of parameters also depends on the number of channels: $(h * w * C + 1) * F$.
h*w: dimensions, C: channels, 1: bias, F: filters.
20. Maxpooling reduces the number of dimensions of the input from previous conv2D layers and don't contribute towards training. It can be considered as extracting the important part from the data and ignoring the noise. This improves the model training, reduces the overfitting and helps in lowering the computational cost too.

5.6 4.5 Dropout regularization

Add dropout regularization between each intermediate dense layer, with dropout probability 50%.

Questions

21. How much did the test accuracy improve with dropout, compared to without dropout?
22. What other types of regularization can be applied? How can you add L2 regularization for the convolutional layers?

Answers

21. The test accuracy improved by approximately 5-6% after including dropout.
22. The other forms of regularization are L1, L2, batch normalization, data augmentation. In tensorflow, we can add kernel regularizer in the Conv2D layer by adding this import line and including the kernel_regularizer parameter in the layer.

```
from tensorflow.keras.regularizers import l2
```

5.6.1 4 convolutional layers with 16 starting filters and 1 intermediate dense layer (50 nodes) with dropout

```
[19]: # -----  
# === Your code here =====  
# -----  
  
# Setup some training parameters  
batch_size = 20  
epochs = 20  
input_shape = (32, 32, 3)  
learning_rate = 0.01  
  
# Build and train model  
model3 = build_CNN(  
    input_shape = input_shape,  
    loss = tf.keras.losses.CategoricalCrossentropy(),  
    n_conv_layers = 4,  
    n_filters = 16,  
    n_dense_layers = 1,  
    n_nodes = 50,  
    use_dropout = True,  
    learning_rate = learning_rate,  
    act_fun = 'relu',  
    optimizer = 'adam',  
    print_summary = True  
)  
  
# Train the model using training data and validation data  
history3 = model3.fit(  
    Xtrain, Ytrain,  
    batch_size = batch_size,  
    epochs = epochs,  
    validation_data = (Xval, Yval)  
)  
  
# Evaluate model on test data  
score = model3.evaluate(Xtest, Ytest, verbose=1)  
  
# =====  
  
print('Test loss: %.4f' % score[0])  
print('Test accuracy: %.4f' % score[1])  
  
plot_results(history3)
```

Model: "sequential_5"

Layer (type)	Output Shape	Param #
conv2d_13 (Conv2D)	(None, 32, 32, 16)	448
batch_normalization_17 (Batch Normalization)	(None, 32, 32, 16)	64
max_pooling2d_13 (MaxPooling2D)	(None, 16, 16, 16)	0
dropout_5 (Dropout)	(None, 16, 16, 16)	0
conv2d_14 (Conv2D)	(None, 16, 16, 32)	4640
batch_normalization_18 (Batch Normalization)	(None, 16, 16, 32)	128
max_pooling2d_14 (MaxPooling2D)	(None, 8, 8, 32)	0
dropout_6 (Dropout)	(None, 8, 8, 32)	0
conv2d_15 (Conv2D)	(None, 8, 8, 64)	18496
batch_normalization_19 (Batch Normalization)	(None, 8, 8, 64)	256
max_pooling2d_15 (MaxPooling2D)	(None, 4, 4, 64)	0
dropout_7 (Dropout)	(None, 4, 4, 64)	0
conv2d_16 (Conv2D)	(None, 4, 4, 128)	73856
batch_normalization_20 (Batch Normalization)	(None, 4, 4, 128)	512
max_pooling2d_16 (MaxPooling2D)	(None, 2, 2, 128)	0
dropout_8 (Dropout)	(None, 2, 2, 128)	0
flatten_5 (Flatten)	(None, 512)	0
dense_9 (Dense)	(None, 50)	25650
batch_normalization_21 (Batch Normalization)	(None, 50)	200

dropout_9 (Dropout)	(None, 50)	0
dense_10 (Dense)	(None, 10)	510

```

=====
Total params: 124760 (487.34 KB)
Trainable params: 124180 (485.08 KB)
Non-trainable params: 580 (2.27 KB)
-----

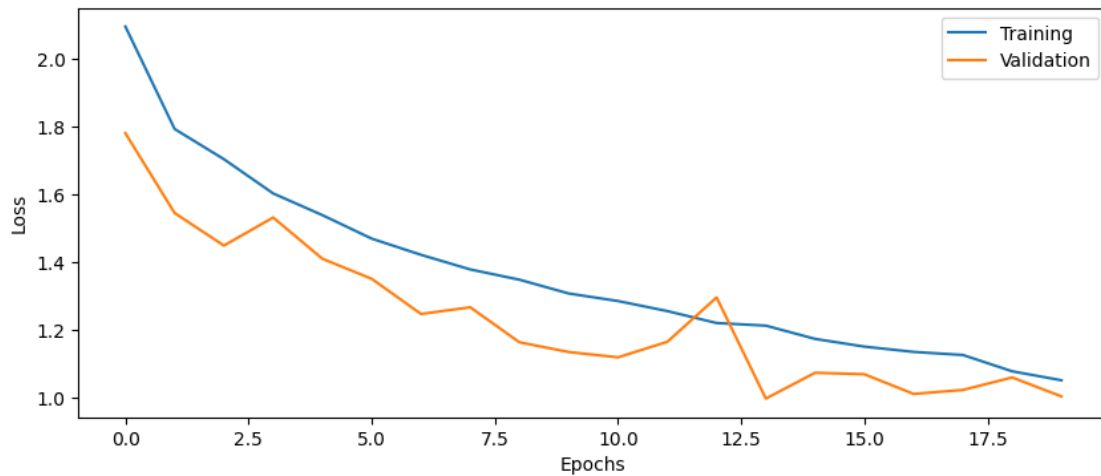
```

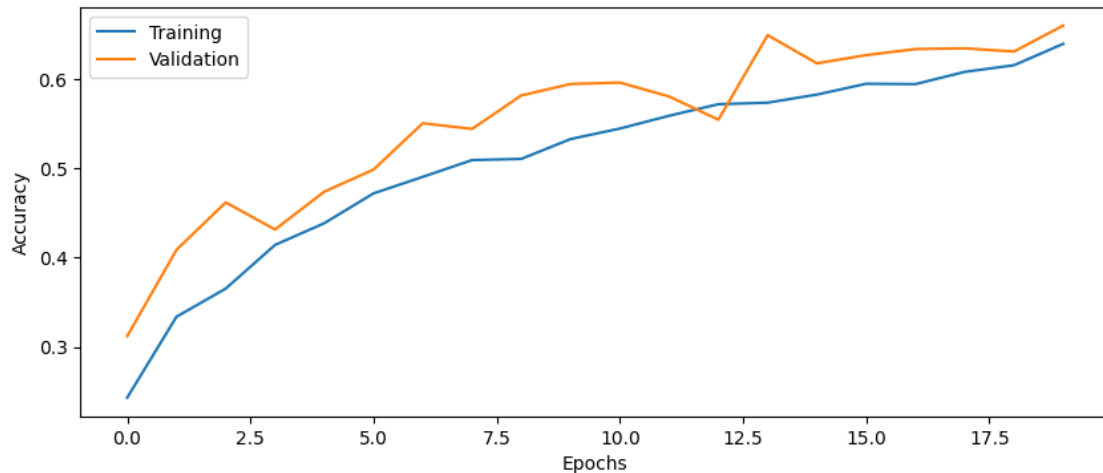
```

Epoch 1/20
375/375 [=====] - 7s 13ms/step - loss: 2.0965 -
accuracy: 0.2431 - val_loss: 1.7815 - val_accuracy: 0.3120
Epoch 2/20
375/375 [=====] - 4s 12ms/step - loss: 1.7938 -
accuracy: 0.3337 - val_loss: 1.5456 - val_accuracy: 0.4088
Epoch 3/20
375/375 [=====] - 5s 12ms/step - loss: 1.7046 -
accuracy: 0.3653 - val_loss: 1.4494 - val_accuracy: 0.4620
Epoch 4/20
375/375 [=====] - 5s 12ms/step - loss: 1.6035 -
accuracy: 0.4143 - val_loss: 1.5323 - val_accuracy: 0.4316
Epoch 5/20
375/375 [=====] - 5s 12ms/step - loss: 1.5392 -
accuracy: 0.4387 - val_loss: 1.4104 - val_accuracy: 0.4740
Epoch 6/20
375/375 [=====] - 4s 11ms/step - loss: 1.4699 -
accuracy: 0.4721 - val_loss: 1.3512 - val_accuracy: 0.4988
Epoch 7/20
375/375 [=====] - 4s 11ms/step - loss: 1.4221 -
accuracy: 0.4907 - val_loss: 1.2474 - val_accuracy: 0.5508
Epoch 8/20
375/375 [=====] - 4s 12ms/step - loss: 1.3789 -
accuracy: 0.5095 - val_loss: 1.2671 - val_accuracy: 0.5444
Epoch 9/20
375/375 [=====] - 4s 12ms/step - loss: 1.3486 -
accuracy: 0.5108 - val_loss: 1.1637 - val_accuracy: 0.5820
Epoch 10/20
375/375 [=====] - 5s 12ms/step - loss: 1.3078 -
accuracy: 0.5331 - val_loss: 1.1349 - val_accuracy: 0.5948
Epoch 11/20
375/375 [=====] - 5s 13ms/step - loss: 1.2855 -
accuracy: 0.5448 - val_loss: 1.1192 - val_accuracy: 0.5964
Epoch 12/20
375/375 [=====] - 4s 12ms/step - loss: 1.2559 -
accuracy: 0.5592 - val_loss: 1.1651 - val_accuracy: 0.5808
Epoch 13/20
375/375 [=====] - 4s 12ms/step - loss: 1.2206 -

```

accuracy: 0.5721 - val_loss: 1.2962 - val_accuracy: 0.5548
 Epoch 14/20
 375/375 [=====] - 4s 12ms/step - loss: 1.2129 -
 accuracy: 0.5739 - val_loss: 0.9974 - val_accuracy: 0.6496
 Epoch 15/20
 375/375 [=====] - 4s 12ms/step - loss: 1.1737 -
 accuracy: 0.5829 - val_loss: 1.0737 - val_accuracy: 0.6180
 Epoch 16/20
 375/375 [=====] - 4s 12ms/step - loss: 1.1509 -
 accuracy: 0.5951 - val_loss: 1.0693 - val_accuracy: 0.6272
 Epoch 17/20
 375/375 [=====] - 4s 12ms/step - loss: 1.1353 -
 accuracy: 0.5947 - val_loss: 1.0111 - val_accuracy: 0.6340
 Epoch 18/20
 375/375 [=====] - 4s 12ms/step - loss: 1.1262 -
 accuracy: 0.6084 - val_loss: 1.0229 - val_accuracy: 0.6348
 Epoch 19/20
 375/375 [=====] - 4s 12ms/step - loss: 1.0780 -
 accuracy: 0.6159 - val_loss: 1.0598 - val_accuracy: 0.6312
 Epoch 20/20
 375/375 [=====] - 4s 11ms/step - loss: 1.0515 -
 accuracy: 0.6399 - val_loss: 1.0038 - val_accuracy: 0.6604
 63/63 [=====] - 1s 5ms/step - loss: 0.9873 - accuracy:
 0.6460
 Test loss: 0.9873
 Test accuracy: 0.6460





5.7 4.6 Tweaking model performance

You have now seen the basic building blocks of a 2D CNN. To further improve performance involves changing the number of convolutional layers, the number of filters per layer, the number of intermediate dense layers, the number of nodes in the intermediate dense layers, batch size, learning rate, number of epochs, etc. Spend some time (30 - 90 minutes) testing different settings.

Questions

23. How high test accuracy can you obtain? What is your best configuration?

Answers

23. We tried a bunch of configurations and were able to get a test accuracy of ~67-69% all the time. In our best configuration, we had number of convolutional layers = 5, the number of filters per layer = 32, the number of intermediate dense layers = 2, the number of nodes in the intermediate dense layers = 128, batch size = 32, learning rate = 0.001, number of epochs = 30, dropout = True

5.8 Your best config

```
[27]: # -----
# === Your code here =====
# -----

# Setup some training parameters
batch_size = 32
epochs = 30
input_shape = (32,32,3)
learning_rate = 0.001
```

```

# Build and train model. Here experiment with several model architecture
↳ configurations to obtain the best performance.
model4 = build_CNN(
    input_shape = input_shape,
    loss = tf.keras.losses.CategoricalCrossentropy(),
    n_conv_layers = 5,
    n_filters = 32,
    n_dense_layers = 2,
    n_nodes = 128,
    use_dropout = True,
    learning_rate = learning_rate,
    act_fun = 'relu',
    optimizer = 'adam',
    print_summary = True
)

history4 = model4.fit(
    Xtrain, Ytrain,
    batch_size = batch_size,
    epochs = epochs,
    validation_data = (Xval, Yval)
)

# Evaluate model on test data
score = model4.evaluate(Xtest, Ytest, verbose=1)

# =====

print('Test loss: %.4f' % score[0])
print('Test accuracy: %.4f' % score[1])

# Plot the history from the training run
plot_results(history4)

```

Model: "sequential_10"

Layer (type)	Output Shape	Param #
conv2d_38 (Conv2D)	(None, 32, 32, 32)	896
batch_normalization_50 (Batch Normalization)	(None, 32, 32, 32)	128
max_pooling2d_38 (MaxPooling2D)	(None, 16, 16, 32)	0
dropout_37 (Dropout)	(None, 16, 16, 32)	0

conv2d_39 (Conv2D)	(None, 16, 16, 64)	18496
batch_normalization_51 (Batch Normalization)	(None, 16, 16, 64)	256
max_pooling2d_39 (MaxPooling2D)	(None, 8, 8, 64)	0
dropout_38 (Dropout)	(None, 8, 8, 64)	0
conv2d_40 (Conv2D)	(None, 8, 8, 128)	73856
batch_normalization_52 (Batch Normalization)	(None, 8, 8, 128)	512
max_pooling2d_40 (MaxPooling2D)	(None, 4, 4, 128)	0
dropout_39 (Dropout)	(None, 4, 4, 128)	0
conv2d_41 (Conv2D)	(None, 4, 4, 256)	295168
batch_normalization_53 (Batch Normalization)	(None, 4, 4, 256)	1024
max_pooling2d_41 (MaxPooling2D)	(None, 2, 2, 256)	0
dropout_40 (Dropout)	(None, 2, 2, 256)	0
conv2d_42 (Conv2D)	(None, 2, 2, 512)	1180160
batch_normalization_54 (Batch Normalization)	(None, 2, 2, 512)	2048
max_pooling2d_42 (MaxPooling2D)	(None, 1, 1, 512)	0
dropout_41 (Dropout)	(None, 1, 1, 512)	0
flatten_9 (Flatten)	(None, 512)	0
dense_21 (Dense)	(None, 128)	65664
batch_normalization_55 (Batch Normalization)	(None, 128)	512

dropout_42 (Dropout)	(None, 128)	0
dense_22 (Dense)	(None, 128)	16512
batch_normalization_56 (Batch Normalization)	(None, 128)	512
dropout_43 (Dropout)	(None, 128)	0
dense_23 (Dense)	(None, 10)	1290

```

=====
Total params: 1657034 (6.32 MB)
Trainable params: 1654538 (6.31 MB)
Non-trainable params: 2496 (9.75 KB)

```

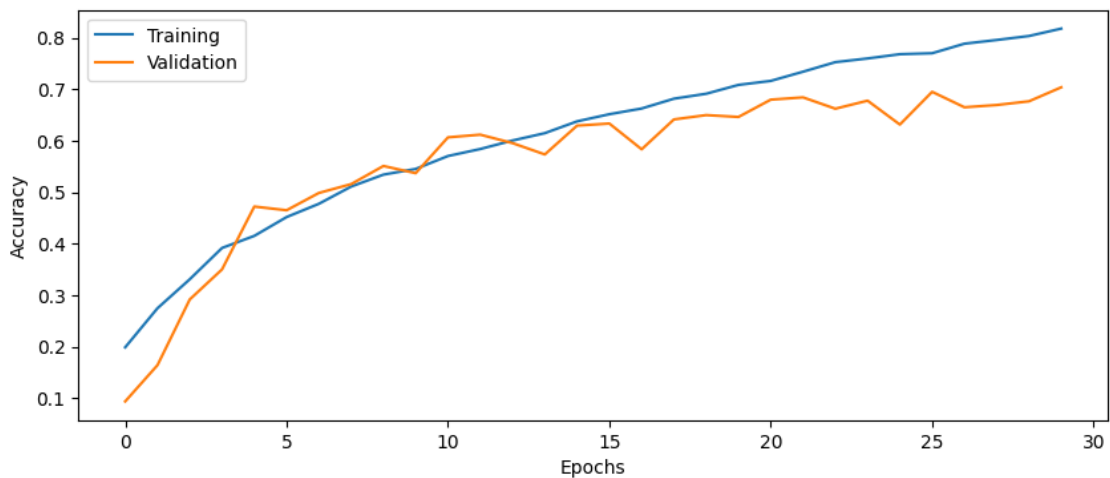
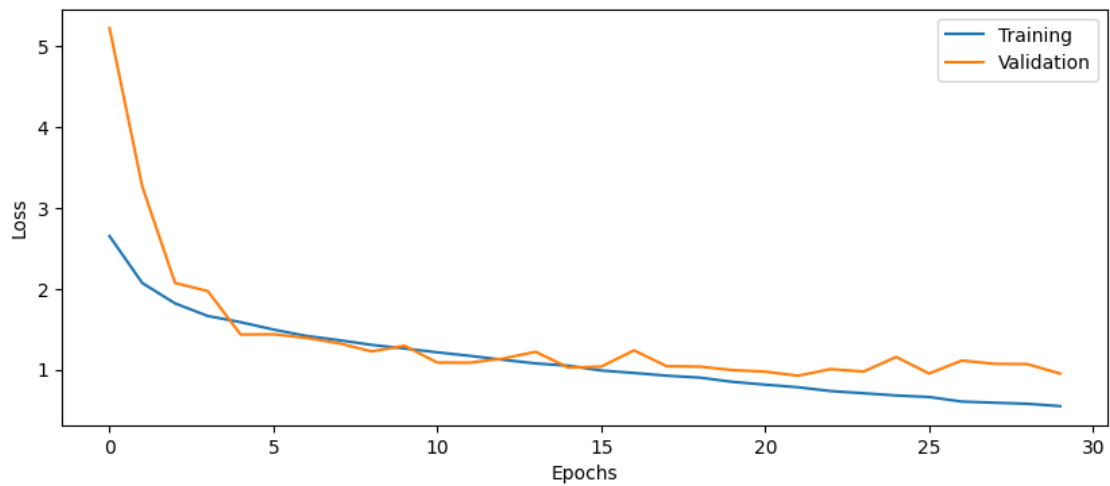
```

-----
Epoch 1/30
235/235 [=====] - 13s 43ms/step - loss: 2.6525 -
accuracy: 0.1987 - val_loss: 5.2276 - val_accuracy: 0.0936
Epoch 2/30
235/235 [=====] - 10s 43ms/step - loss: 2.0717 -
accuracy: 0.2745 - val_loss: 3.2654 - val_accuracy: 0.1640
Epoch 3/30
235/235 [=====] - 10s 41ms/step - loss: 1.8196 -
accuracy: 0.3308 - val_loss: 2.0725 - val_accuracy: 0.2916
Epoch 4/30
235/235 [=====] - 10s 41ms/step - loss: 1.6633 -
accuracy: 0.3916 - val_loss: 1.9715 - val_accuracy: 0.3500
Epoch 5/30
235/235 [=====] - 10s 42ms/step - loss: 1.5868 -
accuracy: 0.4151 - val_loss: 1.4339 - val_accuracy: 0.4720
Epoch 6/30
235/235 [=====] - 10s 44ms/step - loss: 1.4957 -
accuracy: 0.4516 - val_loss: 1.4373 - val_accuracy: 0.4648
Epoch 7/30
235/235 [=====] - 10s 42ms/step - loss: 1.4170 -
accuracy: 0.4773 - val_loss: 1.3922 - val_accuracy: 0.4984
Epoch 8/30
235/235 [=====] - 10s 41ms/step - loss: 1.3639 -
accuracy: 0.5108 - val_loss: 1.3257 - val_accuracy: 0.5156
Epoch 9/30
235/235 [=====] - 9s 40ms/step - loss: 1.3060 -
accuracy: 0.5340 - val_loss: 1.2247 - val_accuracy: 0.5508
Epoch 10/30
235/235 [=====] - 10s 41ms/step - loss: 1.2603 -
accuracy: 0.5451 - val_loss: 1.2949 - val_accuracy: 0.5368
Epoch 11/30
235/235 [=====] - 10s 41ms/step - loss: 1.2135 -

```

accuracy: 0.5701 - val_loss: 1.0869 - val_accuracy: 0.6064
 Epoch 12/30
 235/235 [=====] - 10s 41ms/step - loss: 1.1696 -
 accuracy: 0.5837 - val_loss: 1.0858 - val_accuracy: 0.6116
 Epoch 13/30
 235/235 [=====] - 10s 41ms/step - loss: 1.1215 -
 accuracy: 0.6003 - val_loss: 1.1360 - val_accuracy: 0.5952
 Epoch 14/30
 235/235 [=====] - 10s 42ms/step - loss: 1.0764 -
 accuracy: 0.6145 - val_loss: 1.2200 - val_accuracy: 0.5732
 Epoch 15/30
 235/235 [=====] - 10s 42ms/step - loss: 1.0479 -
 accuracy: 0.6375 - val_loss: 1.0245 - val_accuracy: 0.6292
 Epoch 16/30
 235/235 [=====] - 10s 43ms/step - loss: 0.9888 -
 accuracy: 0.6513 - val_loss: 1.0366 - val_accuracy: 0.6332
 Epoch 17/30
 235/235 [=====] - 10s 42ms/step - loss: 0.9582 -
 accuracy: 0.6624 - val_loss: 1.2376 - val_accuracy: 0.5832
 Epoch 18/30
 235/235 [=====] - 10s 41ms/step - loss: 0.9246 -
 accuracy: 0.6815 - val_loss: 1.0420 - val_accuracy: 0.6412
 Epoch 19/30
 235/235 [=====] - 10s 41ms/step - loss: 0.9008 -
 accuracy: 0.6911 - val_loss: 1.0371 - val_accuracy: 0.6496
 Epoch 20/30
 235/235 [=====] - 10s 42ms/step - loss: 0.8485 -
 accuracy: 0.7083 - val_loss: 0.9936 - val_accuracy: 0.6460
 Epoch 21/30
 235/235 [=====] - 10s 41ms/step - loss: 0.8138 -
 accuracy: 0.7160 - val_loss: 0.9749 - val_accuracy: 0.6796
 Epoch 22/30
 235/235 [=====] - 10s 41ms/step - loss: 0.7816 -
 accuracy: 0.7339 - val_loss: 0.9245 - val_accuracy: 0.6840
 Epoch 23/30
 235/235 [=====] - 10s 41ms/step - loss: 0.7342 -
 accuracy: 0.7524 - val_loss: 1.0062 - val_accuracy: 0.6620
 Epoch 24/30
 235/235 [=====] - 9s 40ms/step - loss: 0.7076 -
 accuracy: 0.7596 - val_loss: 0.9754 - val_accuracy: 0.6776
 Epoch 25/30
 235/235 [=====] - 10s 43ms/step - loss: 0.6795 -
 accuracy: 0.7679 - val_loss: 1.1566 - val_accuracy: 0.6312
 Epoch 26/30
 235/235 [=====] - 10s 42ms/step - loss: 0.6608 -
 accuracy: 0.7697 - val_loss: 0.9512 - val_accuracy: 0.6948
 Epoch 27/30
 235/235 [=====] - 10s 42ms/step - loss: 0.6043 -

accuracy: 0.7883 - val_loss: 1.1117 - val_accuracy: 0.6648
Epoch 28/30
235/235 [=====] - 10s 42ms/step - loss: 0.5900 -
accuracy: 0.7955 - val_loss: 1.0715 - val_accuracy: 0.6692
Epoch 29/30
235/235 [=====] - 10s 42ms/step - loss: 0.5769 -
accuracy: 0.8032 - val_loss: 1.0678 - val_accuracy: 0.6764
Epoch 30/30
235/235 [=====] - 10s 42ms/step - loss: 0.5476 -
accuracy: 0.8176 - val_loss: 0.9501 - val_accuracy: 0.7036
63/63 [=====] - 1s 10ms/step - loss: 0.9894 - accuracy:
0.6775
Test loss: 0.9894
Test accuracy: 0.6775



6 Part 5: Model generalization

How high is the test accuracy if we rotate the test images? In other words, how good is the CNN at generalizing to rotated images?

Rotate each test image 90 degrees, the cells are already finished.

Questions

24. What is the test accuracy for rotated test images, compared to test images without rotation? Explain the difference in accuracy.

Answers

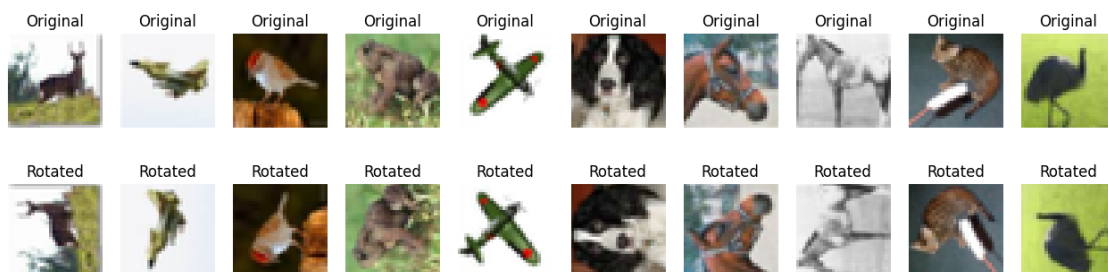
24. Test accuracy of the rotated images is very less as the model did not see these images while training. It is difficult to extract relevant features from them for the model and hence unable to perform effectively.

```
[22]: from utilities import myrotate
# Visualize some rotated images
# Rotate the test images 90 degrees
Xtest_rotated = myrotate(Xtest)

# Look at some rotated images
plt.figure(figsize=(16,4))
for i in range(10):
    idx = np.random.randint(500)

    plt.subplot(2,10,i+1)
    plt.imshow(Xtest[idx]/2+0.5)
    plt.title("Original")
    plt.axis('off')

    plt.subplot(2,10,i+11)
    plt.imshow(Xtest_rotated[idx]/2+0.5)
    plt.title("Rotated")
    plt.axis('off')
plt.show()
```



```
[25]: # Evaluate the trained model on rotated test set
score = model4.evaluate(Xtest_rotated, Ytest, verbose=0)
print('Test loss: %.4f' % score[0])
print('Test accuracy: %.4f' % score[1])
```

Test loss: 3.7079

Test accuracy: 0.2290

6.1 5.1 Augmentation using Keras ImageDataGenerator

We can increase the number of training images through data augmentation (we now ignore that CIFAR10 actually has 60 000 training images). Image augmentation is about creating similar images, by performing operations such as rotation, scaling, elastic deformations and flipping of existing images. This will prevent overfitting, especially if all the training images are in a certain orientation.

We will perform the augmentation on the fly, using a built-in function in Keras, called `ImageDataGenerator`. In particular, we will use the `flow()` functionality (see the [documentation](#) for more details).

Make sure to use different subsets for training and validation when you calling `flow()` on the training data generator in `model.fit()`, otherwise you will validate on the same data.

```
[28]: # Get all 60 000 training images again. ImageDataGenerator manages validation,
      ↪data on its own

# re-load the CIFAR10 train and test data
(X, Y), (Xtest, Ytest) = cifar10.load_data()

# Reduce the number of images for training/validation and testing to 10000 and
      ↪2000 respectively,
# to reduce processing time for this elaboration.
X = X[0:10000]
Y = Y[0:10000]

Xtest = Xtest[0:2000]
Ytest = Ytest[0:2000]

# Change data type and rescale range
X = X.astype('float32')
Xtest = Xtest.astype('float32')

X = X / 127.5 - 1
Xtest = Xtest / 127.5 - 1

# Convert labels to hot encoding
Y = to_categorical(Y, 10)
Ytest = to_categorical(Ytest, 10)
```

```
print("Training/validation images have size {} and labels have size {}".format(X.shape, Y.shape))
print("Test images have size {} and labels have size {}".format(Xtest.shape, Ytest.shape))
```

Training/validation images have size (10000, 32, 32, 3) and labels have size (10000, 10)

Test images have size (2000, 32, 32, 3) and labels have size (2000, 10)

```
[38]: from tensorflow.keras.preprocessing.image import ImageDataGenerator

# -----
# === Your code here =====
# -----

# Use a rotation range of 30 degrees, horizontal and vertical flipping
# Set up image data generator
image_dataset = ImageDataGenerator(
    rotation_range=30,
    horizontal_flip=True,
    vertical_flip=True,
    validation_split=0.2
)

train_flow = image_dataset.flow(X, Y, batch_size = 32)

# =====
```

Questions

25. How would you change the code for the image generator if you cannot fit all training images in CPU memory? What is the disadvantage of doing that change?

Answers

25. We can store the images in directory and use `flow_from_directory()` function to avoid filling up the CPU memory. The disadvantage of doing this is slower training, bottlenecks due to disk I/O and slower processing time.

```
[39]: # Plot some augmented images

plt.figure(figsize=(12,4))
for i in range(18):
    (im, label) = next(train_flow)
    im = (im[0] + 1) * 127.5
```

```

im = im.astype('int')
label = np.flatnonzero(label)[0]

plt.subplot(3,6,i+1)
plt.tight_layout()
plt.imshow(im)
plt.title("Class: {} ({}).format(label, classes[label]))
plt.axis('off')
plt.show()

```



6.2 5.2 Train the CNN with images from the generator

Check the documentation for the `model.fit` method how to use it with a generator instead of a fix dataset (numpy arrays).

To make the comparison fair to training without augmentation

- `steps_per_epoch` should be set to: `len(Xtrain)/batch_size`
- `validation_steps` should be set to: `len(Xval)/batch_size`

This is required since with a generator, the fit function will not know how many examples your original dataset has.

Questions

26. How quickly is the training accuracy increasing compared to without augmentation? Explain why there is a difference compared to without augmentation. We are here talking about the number of training epochs required to reach a certain accuracy, and not the training time in seconds. What parameter is necessary to change to perform more training?
27. What other types of image augmentation can be applied, compared to what we use here?

Answers

26. The training accuracy was increasing slowly as compared to previous models. This is possible because of the variety of data that the model can go through using the augmentation. If we

want to perform more training then we can change the number of epochs and maybe increase the learning rate for a possible faster convergence.

27. `zoom_range`, `width_shift_range`, `height_shift_range`, `shear_range`, `brightness_range`, `contrast_range` are some of the additional parameters that can be used

```
[42]: # -----  
# === Your code here =====  
# -----  
  
# Setup training parameters  
batch_size = 32  
epochs = 30  
input_shape = (32,32,3)  
  
# Build model (your best config)  
model6 = build_CNN(  
    input_shape=input_shape,  
    loss=tf.keras.losses.CategoricalCrossentropy(),  
    n_conv_layers=5,  
    n_filters=32,  
    n_dense_layers=2,  
    n_nodes=128,  
    use_dropout=True,  
    learning_rate=0.001,  
    act_fun='relu',  
    optimizer='adam',  
    print_summary=False  
)  
  
# Set up training and validation dataset flows from image_dataset  
Xtrain, Xval, Ytrain, Yval = train_test_split(X, Y, test_size=0.25,  
    ↪random_state=42)  
  
# flow() for training data  
train_flow = image_dataset.flow(Xtrain, Ytrain, batch_size=batch_size)  
  
# flow() for validation data  
val_flow = image_dataset.flow(Xval, Yval, batch_size=batch_size)  
  
# Train the model using on the fly augmentation  
history6 = model6.fit(  
    train_flow,  
    epochs=epochs,  
    validation_data=val_flow,  
    steps_per_epoch=len(Xtrain)/batch_size,  
    validation_steps=len(Xval)/batch_size
```

)

=====

Epoch 1/30

234/234 [=====] - 15s 51ms/step - loss: 2.7019 -
accuracy: 0.1799 - val_loss: 3.6852 - val_accuracy: 0.1320

Epoch 2/30

234/234 [=====] - 12s 51ms/step - loss: 2.1891 -
accuracy: 0.2336 - val_loss: 3.1933 - val_accuracy: 0.1584

Epoch 3/30

234/234 [=====] - 12s 50ms/step - loss: 1.9933 -
accuracy: 0.2624 - val_loss: 2.0304 - val_accuracy: 0.2564

Epoch 4/30

234/234 [=====] - 11s 48ms/step - loss: 1.8636 -
accuracy: 0.3029 - val_loss: 1.7780 - val_accuracy: 0.3368

Epoch 5/30

234/234 [=====] - 12s 49ms/step - loss: 1.7815 -
accuracy: 0.3351 - val_loss: 1.6800 - val_accuracy: 0.3800

Epoch 6/30

234/234 [=====] - 12s 52ms/step - loss: 1.7361 -
accuracy: 0.3435 - val_loss: 1.7852 - val_accuracy: 0.3524

Epoch 7/30

234/234 [=====] - 12s 51ms/step - loss: 1.6812 -
accuracy: 0.3711 - val_loss: 1.7339 - val_accuracy: 0.3760

Epoch 8/30

234/234 [=====] - 13s 55ms/step - loss: 1.6380 -
accuracy: 0.3891 - val_loss: 1.7939 - val_accuracy: 0.3632

Epoch 9/30

234/234 [=====] - 13s 55ms/step - loss: 1.6191 -
accuracy: 0.3973 - val_loss: 1.5365 - val_accuracy: 0.4312

Epoch 10/30

234/234 [=====] - 12s 50ms/step - loss: 1.6055 -
accuracy: 0.4041 - val_loss: 1.4785 - val_accuracy: 0.4452

Epoch 11/30

234/234 [=====] - 12s 51ms/step - loss: 1.5743 -
accuracy: 0.4169 - val_loss: 1.4638 - val_accuracy: 0.4612

Epoch 12/30

234/234 [=====] - 12s 50ms/step - loss: 1.5476 -
accuracy: 0.4308 - val_loss: 1.4599 - val_accuracy: 0.4648

Epoch 13/30

234/234 [=====] - 12s 50ms/step - loss: 1.5261 -
accuracy: 0.4427 - val_loss: 1.4273 - val_accuracy: 0.4728

Epoch 14/30

234/234 [=====] - 12s 51ms/step - loss: 1.4980 -
accuracy: 0.4541 - val_loss: 1.4353 - val_accuracy: 0.4696

Epoch 15/30

234/234 [=====] - 12s 50ms/step - loss: 1.4831 -
accuracy: 0.4520 - val_loss: 1.4438 - val_accuracy: 0.4792
Epoch 16/30
234/234 [=====] - 13s 53ms/step - loss: 1.4586 -
accuracy: 0.4684 - val_loss: 1.3957 - val_accuracy: 0.4820
Epoch 17/30
234/234 [=====] - 11s 48ms/step - loss: 1.4456 -
accuracy: 0.4724 - val_loss: 1.3546 - val_accuracy: 0.5048
Epoch 18/30
234/234 [=====] - 11s 48ms/step - loss: 1.4356 -
accuracy: 0.4715 - val_loss: 1.2681 - val_accuracy: 0.5432
Epoch 19/30
234/234 [=====] - 11s 48ms/step - loss: 1.4060 -
accuracy: 0.4967 - val_loss: 1.2779 - val_accuracy: 0.5424
Epoch 20/30
234/234 [=====] - 12s 49ms/step - loss: 1.3910 -
accuracy: 0.4996 - val_loss: 1.3782 - val_accuracy: 0.4928
Epoch 21/30
234/234 [=====] - 12s 49ms/step - loss: 1.3754 -
accuracy: 0.5084 - val_loss: 1.3200 - val_accuracy: 0.5264
Epoch 22/30
234/234 [=====] - 12s 49ms/step - loss: 1.3667 -
accuracy: 0.5083 - val_loss: 1.2443 - val_accuracy: 0.5544
Epoch 23/30
234/234 [=====] - 12s 50ms/step - loss: 1.3525 -
accuracy: 0.5117 - val_loss: 1.2454 - val_accuracy: 0.5464
Epoch 24/30
234/234 [=====] - 12s 51ms/step - loss: 1.3297 -
accuracy: 0.5243 - val_loss: 1.2463 - val_accuracy: 0.5524
Epoch 25/30
234/234 [=====] - 13s 55ms/step - loss: 1.3338 -
accuracy: 0.5264 - val_loss: 1.2631 - val_accuracy: 0.5476
Epoch 26/30
234/234 [=====] - 12s 50ms/step - loss: 1.2933 -
accuracy: 0.5397 - val_loss: 1.2317 - val_accuracy: 0.5640
Epoch 27/30
234/234 [=====] - 12s 50ms/step - loss: 1.2919 -
accuracy: 0.5379 - val_loss: 1.2226 - val_accuracy: 0.5496
Epoch 28/30
234/234 [=====] - 12s 50ms/step - loss: 1.2858 -
accuracy: 0.5436 - val_loss: 1.2337 - val_accuracy: 0.5636
Epoch 29/30
234/234 [=====] - 12s 49ms/step - loss: 1.2578 -
accuracy: 0.5569 - val_loss: 1.2057 - val_accuracy: 0.5584
Epoch 30/30
234/234 [=====] - 12s 50ms/step - loss: 1.2524 -
accuracy: 0.5532 - val_loss: 1.1666 - val_accuracy: 0.5844

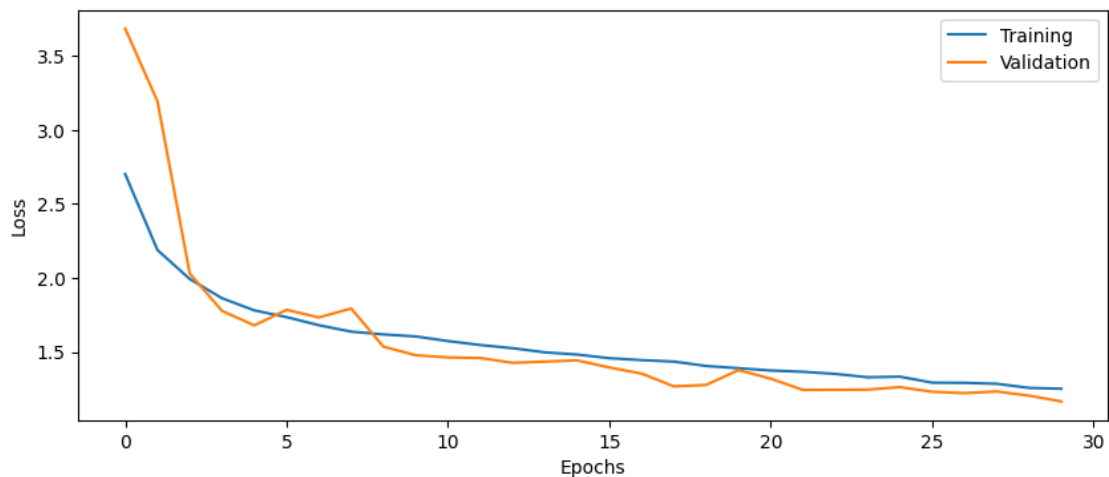
```
[43]: # Check if there is still a big difference in accuracy for original and rotated
      ↪ test images

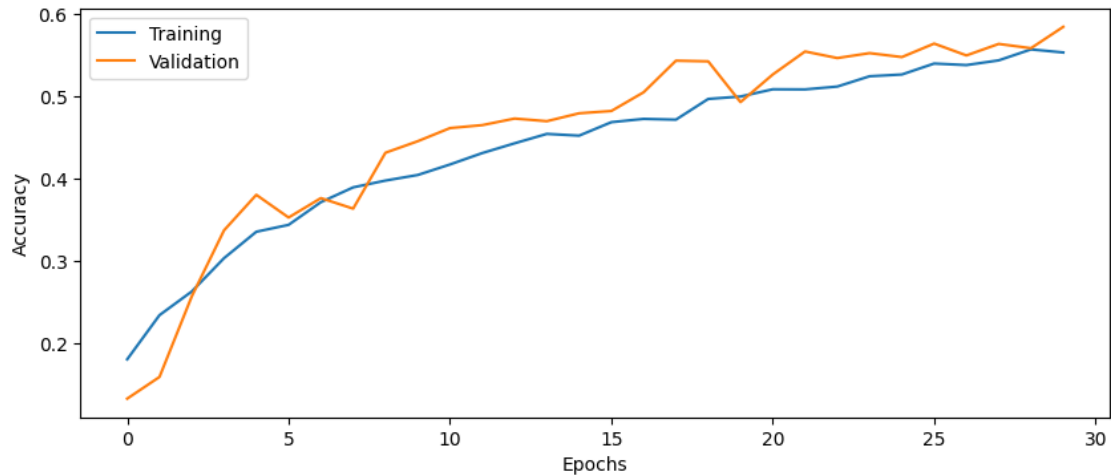
      # Evaluate the trained model on original test set
      score = model6.evaluate(Xtest, Ytest, batch_size = batch_size, verbose=0)
      print('Test loss: %.4f' % score[0])
      print('Test accuracy: %.4f' % score[1])

      # Evaluate the trained model on rotated test set
      score = model6.evaluate(Xtest_rotated, Ytest, batch_size = batch_size,
      ↪ verbose=0)
      print('Test loss: %.4f' % score[0])
      print('Test accuracy: %.4f' % score[1])
```

Test loss: 1.1154
 Test accuracy: 0.5995
 Test loss: 2.3300
 Test accuracy: 0.2710

```
[44]: # Plot the history from the training run
      plot_results(history6)
```





6.3 Plot misclassified images

Lets plot some images where the CNN performed badly.

```
[45]: # Find misclassified images
y_pred=model6.predict(Xtest, verbose=0)
y_pred=np.argmax(y_pred,axis=1)

y_correct = np.argmax(Ytest,axis=-1)

miss = np.flatnonzero(y_correct != y_pred)
```

```
[46]: # Plot a few of them
plt.figure(figsize=(15,4))
perm = np.random.permutation(miss)
for i in range(18):
    im = (Xtest[perm[i]] + 1) * 127.5
    im = im.astype('int')
    label_correct = y_correct[perm[i]]
    label_pred = y_pred[perm[i]]

    plt.subplot(3,6,i+1)
    plt.tight_layout()
    plt.imshow(im)
    plt.axis('off')
    plt.title("{} , classified as {}".format(classes[label_correct],
    ↪classes[label_pred]))
plt.show()
```



6.4 5.3 Testing on another size

Questions

28. This CNN has been trained on 32 x 32 images, can it be applied to images of another size? If not, why is this the case?
29. Is it possible to design a CNN that can be trained on images of one size, and then applied to an image of any size? How?

Answers

28. No, this can't be applied as the first layer is dependent on the input size of the image. The flattening of the 2D vector into 1D also depends on the fixed input size, hence, it will throw errors while training during the forward propagation of the network.
29. It is possible to do so by using the padding functionality. Every image can be converted to the required size by resizing/padding. Global pooling is also one of the solution to apply this design as it reduces the dimension to certain fixed size.

7 Part 6: Carbon footprint

In this next section we will evaluate the carbon footprint of training our CNN model. In particular we will look at the effect of training hyper parameters of carbon footprint. You can read more about this topic [here](#) or [here](#).

In this lab we will use the `carbontracker` library that easily integrates with any model training routine. See the example in the [documentation](#) on how to use the carbon tracker.

Questions

28. Keeping the model architecture fixed, which training parameter impacts the carbon footprint?
29. The choice of batch size can dramatically impact carbon foot print: why is this the case?
30. Assume that you have a model with 100 million parameters running in the backend of a service with 5 million users. How can the carbon footprint of using this model be reduced?

Answers

28. The learning rate, batch size, epochs and complexity of architecture impacts the carbon footprint. It directly correlates to the amount of time the model is training impacting the electricity consumption and heat generation.
29. Batch size directly impacts the training process. Larger batch size means memory consumption and larger time to process every step. Smaller batch size means frequent updates and the model trains for a longer time, more power consumption.
30. This can be reduced by using less complex model, using renewable source of energy to train the model, using efficient algorithms, etc.

```
[16]: from keras.datasets import cifar10
import numpy as np
from tensorflow.keras.utils import to_categorical

# Download CIFAR train and test data
(X, Y), (Xtest, Ytest) = cifar10.load_data()

X = X[0:10000]
Y = Y[0:10000]

Xtest = Xtest[0:2000]
Ytest = Ytest[0:2000]

# Change data type and rescale range
X = X.astype('float32')
Xtest = Xtest.astype('float32')

X = X / 127.5 - 1
Xtest = Xtest / 127.5 - 1

# Convert labels to hot encoding
Y = to_categorical(Y, 10)

# Train-Val split
Xtrain, Xval, Ytrain, Yval = train_test_split(X, Y, test_size=0.25,
random_state=42)
Ytest = to_categorical(Ytest, 10)
```

```
[17]: from carbontracker.tracker import CarbonTracker
from utilities import build_CNN

# -----
# === Your code here =====
# -----
# Setup training parameters
batch_size = 16
epochs = 30
```

```

input_shape = (32,32,3)

# Build model (your best config)
model7 = build_CNN(
    input_shape=input_shape,
    loss=tf.keras.losses.CategoricalCrossentropy(),
    n_conv_layers=5,
    n_filters=32,
    n_dense_layers=2,
    n_nodes=128,
    use_dropout=True,
    learning_rate=0.001,
    act_fun='relu',
    optimizer='adam',
    print_summary=False
)

# Create a CarbonTracker object
tracker = CarbonTracker(epochs=epochs)

# start carbon tracking
tracker.epoch_start()

# fit model
model7.fit(
    Xtrain, Ytrain,
    batch_size=batch_size,
    epochs=epochs,
    validation_data=(Xval, Yval)
)

tracker.epoch_end()

# =====

```

CarbonTracker: The following components were found: GPU with device(s) NVIDIA RTX 4000 Ada Generation. CPU with device(s) cpu:0.

No sudo access to read Intel's RAPL measurements from the energy_uj file.

See issue: <https://github.com/lfwa/carbontracker/issues/40>

Epoch 1/30

CarbonTracker: WARNING - ElectricityMaps API key not set. Will default to average carbon intensity.

CarbonTracker: WARNING - Failed to retrieve carbon intensity: Defaulting to average carbon intensity 40.694878 gCO2/kWh.

E0000 00:00:1746535149.643249 736732 meta_optimizer.cc:966] layout failed: INVALID_ARGUMENT: Size of values 0 does not match size of permutation 4 @ fanin

shape insequential_2/dropout_5/dropout/SelectV2-2-TransposeNHWCtoNCHW-LayoutOptimizer

469/469 [=====] - 6s 9ms/step - loss: 2.5160 - accuracy: 0.2061 - val_loss: 3.3692 - val_accuracy: 0.1684

Epoch 2/30

469/469 [=====] - 4s 9ms/step - loss: 1.9715 - accuracy: 0.2795 - val_loss: 1.7655 - val_accuracy: 0.3412

Epoch 3/30

469/469 [=====] - 4s 9ms/step - loss: 1.7582 - accuracy: 0.3452 - val_loss: 1.5475 - val_accuracy: 0.4120

Epoch 4/30

469/469 [=====] - 4s 9ms/step - loss: 1.6467 - accuracy: 0.3859 - val_loss: 1.5040 - val_accuracy: 0.4332

Epoch 5/30

469/469 [=====] - 4s 8ms/step - loss: 1.5795 - accuracy: 0.4103 - val_loss: 1.3935 - val_accuracy: 0.4804

Epoch 6/30

469/469 [=====] - 4s 9ms/step - loss: 1.5138 - accuracy: 0.4509 - val_loss: 1.3345 - val_accuracy: 0.4884

Epoch 7/30

469/469 [=====] - 4s 8ms/step - loss: 1.4353 - accuracy: 0.4764 - val_loss: 1.3204 - val_accuracy: 0.5176

Epoch 8/30

469/469 [=====] - 4s 9ms/step - loss: 1.4156 - accuracy: 0.4847 - val_loss: 1.2017 - val_accuracy: 0.5676

Epoch 9/30

469/469 [=====] - 4s 8ms/step - loss: 1.3581 - accuracy: 0.5117 - val_loss: 1.2702 - val_accuracy: 0.5452

Epoch 10/30

469/469 [=====] - 4s 9ms/step - loss: 1.2973 - accuracy: 0.5304 - val_loss: 1.1804 - val_accuracy: 0.5672

Epoch 11/30

469/469 [=====] - 4s 9ms/step - loss: 1.2532 - accuracy: 0.5591 - val_loss: 1.1187 - val_accuracy: 0.5924

Epoch 12/30

469/469 [=====] - 4s 9ms/step - loss: 1.1927 - accuracy: 0.5779 - val_loss: 1.0332 - val_accuracy: 0.6288

Epoch 13/30

469/469 [=====] - 4s 9ms/step - loss: 1.1511 - accuracy: 0.5952 - val_loss: 1.0730 - val_accuracy: 0.6176

Epoch 14/30

469/469 [=====] - 4s 9ms/step - loss: 1.1181 - accuracy: 0.6063 - val_loss: 1.0170 - val_accuracy: 0.6464

Epoch 15/30

469/469 [=====] - 4s 9ms/step - loss: 1.0596 - accuracy: 0.6297 - val_loss: 1.0506 - val_accuracy: 0.6388

Epoch 16/30

469/469 [=====] - 4s 8ms/step - loss: 1.0129 - accuracy: 0.6500 - val_loss: 1.0100 - val_accuracy: 0.6400
Epoch 17/30
469/469 [=====] - 4s 8ms/step - loss: 0.9715 - accuracy: 0.6651 - val_loss: 1.0186 - val_accuracy: 0.6508
Epoch 18/30
469/469 [=====] - 4s 9ms/step - loss: 0.9227 - accuracy: 0.6780 - val_loss: 1.0542 - val_accuracy: 0.6436
Epoch 19/30
469/469 [=====] - 4s 8ms/step - loss: 0.8740 - accuracy: 0.6983 - val_loss: 0.9526 - val_accuracy: 0.6796
Epoch 20/30
469/469 [=====] - 4s 9ms/step - loss: 0.8543 - accuracy: 0.7075 - val_loss: 0.9359 - val_accuracy: 0.6744
Epoch 21/30
469/469 [=====] - 4s 9ms/step - loss: 0.7956 - accuracy: 0.7313 - val_loss: 0.9653 - val_accuracy: 0.6812
Epoch 22/30
469/469 [=====] - 4s 9ms/step - loss: 0.7560 - accuracy: 0.7431 - val_loss: 0.9640 - val_accuracy: 0.6908
Epoch 23/30
469/469 [=====] - 4s 9ms/step - loss: 0.7398 - accuracy: 0.7456 - val_loss: 0.9278 - val_accuracy: 0.6912
Epoch 24/30
469/469 [=====] - 4s 9ms/step - loss: 0.6987 - accuracy: 0.7673 - val_loss: 0.9629 - val_accuracy: 0.6944
Epoch 25/30
469/469 [=====] - 4s 8ms/step - loss: 0.6505 - accuracy: 0.7803 - val_loss: 0.9711 - val_accuracy: 0.6916
Epoch 26/30
469/469 [=====] - 4s 8ms/step - loss: 0.6251 - accuracy: 0.7876 - val_loss: 0.9128 - val_accuracy: 0.7156
Epoch 27/30
469/469 [=====] - 4s 9ms/step - loss: 0.6158 - accuracy: 0.7903 - val_loss: 0.9906 - val_accuracy: 0.6952
Epoch 28/30
469/469 [=====] - 4s 8ms/step - loss: 0.5834 - accuracy: 0.7984 - val_loss: 0.9452 - val_accuracy: 0.7100
Epoch 29/30
469/469 [=====] - 4s 8ms/step - loss: 0.5760 - accuracy: 0.8069 - val_loss: 0.9529 - val_accuracy: 0.7076
Epoch 30/30
469/469 [=====] - 4s 8ms/step - loss: 0.5304 - accuracy: 0.8271 - val_loss: 1.0738 - val_accuracy: 0.6880
CarbonTracker: WARNING - ElectricityMaps API key not set. Will default to average carbon intensity.
CarbonTracker: WARNING - Failed to retrieve carbon intensity: Defaulting to average carbon intensity 40.694878 gCO2/kWh.

CarbonTracker: Live carbon intensity could not be fetched at detected location: Linköping, Östergötland, SE. Defaulted to average carbon intensity for SE in 2023 of 40.69 gCO2/kWh. at detected location: Linköping, Östergötland, SE.

CarbonTracker:

Predicted consumption for 30 epoch(s):

Time: 1:01:34

Energy: 0.057393594142 kWh

CO2eq: 2.335625311580 g

This is equivalent to:

0.021726747084 km travelled by car

8 Part 7: Pre-trained 2D CNNs

There are many deep 2D CNNs that have been pre-trained using the large ImageNet database (several million images, 1000 classes). Import a pre-trained ResNet50 network from Keras applications. Show the network using `model.summary()`

Questions

31. How many convolutional layers does ResNet50 have?
32. How many trainable parameters does the ResNet50 network have?
33. What is the size of the images that ResNet50 expects as input?
34. Using the answer to question 30, explain why the second derivative is seldom used when training deep networks.
35. What do you expect the carbon footprint of using pre-trained networks to be compared to training a model from scratch?

Answers

31. ResNet50 has 49 convolutional layers and 1 Dense layer, making total 50 layers
32. It has 25583592 trainable parameters.
33. (224, 224, 3) is the expected input size
34. Due to the computational complexity, the second derivative is rarely use in training deep networks
35. Using a pretrained model and just fine-tuning it significantly reduces the carbon footprint compared to training it from scratch

After loading the pre-trained CNN, apply it to 5 random color images that you download and copy to the cloud machine or your own computer. Are the predictions correct? How certain is the network of each image class?

The objects were predicted clearly with 98+ probability. But the cat and dog were not because, they have subclasses in the dataset, so it had different prediction probabilities for them.

These pre-trained networks can be fine tuned to your specific data, and normally only the last layers need to be re-trained, but it will still be too time consuming to do in this elaboration.

Some useful functions: - `load_img` and `img_to_array` in `tf.keras.utils`. - `ResNet50` in `tf.keras.applications.ResNet50`. - `preprocess_input` in `tf.keras.applications.resnet`. - `decode_predictions` in `tf.keras.applications.resnet`. - `expand_dims` in `numpy`.

See `keras applications` and the `keras resnet50-function` for more details.

```
[58]: # -----
# === Your code here =====
# -----
# import the necessary libraries and functions
from tf.keras.applications import ResNet50
from tf.keras.utils import load_img, img_to_array
from tf.keras.applications.resnet import preprocess_input, decode_predictions
import numpy as np

# load the pre-trained ResNet50 model
resnet50 = ResNet50(weights='imagenet')

# print the model summary
resnet50.summary()

# load the image and preprocess it
# we used hammer.jpeg, glass.jpeg, dog.jpeg, cat.jpeg, mug.jpeg
image_path = "hammer.jpeg"
image = load_img(image_path, target_size=(224, 224))
image_array = img_to_array(image)
image_array = np.expand_dims(image_array, axis=0)
image_array = preprocess_input(image_array)

# predict the image
label = resnet50.predict(image_array)
decoded_predictions = decode_predictions(label, top=3)[0]

# print the predicted label
#print(label)
for i, (imagenet_id, label, score) in enumerate(decoded_predictions):
    print(f"{i + 1}: {label} ({score * 100:.2f}%)")

# =====
```

Model: "resnet50"

```
-----
Layer (type)                Output Shape              Param #   Connected to
=====
input_8 (InputLayer)        [(None, 224, 224, 3)]    0         []
```

conv1_pad (ZeroPadding2D) ['input_8[0][0]']	(None, 230, 230, 3)	0
conv1_conv (Conv2D) ['conv1_pad[0][0]']	(None, 112, 112, 64)	9472
conv1_bn (BatchNormalizati on) ['conv1_conv[0][0]']	(None, 112, 112, 64)	256
conv1_relu (Activation) ['conv1_bn[0][0]']	(None, 112, 112, 64)	0
pool1_pad (ZeroPadding2D) ['conv1_relu[0][0]']	(None, 114, 114, 64)	0
pool1_pool (MaxPooling2D) ['pool1_pad[0][0]']	(None, 56, 56, 64)	0
conv2_block1_1_conv (Conv2 D) ['pool1_pool[0][0]']	(None, 56, 56, 64)	4160
conv2_block1_1_bn (BatchNo rmalization) ['conv2_block1_1_conv[0][0]']	(None, 56, 56, 64)	256
conv2_block1_1_relu (Activ ation) ['conv2_block1_1_bn[0][0]']	(None, 56, 56, 64)	0
conv2_block1_2_conv (Conv2 D) ['conv2_block1_1_relu[0][0]']	(None, 56, 56, 64)	36928
conv2_block1_2_bn (BatchNo rmalization) ['conv2_block1_2_conv[0][0]']	(None, 56, 56, 64)	256
conv2_block1_2_relu (Activ ation) ['conv2_block1_2_bn[0][0]']	(None, 56, 56, 64)	0
conv2_block1_0_conv (Conv2 D) ['pool1_pool[0][0]']	(None, 56, 56, 256)	16640
conv2_block1_3_conv (Conv2	(None, 56, 56, 256)	16640

```

['conv2_block1_2_relu[0][0]']
D)

conv2_block1_0_bn (BatchNo (None, 56, 56, 256)          1024
['conv2_block1_0_conv[0][0]']
rmalization)

conv2_block1_3_bn (BatchNo (None, 56, 56, 256)          1024
['conv2_block1_3_conv[0][0]']
rmalization)

conv2_block1_add (Add)          (None, 56, 56, 256)          0
['conv2_block1_0_bn[0][0]',
'conv2_block1_3_bn[0][0]']

conv2_block1_out (Activati (None, 56, 56, 256)          0
['conv2_block1_add[0][0]']
on)

conv2_block2_1_conv (Conv2 (None, 56, 56, 64)          16448
['conv2_block1_out[0][0]']
D)

conv2_block2_1_bn (BatchNo (None, 56, 56, 64)          256
['conv2_block2_1_conv[0][0]']
rmalization)

conv2_block2_1_relu (Activ (None, 56, 56, 64)          0
['conv2_block2_1_bn[0][0]']
ation)

conv2_block2_2_conv (Conv2 (None, 56, 56, 64)          36928
['conv2_block2_1_relu[0][0]']
D)

conv2_block2_2_bn (BatchNo (None, 56, 56, 64)          256
['conv2_block2_2_conv[0][0]']
rmalization)

conv2_block2_2_relu (Activ (None, 56, 56, 64)          0
['conv2_block2_2_bn[0][0]']
ation)

conv2_block2_3_conv (Conv2 (None, 56, 56, 256)          16640
['conv2_block2_2_relu[0][0]']
D)

conv2_block2_3_bn (BatchNo (None, 56, 56, 256)          1024

```

['conv2_block2_3_conv[0][0]'] rmalization)		
conv2_block2_add (Add) ['conv2_block1_out[0][0]', 'conv2_block2_3_bn[0][0]']	(None, 56, 56, 256)	0
conv2_block2_out (Activati ['conv2_block2_add[0][0]'] on)	(None, 56, 56, 256)	0
conv2_block3_1_conv (Conv2 ['conv2_block2_out[0][0]'] D)	(None, 56, 56, 64)	16448
conv2_block3_1_bn (BatchNo ['conv2_block3_1_conv[0][0]'] rmalization)	(None, 56, 56, 64)	256
conv2_block3_1_relu (Activ ['conv2_block3_1_bn[0][0]'] ation)	(None, 56, 56, 64)	0
conv2_block3_2_conv (Conv2 ['conv2_block3_1_relu[0][0]'] D)	(None, 56, 56, 64)	36928
conv2_block3_2_bn (BatchNo ['conv2_block3_2_conv[0][0]'] rmalization)	(None, 56, 56, 64)	256
conv2_block3_2_relu (Activ ['conv2_block3_2_bn[0][0]'] ation)	(None, 56, 56, 64)	0
conv2_block3_3_conv (Conv2 ['conv2_block3_2_relu[0][0]'] D)	(None, 56, 56, 256)	16640
conv2_block3_3_bn (BatchNo ['conv2_block3_3_conv[0][0]'] rmalization)	(None, 56, 56, 256)	1024
conv2_block3_add (Add) ['conv2_block2_out[0][0]', 'conv2_block3_3_bn[0][0]']	(None, 56, 56, 256)	0
conv2_block3_out (Activati	(None, 56, 56, 256)	0

['conv2_block3_add[0][0]'] on)		
conv3_block1_1_conv (Conv2 (None, 28, 28, 128) ['conv2_block3_out[0][0]'] D)		32896
conv3_block1_1_bn (BatchNo (None, 28, 28, 128) ['conv3_block1_1_conv[0][0]'] rmalization)		512
conv3_block1_1_relu (Activ (None, 28, 28, 128) ['conv3_block1_1_bn[0][0]'] ation)		0
conv3_block1_2_conv (Conv2 (None, 28, 28, 128) ['conv3_block1_1_relu[0][0]'] D)		147584
conv3_block1_2_bn (BatchNo (None, 28, 28, 128) ['conv3_block1_2_conv[0][0]'] rmalization)		512
conv3_block1_2_relu (Activ (None, 28, 28, 128) ['conv3_block1_2_bn[0][0]'] ation)		0
conv3_block1_0_conv (Conv2 (None, 28, 28, 512) ['conv2_block3_out[0][0]'] D)		131584
conv3_block1_3_conv (Conv2 (None, 28, 28, 512) ['conv3_block1_2_relu[0][0]'] D)		66048
conv3_block1_0_bn (BatchNo (None, 28, 28, 512) ['conv3_block1_0_conv[0][0]'] rmalization)		2048
conv3_block1_3_bn (BatchNo (None, 28, 28, 512) ['conv3_block1_3_conv[0][0]'] rmalization)		2048
conv3_block1_add (Add) (None, 28, 28, 512) ['conv3_block1_0_bn[0][0]', 'conv3_block1_3_bn[0][0]']		0
conv3_block1_out (Activati (None, 28, 28, 512)		0

['conv3_block1_add[0][0]'] on)		
conv3_block2_1_conv (Conv2 (None, 28, 28, 128) ['conv3_block1_out[0][0]'] D)		65664
conv3_block2_1_bn (BatchNo (None, 28, 28, 128) ['conv3_block2_1_conv[0][0]'] rmalization)		512
conv3_block2_1_relu (Activ (None, 28, 28, 128) ['conv3_block2_1_bn[0][0]'] ation)		0
conv3_block2_2_conv (Conv2 (None, 28, 28, 128) ['conv3_block2_1_relu[0][0]'] D)		147584
conv3_block2_2_bn (BatchNo (None, 28, 28, 128) ['conv3_block2_2_conv[0][0]'] rmalization)		512
conv3_block2_2_relu (Activ (None, 28, 28, 128) ['conv3_block2_2_bn[0][0]'] ation)		0
conv3_block2_3_conv (Conv2 (None, 28, 28, 512) ['conv3_block2_2_relu[0][0]'] D)		66048
conv3_block2_3_bn (BatchNo (None, 28, 28, 512) ['conv3_block2_3_conv[0][0]'] rmalization)		2048
conv3_block2_add (Add) (None, 28, 28, 512) ['conv3_block1_out[0][0]', 'conv3_block2_3_bn[0][0]']		0
conv3_block2_out (Activati (None, 28, 28, 512) ['conv3_block2_add[0][0]'] on)		0
conv3_block3_1_conv (Conv2 (None, 28, 28, 128) ['conv3_block2_out[0][0]'] D)		65664
conv3_block3_1_bn (BatchNo (None, 28, 28, 128)		512

['conv3_block3_1_conv[0][0]'] rmalization)		
conv3_block3_1_relu (Activ (None, 28, 28, 128) ['conv3_block3_1_bn[0][0]'] ation)		0
conv3_block3_2_conv (Conv2 (None, 28, 28, 128) ['conv3_block3_1_relu[0][0]'] D)		147584
conv3_block3_2_bn (BatchNo (None, 28, 28, 128) ['conv3_block3_2_conv[0][0]'] rmalization)		512
conv3_block3_2_relu (Activ (None, 28, 28, 128) ['conv3_block3_2_bn[0][0]'] ation)		0
conv3_block3_3_conv (Conv2 (None, 28, 28, 512) ['conv3_block3_2_relu[0][0]'] D)		66048
conv3_block3_3_bn (BatchNo (None, 28, 28, 512) ['conv3_block3_3_conv[0][0]'] rmalization)		2048
conv3_block3_add (Add) (None, 28, 28, 512) ['conv3_block2_out[0][0]', 'conv3_block3_3_bn[0][0]']		0
conv3_block3_out (Activati (None, 28, 28, 512) ['conv3_block3_add[0][0]'] on)		0
conv3_block4_1_conv (Conv2 (None, 28, 28, 128) ['conv3_block3_out[0][0]'] D)		65664
conv3_block4_1_bn (BatchNo (None, 28, 28, 128) ['conv3_block4_1_conv[0][0]'] rmalization)		512
conv3_block4_1_relu (Activ (None, 28, 28, 128) ['conv3_block4_1_bn[0][0]'] ation)		0
conv3_block4_2_conv (Conv2 (None, 28, 28, 128)		147584

['conv3_block4_1_relu[0][0]'] D)		
conv3_block4_2_bn (BatchNo (None, 28, 28, 128) ['conv3_block4_2_conv[0][0]'] rmalization)		512
conv3_block4_2_relu (Activ (None, 28, 28, 128) ['conv3_block4_2_bn[0][0]'] ation)		0
conv3_block4_3_conv (Conv2 (None, 28, 28, 512) ['conv3_block4_2_relu[0][0]'] D)		66048
conv3_block4_3_bn (BatchNo (None, 28, 28, 512) ['conv3_block4_3_conv[0][0]'] rmalization)		2048
conv3_block4_add (Add) (None, 28, 28, 512) ['conv3_block3_out[0][0]', 'conv3_block4_3_bn[0][0]']		0
conv3_block4_out (Activati (None, 28, 28, 512) ['conv3_block4_add[0][0]'] on)		0
conv4_block1_1_conv (Conv2 (None, 14, 14, 256) ['conv3_block4_out[0][0]'] D)		131328
conv4_block1_1_bn (BatchNo (None, 14, 14, 256) ['conv4_block1_1_conv[0][0]'] rmalization)		1024
conv4_block1_1_relu (Activ (None, 14, 14, 256) ['conv4_block1_1_bn[0][0]'] ation)		0
conv4_block1_2_conv (Conv2 (None, 14, 14, 256) ['conv4_block1_1_relu[0][0]'] D)		590080
conv4_block1_2_bn (BatchNo (None, 14, 14, 256) ['conv4_block1_2_conv[0][0]'] rmalization)		1024
conv4_block1_2_relu (Activ (None, 14, 14, 256)		0

['conv4_block1_2_bn[0][0]'] ation)		
conv4_block1_0_conv (Conv2 (None, 14, 14, 1024) ['conv3_block4_out[0][0]'] D)		525312
conv4_block1_3_conv (Conv2 (None, 14, 14, 1024) ['conv4_block1_2_relu[0][0]'] D)		263168
conv4_block1_0_bn (BatchNo (None, 14, 14, 1024) ['conv4_block1_0_conv[0][0]'] rmalization)		4096
conv4_block1_3_bn (BatchNo (None, 14, 14, 1024) ['conv4_block1_3_conv[0][0]'] rmalization)		4096
conv4_block1_add (Add) (None, 14, 14, 1024) ['conv4_block1_0_bn[0][0]', 'conv4_block1_3_bn[0][0]']		0
conv4_block1_out (Activati (None, 14, 14, 1024) ['conv4_block1_add[0][0]'] on)		0
conv4_block2_1_conv (Conv2 (None, 14, 14, 256) ['conv4_block1_out[0][0]'] D)		262400
conv4_block2_1_bn (BatchNo (None, 14, 14, 256) ['conv4_block2_1_conv[0][0]'] rmalization)		1024
conv4_block2_1_relu (Activ (None, 14, 14, 256) ['conv4_block2_1_bn[0][0]'] ation)		0
conv4_block2_2_conv (Conv2 (None, 14, 14, 256) ['conv4_block2_1_relu[0][0]'] D)		590080
conv4_block2_2_bn (BatchNo (None, 14, 14, 256) ['conv4_block2_2_conv[0][0]'] rmalization)		1024
conv4_block2_2_relu (Activ (None, 14, 14, 256)		0

['conv4_block2_2_bn[0][0]'] ation)	
conv4_block2_3_conv (Conv2 (None, 14, 14, 1024) ['conv4_block2_2_relu[0][0]'] D)	263168
conv4_block2_3_bn (BatchNo (None, 14, 14, 1024) ['conv4_block2_3_conv[0][0]'] rmalization)	4096
conv4_block2_add (Add) (None, 14, 14, 1024) ['conv4_block1_out[0][0]', 'conv4_block2_3_bn[0][0]']	0
conv4_block2_out (Activati (None, 14, 14, 1024) ['conv4_block2_add[0][0]'] on)	0
conv4_block3_1_conv (Conv2 (None, 14, 14, 256) ['conv4_block2_out[0][0]'] D)	262400
conv4_block3_1_bn (BatchNo (None, 14, 14, 256) ['conv4_block3_1_conv[0][0]'] rmalization)	1024
conv4_block3_1_relu (Activ (None, 14, 14, 256) ['conv4_block3_1_bn[0][0]'] ation)	0
conv4_block3_2_conv (Conv2 (None, 14, 14, 256) ['conv4_block3_1_relu[0][0]'] D)	590080
conv4_block3_2_bn (BatchNo (None, 14, 14, 256) ['conv4_block3_2_conv[0][0]'] rmalization)	1024
conv4_block3_2_relu (Activ (None, 14, 14, 256) ['conv4_block3_2_bn[0][0]'] ation)	0
conv4_block3_3_conv (Conv2 (None, 14, 14, 1024) ['conv4_block3_2_relu[0][0]'] D)	263168
conv4_block3_3_bn (BatchNo (None, 14, 14, 1024)	4096

['conv4_block3_3_conv[0][0]'] rmalization)		
conv4_block3_add (Add) ['conv4_block2_out[0][0]', 'conv4_block3_3_bn[0][0]']	(None, 14, 14, 1024)	0
conv4_block3_out (Activati ['conv4_block3_add[0][0]'] on)	(None, 14, 14, 1024)	0
conv4_block4_1_conv (Conv2 ['conv4_block3_out[0][0]'] D)	(None, 14, 14, 256)	262400
conv4_block4_1_bn (BatchNo ['conv4_block4_1_conv[0][0]'] rmalization)	(None, 14, 14, 256)	1024
conv4_block4_1_relu (Activ ['conv4_block4_1_bn[0][0]'] ation)	(None, 14, 14, 256)	0
conv4_block4_2_conv (Conv2 ['conv4_block4_1_relu[0][0]'] D)	(None, 14, 14, 256)	590080
conv4_block4_2_bn (BatchNo ['conv4_block4_2_conv[0][0]'] rmalization)	(None, 14, 14, 256)	1024
conv4_block4_2_relu (Activ ['conv4_block4_2_bn[0][0]'] ation)	(None, 14, 14, 256)	0
conv4_block4_3_conv (Conv2 ['conv4_block4_2_relu[0][0]'] D)	(None, 14, 14, 1024)	263168
conv4_block4_3_bn (BatchNo ['conv4_block4_3_conv[0][0]'] rmalization)	(None, 14, 14, 1024)	4096
conv4_block4_add (Add) ['conv4_block3_out[0][0]', 'conv4_block4_3_bn[0][0]']	(None, 14, 14, 1024)	0
conv4_block4_out (Activati (None, 14, 14, 1024)		0

['conv4_block4_add[0][0]'] on)		
conv4_block5_1_conv (Conv2 (None, 14, 14, 256) ['conv4_block4_out[0][0]'] D)		262400
conv4_block5_1_bn (BatchNo (None, 14, 14, 256) ['conv4_block5_1_conv[0][0]'] rmalization)		1024
conv4_block5_1_relu (Activ (None, 14, 14, 256) ['conv4_block5_1_bn[0][0]'] ation)		0
conv4_block5_2_conv (Conv2 (None, 14, 14, 256) ['conv4_block5_1_relu[0][0]'] D)		590080
conv4_block5_2_bn (BatchNo (None, 14, 14, 256) ['conv4_block5_2_conv[0][0]'] rmalization)		1024
conv4_block5_2_relu (Activ (None, 14, 14, 256) ['conv4_block5_2_bn[0][0]'] ation)		0
conv4_block5_3_conv (Conv2 (None, 14, 14, 1024) ['conv4_block5_2_relu[0][0]'] D)		263168
conv4_block5_3_bn (BatchNo (None, 14, 14, 1024) ['conv4_block5_3_conv[0][0]'] rmalization)		4096
conv4_block5_add (Add) (None, 14, 14, 1024) ['conv4_block4_out[0][0]', 'conv4_block5_3_bn[0][0]']		0
conv4_block5_out (Activati (None, 14, 14, 1024) ['conv4_block5_add[0][0]'] on)		0
conv4_block6_1_conv (Conv2 (None, 14, 14, 256) ['conv4_block5_out[0][0]'] D)		262400
conv4_block6_1_bn (BatchNo (None, 14, 14, 256)		1024

['conv4_block6_1_conv[0][0]'] rmalization)		
conv4_block6_1_relu (Activ (None, 14, 14, 256) ['conv4_block6_1_bn[0][0]'] ation)		0
conv4_block6_2_conv (Conv2 (None, 14, 14, 256) ['conv4_block6_1_relu[0][0]'] D)		590080
conv4_block6_2_bn (BatchNo (None, 14, 14, 256) ['conv4_block6_2_conv[0][0]'] rmalization)		1024
conv4_block6_2_relu (Activ (None, 14, 14, 256) ['conv4_block6_2_bn[0][0]'] ation)		0
conv4_block6_3_conv (Conv2 (None, 14, 14, 1024) ['conv4_block6_2_relu[0][0]'] D)		263168
conv4_block6_3_bn (BatchNo (None, 14, 14, 1024) ['conv4_block6_3_conv[0][0]'] rmalization)		4096
conv4_block6_add (Add) (None, 14, 14, 1024) ['conv4_block5_out[0][0]', 'conv4_block6_3_bn[0][0]']		0
conv4_block6_out (Activati (None, 14, 14, 1024) ['conv4_block6_add[0][0]'] on)		0
conv5_block1_1_conv (Conv2 (None, 7, 7, 512) ['conv4_block6_out[0][0]'] D)		524800
conv5_block1_1_bn (BatchNo (None, 7, 7, 512) ['conv5_block1_1_conv[0][0]'] rmalization)		2048
conv5_block1_1_relu (Activ (None, 7, 7, 512) ['conv5_block1_1_bn[0][0]'] ation)		0
conv5_block1_2_conv (Conv2 (None, 7, 7, 512)		2359808

['conv5_block1_1_relu[0][0]'] D)	
conv5_block1_2_bn (BatchNo (None, 7, 7, 512) ['conv5_block1_2_conv[0][0]'] rmalization)	2048
conv5_block1_2_relu (Activ (None, 7, 7, 512) ['conv5_block1_2_bn[0][0]'] ation)	0
conv5_block1_0_conv (Conv2 (None, 7, 7, 2048) ['conv4_block6_out[0][0]'] D)	2099200
conv5_block1_3_conv (Conv2 (None, 7, 7, 2048) ['conv5_block1_2_relu[0][0]'] D)	1050624
conv5_block1_0_bn (BatchNo (None, 7, 7, 2048) ['conv5_block1_0_conv[0][0]'] rmalization)	8192
conv5_block1_3_bn (BatchNo (None, 7, 7, 2048) ['conv5_block1_3_conv[0][0]'] rmalization)	8192
conv5_block1_add (Add) (None, 7, 7, 2048) ['conv5_block1_0_bn[0][0]', 'conv5_block1_3_bn[0][0]']	0
conv5_block1_out (Activati (None, 7, 7, 2048) ['conv5_block1_add[0][0]'] on)	0
conv5_block2_1_conv (Conv2 (None, 7, 7, 512) ['conv5_block1_out[0][0]'] D)	1049088
conv5_block2_1_bn (BatchNo (None, 7, 7, 512) ['conv5_block2_1_conv[0][0]'] rmalization)	2048
conv5_block2_1_relu (Activ (None, 7, 7, 512) ['conv5_block2_1_bn[0][0]'] ation)	0
conv5_block2_2_conv (Conv2 (None, 7, 7, 512)	2359808

['conv5_block2_1_relu[0][0]'] D)	
conv5_block2_2_bn (BatchNo (None, 7, 7, 512) ['conv5_block2_2_conv[0][0]'] rmalization)	2048
conv5_block2_2_relu (Activ (None, 7, 7, 512) ['conv5_block2_2_bn[0][0]'] ation)	0
conv5_block2_3_conv (Conv2 (None, 7, 7, 2048) ['conv5_block2_2_relu[0][0]'] D)	1050624
conv5_block2_3_bn (BatchNo (None, 7, 7, 2048) ['conv5_block2_3_conv[0][0]'] rmalization)	8192
conv5_block2_add (Add) (None, 7, 7, 2048) ['conv5_block1_out[0][0]', 'conv5_block2_3_bn[0][0]']	0
conv5_block2_out (Activati (None, 7, 7, 2048) ['conv5_block2_add[0][0]'] on)	0
conv5_block3_1_conv (Conv2 (None, 7, 7, 512) ['conv5_block2_out[0][0]'] D)	1049088
conv5_block3_1_bn (BatchNo (None, 7, 7, 512) ['conv5_block3_1_conv[0][0]'] rmalization)	2048
conv5_block3_1_relu (Activ (None, 7, 7, 512) ['conv5_block3_1_bn[0][0]'] ation)	0
conv5_block3_2_conv (Conv2 (None, 7, 7, 512) ['conv5_block3_1_relu[0][0]'] D)	2359808
conv5_block3_2_bn (BatchNo (None, 7, 7, 512) ['conv5_block3_2_conv[0][0]'] rmalization)	2048
conv5_block3_2_relu (Activ (None, 7, 7, 512)	0

```

['conv5_block3_2_bn[0][0]']
ation)

conv5_block3_3_conv (Conv2 (None, 7, 7, 2048)      1050624
['conv5_block3_2_relu[0][0]']
D)

conv5_block3_3_bn (BatchNo (None, 7, 7, 2048)      8192
['conv5_block3_3_conv[0][0]']
rmalization)

conv5_block3_add (Add) (None, 7, 7, 2048)          0
['conv5_block2_out[0][0]',
'conv5_block3_3_bn[0][0]']

conv5_block3_out (Activati (None, 7, 7, 2048)      0
['conv5_block3_add[0][0]']
on)

avg_pool (GlobalAveragePoo (None, 2048)           0
['conv5_block3_out[0][0]']
ling2D)

predictions (Dense) (None, 1000)                 2049000
['avg_pool[0][0]']

```

```

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```

Total params: 25636712 (97.80 MB)
Trainable params: 25583592 (97.59 MB)
Non-trainable params: 53120 (207.50 KB)

```

```

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```

```

1/1 [=====] - 1s 1s/step
1: hammer (87.70%)
2: nail (10.18%)
3: hatchet (0.77%)

```

9 Part 8 (OPTIONAL)

Set up Ray Tune and run automatic hyper parameter optimization for the CNN model as we have done in the DNN lab. Remember that you have to define the `train_CNN` function, specify the hyper parameter search space and the number of samples to evaluate, among other.

[]: