

# Image Classifier Project

February 9, 2019

## 1 Developing an AI application

Going forward, AI algorithms will be incorporated into more and more everyday applications. For example, you might want to include an image classifier in a smart phone app. To do this, you'd use a deep learning model trained on hundreds of thousands of images as part of the overall application architecture. A large part of software development in the future will be using these types of models as common parts of applications.

In this project, you'll train an image classifier to recognize different species of flowers. You can imagine using something like this in a phone app that tells you the name of the flower your camera is looking at. In practice you'd train this classifier, then export it for use in your application. We'll be using [this dataset](#) of 102 flower categories, you can see a few examples below.

The project is broken down into multiple steps:

- Load and preprocess the image dataset
- Train the image classifier on your dataset
- Use the trained classifier to predict image content

We'll lead you through each part which you'll implement in Python.

When you've completed this project, you'll have an application that can be trained on any set of labeled images. Here your network will be learning about flowers and end up as a command line application. But, what you do with your new skills depends on your imagination and effort in building a dataset. For example, imagine an app where you take a picture of a car, it tells you what the make and model is, then looks up information about it. Go build your own dataset and make something new.

First up is importing the packages you'll need. It's good practice to keep all the imports at the beginning of your code. As you work through this notebook and find you need to import a package, make sure to add the import up here.

Please make sure if you are running this notebook in the workspace that you have chosen GPU rather than CPU mode.

```
In [77]: # Imports here
import torch
import numpy as np
from torchvision import datasets, transforms, models
from torch import nn, optim
import torch.nn.functional as F
import matplotlib.pyplot as plt
import seaborn as sns
```

## 1.1 Load the data

Here you'll use `torchvision` to load the data ([documentation](#)). The data should be included alongside this notebook, otherwise you can [download it here](#). The dataset is split into three parts, training, validation, and testing. For the training, you'll want to apply transformations such as random scaling, cropping, and flipping. This will help the network generalize leading to better performance. You'll also need to make sure the input data is resized to 224x224 pixels as required by the pre-trained networks.

The validation and testing sets are used to measure the model's performance on data it hasn't seen yet. For this you don't want any scaling or rotation transformations, but you'll need to resize then crop the images to the appropriate size.

The pre-trained networks you'll use were trained on the ImageNet dataset where each color channel was normalized separately. For all three sets you'll need to normalize the means and standard deviations of the images to what the network expects. For the means, it's [0.485, 0.456, 0.406] and for the standard deviations [0.229, 0.224, 0.225], calculated from the ImageNet images. These values will shift each color channel to be centered at 0 and range from -1 to 1.

```
In [78]: data_dir = 'flowers'
        train_dir = data_dir + '/train'
        valid_dir = data_dir + '/valid'
        test_dir = data_dir + '/test'

In [79]: # TODO: Define your transforms for the training, validation, and testing sets
        # Transforms for training includes random rotations, flips and normalisations
        train_transforms = transforms.Compose([transforms.RandomRotation(30),
                                              transforms.RandomResizedCrop(224),
                                              transforms.RandomHorizontalFlip(),
                                              transforms.ToTensor(),
                                              transforms.Normalize([0.485, 0.456, 0.406],
                                                                  [0.229, 0.224, 0.225])])

        # Transforms for validation
        validation_transforms = transforms.Compose([transforms.Resize(255),
                                                  transforms.CenterCrop(224),
                                                  transforms.ToTensor(),
                                                  transforms.Normalize([0.485, 0.456, 0.406],
                                                                      [0.229, 0.224, 0.225])])

        # Transforms for testing
        test_transforms = transforms.Compose([transforms.Resize(255),
                                              transforms.CenterCrop(224),
                                              transforms.ToTensor(),
                                              transforms.Normalize([0.485, 0.456, 0.406],
                                                                  [0.229, 0.224, 0.225])])

        # data_transforms =

        # TODO: Load the datasets with ImageFolder
        # datasets =
```

```

train_data = datasets.ImageFolder(train_dir, transform = train_transforms)
valid_data = datasets.ImageFolder(valid_dir, transform = validation_transforms)
test_data = datasets.ImageFolder(test_dir, transform = test_transforms)

# TODO: Using the image datasets and the trainforms, define the dataloaders
# dataloaders =
trainloader = torch.utils.data.DataLoader(train_data, batch_size = 64, shuffle = True)
validloader = torch.utils.data.DataLoader(valid_data, batch_size = 32, shuffle = True)
testloader = torch.utils.data.DataLoader(test_data, batch_size = 32, shuffle = True)

```

### 1.1.1 Label mapping

You'll also need to load in a mapping from category label to category name. You can find this in the file `cat_to_name.json`. It's a JSON object which you can read in with the [json module](#). This will give you a dictionary mapping the integer encoded categories to the actual names of the flowers.

```

In [80]: import json

        with open('cat_to_name.json', 'r') as f:
            cat_to_name = json.load(f)

In [81]: # Find the number of categories that we are working with
        # This will represent the number of nodes in our output layer
        len(cat_to_name)

Out[81]: 102

```

## 2 Building and training the classifier

Now that the data is ready, it's time to build and train the classifier. As usual, you should use one of the pretrained models from `torchvision.models` to get the image features. Build and train a new feed-forward classifier using those features.

We're going to leave this part up to you. Refer to [the rubric](#) for guidance on successfully completing this section. Things you'll need to do:

- Load a [pre-trained network](#) (If you need a starting point, the VGG networks work great and are straightforward to use)
- Define a new, untrained feed-forward network as a classifier, using ReLU activations and dropout
- Train the classifier layers using backpropagation using the pre-trained network to get the features
- Track the loss and accuracy on the validation set to determine the best hyperparameters

We've left a cell open for you below, but use as many as you need. Our advice is to break the problem up into smaller parts you can run separately. Check that each part is doing what you expect, then move on to the next. You'll likely find that as you work through each part, you'll need to go back and modify your previous code. This is totally normal!

When training make sure you're updating only the weights of the feed-forward network. You should be able to get the validation accuracy above 70% if you build everything right. Make sure to try different hyperparameters (learning rate, units in the classifier, epochs, etc) to find the best model. Save those hyperparameters to use as default values in the next part of the project.

One last important tip if you're using the workspace to run your code: To avoid having your workspace disconnect during the long-running tasks in this notebook, please read in the earlier page in this lesson called Intro to GPU Workspaces about Keeping Your Session Active. You'll want to include code from the `workspace_utils.py` module.

```
In [82]: # TODO: Build and train your network
# Load an initial pre-trained model - VGG
#model = models.vgg16(pretrained = True)
model = models.densenet121(pretrained = True)
model
```

```
/opt/conda/lib/python3.6/site-packages/torchvision-0.2.1-py3.6.egg/torchvision/models/densenet.py
    nn.init.kaiming_normal(m.weight.data)
```

```
Out[82]: DenseNet(
  (features): Sequential(
    (conv0): Conv2d(3, 64, kernel_size=(7, 7), stride=(2, 2), padding=(3, 3), bias=False)
    (norm0): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu0): ReLU(inplace)
    (pool0): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ceil_mode=False)
    (denseblock1): _DenseBlock(
      (denselayer1): _DenseLayer(
        (norm1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu1): ReLU(inplace)
        (conv1): Conv2d(64, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=False)
      )
      (denselayer2): _DenseLayer(
        (norm1): BatchNorm2d(96, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu1): ReLU(inplace)
        (conv1): Conv2d(96, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=False)
      )
      (denselayer3): _DenseLayer(
        (norm1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu1): ReLU(inplace)
        (conv1): Conv2d(128, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
        (relu2): ReLU(inplace)
```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer4): _DenseLayer(
        (norm1): BatchNorm2d(160, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(160, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer5): _DenseLayer(
        (norm1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(192, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer6): _DenseLayer(
        (norm1): BatchNorm2d(224, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(224, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    )
    (transition1): _Transition(
        (norm): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_running_stat
        (relu): ReLU(inplace)
        (conv): Conv2d(256, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (pool): AvgPool2d(kernel_size=2, stride=2, padding=0)
    )
    (denseblock2): _DenseBlock(
        (denselayer1): _DenseLayer(
            (norm1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu1): ReLU(inplace)
            (conv1): Conv2d(128, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu2): ReLU(inplace)
            (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
        )
        (denselayer2): _DenseLayer(
            (norm1): BatchNorm2d(160, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu1): ReLU(inplace)
            (conv1): Conv2d(160, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer3): _DenseLayer(
        (norm1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(192, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer4): _DenseLayer(
        (norm1): BatchNorm2d(224, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(224, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer5): _DenseLayer(
        (norm1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(256, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer6): _DenseLayer(
        (norm1): BatchNorm2d(288, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(288, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer7): _DenseLayer(
        (norm1): BatchNorm2d(320, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(320, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer8): _DenseLayer(
        (norm1): BatchNorm2d(352, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(352, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer9): _DenseLayer(
        (norm1): BatchNorm2d(384, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(384, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer10): _DenseLayer(
        (norm1): BatchNorm2d(416, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(416, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer11): _DenseLayer(
        (norm1): BatchNorm2d(448, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(448, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer12): _DenseLayer(
        (norm1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(480, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    )
    (transition2): _Transition(
        (norm): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_running_stat
        (relu): ReLU(inplace)
        (conv): Conv2d(512, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (pool): AvgPool2d(kernel_size=2, stride=2, padding=0)
    )
    (denseblock3): _DenseBlock(
        (denselayer1): _DenseLayer(
            (norm1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu1): ReLU(inplace)
            (conv1): Conv2d(256, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
            (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer2): _DenseLayer(
        (norm1): BatchNorm2d(288, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(288, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer3): _DenseLayer(
        (norm1): BatchNorm2d(320, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(320, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer4): _DenseLayer(
        (norm1): BatchNorm2d(352, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(352, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer5): _DenseLayer(
        (norm1): BatchNorm2d(384, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(384, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer6): _DenseLayer(
        (norm1): BatchNorm2d(416, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(416, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer7): _DenseLayer(
        (norm1): BatchNorm2d(448, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(448, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)

```



```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
(denselayer8): _DenseLayer(
  (norm1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(480, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer9): _DenseLayer(
  (norm1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(512, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer10): _DenseLayer(
  (norm1): BatchNorm2d(544, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(544, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer11): _DenseLayer(
  (norm1): BatchNorm2d(576, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(576, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer12): _DenseLayer(
  (norm1): BatchNorm2d(608, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(608, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer13): _DenseLayer(
  (norm1): BatchNorm2d(640, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(640, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
(denselayer14): _DenseLayer(
  (norm1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(672, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer15): _DenseLayer(
  (norm1): BatchNorm2d(704, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(704, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer16): _DenseLayer(
  (norm1): BatchNorm2d(736, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(736, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer17): _DenseLayer(
  (norm1): BatchNorm2d(768, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(768, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer18): _DenseLayer(
  (norm1): BatchNorm2d(800, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(800, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)
  (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
)
(denselayer19): _DenseLayer(
  (norm1): BatchNorm2d(832, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu1): ReLU(inplace)
  (conv1): Conv2d(832, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
  (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer20): _DenseLayer(
        (norm1): BatchNorm2d(864, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(864, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer21): _DenseLayer(
        (norm1): BatchNorm2d(896, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(896, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer22): _DenseLayer(
        (norm1): BatchNorm2d(928, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(928, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer23): _DenseLayer(
        (norm1): BatchNorm2d(960, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(960, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer24): _DenseLayer(
        (norm1): BatchNorm2d(992, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(992, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    )
    (transition3): _Transition(
        (norm): BatchNorm2d(1024, eps=1e-05, momentum=0.1, affine=True, track_running_sta
        (relu): ReLU(inplace)
        (conv): Conv2d(1024, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (pool): AvgPool2d(kernel_size=2, stride=2, padding=0)

```

```

)
(denseblock4): _DenseBlock(
  (denselayer1): _DenseLayer(
    (norm1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(512, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)
    (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
  )
  (denselayer2): _DenseLayer(
    (norm1): BatchNorm2d(544, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(544, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)
    (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
  )
  (denselayer3): _DenseLayer(
    (norm1): BatchNorm2d(576, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(576, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)
    (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
  )
  (denselayer4): _DenseLayer(
    (norm1): BatchNorm2d(608, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(608, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)
    (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
  )
  (denselayer5): _DenseLayer(
    (norm1): BatchNorm2d(640, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(640, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)
    (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
  )
  (denselayer6): _DenseLayer(
    (norm1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu1): ReLU(inplace=True)
    (conv1): Conv2d(672, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
    (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
    (relu2): ReLU(inplace=True)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias
    )
    (denselayer7): _DenseLayer(
        (norm1): BatchNorm2d(704, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(704, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer8): _DenseLayer(
        (norm1): BatchNorm2d(736, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(736, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer9): _DenseLayer(
        (norm1): BatchNorm2d(768, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(768, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer10): _DenseLayer(
        (norm1): BatchNorm2d(800, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(800, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer11): _DenseLayer(
        (norm1): BatchNorm2d(832, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(832, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)
        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
    )
    (denselayer12): _DenseLayer(
        (norm1): BatchNorm2d(864, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu1): ReLU(inplace)
        (conv1): Conv2d(864, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_s
        (relu2): ReLU(inplace)

```

```

        (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
    )
    (denselayer13): _DenseLayer(
      (norm1): BatchNorm2d(896, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu1): ReLU(inplace)
      (conv1): Conv2d(896, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
      (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu2): ReLU(inplace)
      (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
    )
    (denselayer14): _DenseLayer(
      (norm1): BatchNorm2d(928, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu1): ReLU(inplace)
      (conv1): Conv2d(928, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
      (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu2): ReLU(inplace)
      (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
    )
    (denselayer15): _DenseLayer(
      (norm1): BatchNorm2d(960, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu1): ReLU(inplace)
      (conv1): Conv2d(960, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
      (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu2): ReLU(inplace)
      (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
    )
    (denselayer16): _DenseLayer(
      (norm1): BatchNorm2d(992, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu1): ReLU(inplace)
      (conv1): Conv2d(992, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
      (norm2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
      (relu2): ReLU(inplace)
      (conv2): Conv2d(128, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=True)
    )
  )
  (norm5): BatchNorm2d(1024, eps=1e-05, momentum=0.1, affine=True, track_running_stats=True)
)
(classifier): Linear(in_features=1024, out_features=1000, bias=True)
)

```

```

In [83]: #images = next(iter(trainloader))[0]
         #images_flat = images.view(images.shape[0], -1)
         #images_flat.shape

```

```

In [84]: for param in model.parameters():
         param.requires_grad = False

```

```

class Classifier(nn.Module):

```

```

def __init__(self):
    super().__init__()

    # Note the change of input size depending on pre trained classifier
    # self.fc1 = nn.Linear(25088, 128)
    self.fc1 = nn.Linear(1024, 256)
    self.fc2 = nn.Linear(256, 102)

    # Set the dropout rate for during training
    self.dropout = nn.Dropout(p=0.5)

def forward(self, x):
    # We can flatten the tensor in this section of the classifier
    x = x.view(x.shape[0], -1)

    x = self.dropout(F.relu(self.fc1(x)))

    # No dropout for the output
    x = F.log_softmax(self.fc2(x), dim=1)

    return x

# Set the classifier
our_classifier = Classifier()

# View the forward structure of our classifier that we have created
our_classifier.forward

```

```

Out[84]: <bound method Classifier.forward of Classifier(
  (fc1): Linear(in_features=1024, out_features=256, bias=True)
  (fc2): Linear(in_features=256, out_features=102, bias=True)
  (dropout): Dropout(p=0.5)
)>

```

```

In [85]: # Assign our classifier to the model
model.classifier = our_classifier

```

```

In [86]: # Dynamically set to use the GPU
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

# Define the loss function
criterion = nn.NLLLoss()

# Only train the classifier parameters, feature parameters are frozen
optimiser = optim.Adam(model.classifier.parameters(), lr = 0.001)

# Make sure that the model is available on the device
model.to(device);

```

```
In [87]: # Check that the classifier has successfully been applied to the model
        model.classifier
```

```
Out[87]: Classifier(
  (fc1): Linear(in_features=1024, out_features=256, bias=True)
  (fc2): Linear(in_features=256, out_features=102, bias=True)
  (dropout): Dropout(p=0.5)
)
```

```
In [88]: # Check the device type
        device
```

```
Out[88]: device(type='cuda')
```

```
In [89]: # Define training variables
        epochs = 6
        steps = 0
```

```
        # Having a higher print_every means that there are more images trained per print statement
        # Represents how many batches we should train before each validation check
        print_every = 32
```

```
In [92]: print('Training start\n')
```

```
        # Loop through each epoch for training
        for epoch in range(epochs):
            running_loss = 0
```

```
            # Go through the training batches
            for inputs_1, labels_1 in trainloader:
                # Update the steps progress
                steps += 1
```

```
            # Move input and label tensors to the default device so they are available
            inputs_1, labels_1 = inputs_1.to(device), labels_1.to(device)
```

```
            optimiser.zero_grad()
```

```
            outputs = model.forward(inputs_1)
            loss = criterion(outputs, labels_1)
```

```
            # Update the gradients
            loss.backward()
            optimiser.step()
```

```
            running_loss += loss.item()
```

```
            # Only print every n steps
            if steps % print_every == 0:
```



```

# Turn off the dropout for the validation phase so that all inputs are used
model.eval()

validation_loss = 0
accuracy = 0

with torch.no_grad():
    for inputs_2, labels_2 in validloader:
        optimiser.zero_grad()

        # Move the validation examples to the relevant device
        inputs_2, labels_2 = inputs_2.to(device), labels_2.to(device)
        model.to(device)

        # Get the outputs from the model
        outputs_2 = model.forward(inputs_2)

        # Calculate the loss
        batch_loss = criterion(outputs_2, labels_2)
        validation_loss += batch_loss.item()

        # Find the probabilities
        ps = torch.exp(outputs_2)

        # Get the top result
        top_p, top_class = ps.topk(1, dim=1)

        # Calculate accuracy
        equals = top_class == labels_2.view(*top_class.shape)

        accuracy += torch.mean(equals.type(torch.FloatTensor)).item()

print(f"Epoch: {epoch+1}/{epochs} - "
      f"Train loss: {running_loss/print_every:.4f} - "
      f"Validation loss: {validation_loss/len(validloader):.4f} - "
      f"Validation accuracy: {accuracy/len(validloader):.4f}")

# Set the model back to training mode with dropout included for training se
model.train()
# Reset running_loss
running_loss = 0

print('\nTraining end')

```

Training start

Epoch: 1/6 - Train loss: 4.4512 - Validation loss: 4.1257 - Validation accuracy: 0.1943  
Epoch: 1/6 - Train loss: 4.0023 - Validation loss: 3.4619 - Validation accuracy: 0.2810

```

Epoch: 1/6 - Train loss: 3.3995 - Validation loss: 2.8502 - Validation accuracy: 0.4339
Epoch: 2/6 - Train loss: 2.2704 - Validation loss: 2.3052 - Validation accuracy: 0.5286
Epoch: 2/6 - Train loss: 2.5454 - Validation loss: 1.8759 - Validation accuracy: 0.6048
Epoch: 2/6 - Train loss: 2.2866 - Validation loss: 1.6016 - Validation accuracy: 0.6587
Epoch: 3/6 - Train loss: 1.1361 - Validation loss: 1.3583 - Validation accuracy: 0.7257
Epoch: 3/6 - Train loss: 1.9232 - Validation loss: 1.1877 - Validation accuracy: 0.7736
Epoch: 3/6 - Train loss: 1.7328 - Validation loss: 1.0023 - Validation accuracy: 0.7989
Epoch: 4/6 - Train loss: 0.5607 - Validation loss: 0.9509 - Validation accuracy: 0.8133
Epoch: 4/6 - Train loss: 1.5505 - Validation loss: 0.8763 - Validation accuracy: 0.8397
Epoch: 4/6 - Train loss: 1.4875 - Validation loss: 0.8055 - Validation accuracy: 0.8416
Epoch: 5/6 - Train loss: 0.1780 - Validation loss: 0.7510 - Validation accuracy: 0.8542
Epoch: 5/6 - Train loss: 1.3605 - Validation loss: 0.6778 - Validation accuracy: 0.8632
Epoch: 5/6 - Train loss: 1.2645 - Validation loss: 0.6293 - Validation accuracy: 0.8647
Epoch: 5/6 - Train loss: 1.2897 - Validation loss: 0.5897 - Validation accuracy: 0.8801
Epoch: 6/6 - Train loss: 1.1045 - Validation loss: 0.5976 - Validation accuracy: 0.8698
Epoch: 6/6 - Train loss: 1.1430 - Validation loss: 0.5497 - Validation accuracy: 0.8750
Epoch: 6/6 - Train loss: 1.1863 - Validation loss: 0.5313 - Validation accuracy: 0.8722

```

Training end

## 2.1 Testing your network

It's good practice to test your trained network on test data, images the network has never seen either in training or validation. This will give you a good estimate for the model's performance on completely new images. Run the test images through the network and measure the accuracy, the same way you did validation. You should be able to reach around 70% accuracy on the test set if the model has been trained well.

```

In [93]: # TODO: Do validation on the test set
         total_images = 0
         correctly_classified = 0
         total_test_batches = len(testloader)
         print(f'Total test batches: {total_test_batches}')

         with torch.no_grad():
             model.eval()
             for images, labels in testloader:
                 images, labels = images.to(device), labels.to(device)
                 output = model.forward(images)
                 ps = torch.exp(output)
                 top_p, top_class = ps.topk(1, dim=1)
                 equals = top_class == labels.view(*top_class.shape)
                 # print(f'Images in batch: {len(equals)}')
                 # print(f'Wrongly classified: {torch.sum(equals==0)}')
                 total_images += len(images)
                 correctly_classified += torch.sum(equals.type(torch.FloatTensor)).item()
             #ãprint(correctly_classified)

```

```
print(f"Testing accuracy: {correctly_classified/total_images:.4f}")
```

Total test batches: 26

Testing accuracy: 0.8852

## 2.2 Save the checkpoint

Now that your network is trained, save the model so you can load it later for making predictions. You probably want to save other things such as the mapping of classes to indices which you get from one of the image datasets: `image_datasets['train'].class_to_idx`. You can attach this to the model as an attribute which makes inference easier later on.

```
model.class_to_idx = image_datasets['train'].class_to_idx
```

Remember that you'll want to completely rebuild the model later so you can use it for inference. Make sure to include any information you need in the checkpoint. If you want to load the model and keep training, you'll want to save the number of epochs as well as the optimizer state, `optimizer.state_dict`. You'll likely want to use this trained model in the next part of the project, so best to save it now.

```
In [94]: # TODO: Save the checkpoint
# print("Our model: \n\n", model, '\n')
# print("The state dict keys: \n\n", model.state_dict().keys())
checkpoint = {'state_dict': model.state_dict(),
              'classifier': model.classifier,
              'class_to_idx': train_data.class_to_idx}

torch.save(checkpoint, 'checkpoint.pth')
```

```
/opt/conda/lib/python3.6/site-packages/torch/serialization.py:193: UserWarning: Couldn't retrieve
"type " + obj.__name__ + ". It won't be checked "
```

## 2.3 Loading the checkpoint

At this point it's good to write a function that can load a checkpoint and rebuild the model. That way you can come back to this project and keep working on it without having to retrain the network.

```
In [95]: # TODO: Write a function that loads a checkpoint and rebuilds the model
def load_model_from_checkpoint(path):
    """
    Load a model using a saved checkpoint
    """

    # Load the saved file
    checkpoint = torch.load(path)
    model = models.densenet121(pretrained = True)
```

```

        # Use the checkpoint to update the model
        model.class_to_idx = checkpoint['class_to_idx']
        model.classifier = checkpoint['classifier']
        model.load_state_dict(checkpoint['state_dict'])

    return model

# Use the function to reload the model using our checkpoint
model_from_checkpoint = load_model_from_checkpoint('checkpoint.pth')

/opt/conda/lib/python3.6/site-packages/torchvision-0.2.1-py3.6.egg/torchvision/models/densenet.py
    nn.init.kaiming_normal(m.weight.data)

In [105]: # Check the loaded model on the testing set to see that it was loaded successfully
    total_images = 0
    correctly_classified = 0
    total_test_batches = len(testloader)
    print(f'Total test batches: {total_test_batches}')

    # Move the model to the correct device
    model_from_checkpoint.to(device)

    with torch.no_grad():
        model_from_checkpoint.eval()
        for images, labels in testloader:
            images, labels = images.to(device), labels.to(device)
            output = model_from_checkpoint.forward(images)
            ps = torch.exp(output)
            top_p, top_class = ps.topk(1, dim=1)
            equals = top_class == labels.view(*top_class.shape)
            # print(f'Images in batch: {len(equals)}')
            # print(f'Wrongly classified: {torch.sum(equals==0)}')
            total_images += len(images)
            correctly_classified += torch.sum(equals.type(torch.FloatTensor)).item()
            # print(correctly_classified)

    print(f"Testing accuracy: {correctly_classified/total_images:.4f}")

Total test batches: 26
Testing accuracy: 0.8852

```

### 3 Inference for classification

Now you'll write a function to use a trained network for inference. That is, you'll pass an image into the network and predict the class of the flower in the image. Write a function called `predict` that takes an image and a model, then returns the top *K* most likely classes along with the probabilities. It should look like

```

probs, classes = predict(image_path, model)
print(probs)
print(classes)
> [ 0.01558163  0.01541934  0.01452626  0.01443549  0.01407339]
> ['70', '3', '45', '62', '55']

```

First you'll need to handle processing the input image such that it can be used in your network.

### 3.1 Image Preprocessing

You'll want to use PIL to load the image ([documentation](#)). It's best to write a function that preprocesses the image so it can be used as input for the model. This function should process the images in the same manner used for training.

First, resize the images where the shortest side is 256 pixels, keeping the aspect ratio. This can be done with the `thumbnail` or `resize` methods. Then you'll need to crop out the center 224x224 portion of the image.

Color channels of images are typically encoded as integers 0-255, but the model expects floats 0-1. You'll need to convert the values. It's easiest with a Numpy array, which you can get from a PIL image like so `np_image = np.array(pil_image)`.

As before, the network expects the images to be normalized in a specific way. For the means, it's [0.485, 0.456, 0.406] and for the standard deviations [0.229, 0.224, 0.225]. You'll want to subtract the means from each color channel, then divide by the standard deviation.

And finally, PyTorch expects the color channel to be the first dimension but it's the third dimension in the PIL image and Numpy array. You can reorder dimensions using `ndarray.transpose`. The color channel needs to be first and retain the order of the other two dimensions.

```

In [106]: from PIL import Image
          def process_image(image_path):
              ''' Scales, crops, and normalizes a PIL image for a PyTorch model,
                  returns a Numpy array
              '''
              image = Image.open(image_path)

              image_processing = transforms.Compose([
                  transforms.Resize(256),
                  transforms.CenterCrop(224),
                  transforms.ToTensor(),
                  transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0.229, 0.224, 0.225])
              ])

              image_tensor = image_processing(image)

              # Must return a numpy array so that it can be transposed for plotting
              return image_tensor.numpy()

```

To check your work, the function below converts a PyTorch tensor and displays it in the notebook. If your `process_image` function works, running the output through this function should return the original image (except for the cropped out portions).

```
In [107]: def imshow(image, ax=None, title=None):
            if ax is None:
                fig, ax = plt.subplots()

            # PyTorch tensors assume the color channel is the first dimension
            # but matplotlib assumes is the third dimension
            image = image.transpose((1, 2, 0))

            # Undo preprocessing
            mean = np.array([0.485, 0.456, 0.406])
            std = np.array([0.229, 0.224, 0.225])
            image = std * image + mean

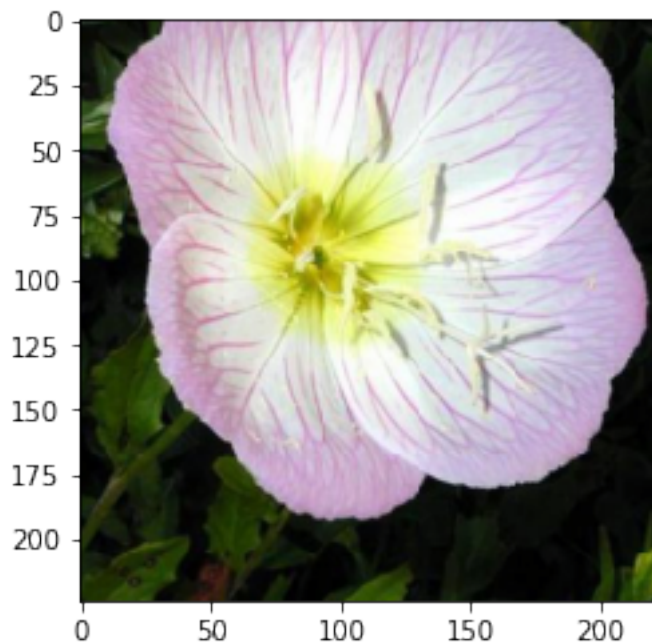
            # Image needs to be clipped between 0 and 1 or it looks like noise when displayed
            image = np.clip(image, 0, 1)

            ax.imshow(image)

            return ax
```

```
In [108]: imshow(process_image("flowers/test/1/image_06743.jpg"))
```

```
Out[108]: <matplotlib.axes._subplots.AxesSubplot at 0x7f8d80c7e550>
```



## 3.2 Class Prediction

Once you can get images in the correct format, it's time to write a function for making predictions with your model. A common practice is to predict the top 5 or so (usually called top-K) most probable classes. You'll want to calculate the class probabilities then find the  $K$  largest values.

To get the top  $K$  largest values in a tensor use `x.topk(k)`. This method returns both the highest  $k$  probabilities and the indices of those probabilities corresponding to the classes. You need to convert from these indices to the actual class labels using `class_to_idx` which hopefully you added to the model or from an `ImageFolder` you used to load the data (Section 2.2). Make sure to invert the dictionary so you get a mapping from index to class as well.

Again, this method should take a path to an image and a model checkpoint, then return the probabilities and classes.

```
probs, classes = predict(image_path, model)
print(probs)
print(classes)
> [ 0.01558163  0.01541934  0.01452626  0.01443549  0.01407339]
> ['70', '3', '45', '62', '55']

In [109]: def predict(image_path, model, topk = 5):
           ''' Predict the class (or classes) of an image using a trained deep learning model '''

           # TODO: Implement the code to predict the class from an image file
           # Set the model to evaluate
           model.eval()
           model.to('cpu')

           processed_image = torch.from_numpy(process_image(image_path)).type(torch.FloatTensor)

           # Add batch dimensioning as it is missing with single image
           # https://discuss.pytorch.org/t/expected-stride-to-be-a-single-integer-value-or-a-
           processed_image.unsqueeze_(0)

           # Feed forward through the model
           output = model.forward(processed_image)
           probs = torch.exp(output)

           # Find the top k labels and their classes
           top_probs, top_labels = probs.topk(topk, dim = 1)

           # Simplify the output to make it easier to work with in future
           labels = [cat_to_name[str(i + 1)] for i in np.array(top_labels)[0]]
           probs = [i for i in top_probs.detach().numpy()[0]]

           return probs, labels

top_p, top_flower = predict("flowers/test/1/image_06743.jpg", model)
```

```

# Slight conversions, and then the index has to be a string to find the flower names
# labels = [cat_to_name[str(i)] for i in np.array(top_flower)[0]]
# print(labels)
print(top_p)
print(top_flower)

```

```

[0.73327833, 0.054625072, 0.021386931, 0.020671606, 0.016641088]
['pink primrose', 'petunia', 'common dandelion', 'gazania', 'yellow iris']

```

### 3.3 Sanity Checking

Now that you can use a trained model for predictions, check to make sure it makes sense. Even if the testing accuracy is high, it's always good to check that there aren't obvious bugs. Use matplotlib to plot the probabilities for the top 5 classes as a bar graph, along with the input image. It should look like this:

You can convert from the class integer encoding to actual flower names with the `cat_to_name.json` file (should have been loaded earlier in the notebook). To show a PyTorch tensor as an image, use the `imshow` function defined above.

```

In [110]: # TODO: Display an image along with the top 5 classes
def sanity_check(path = "flowers/test/1/image_06743.jpg", model = model):

    # Define the plot parameters
    figure = plt.subplot(211)
    imshow(process_image(path), figure)

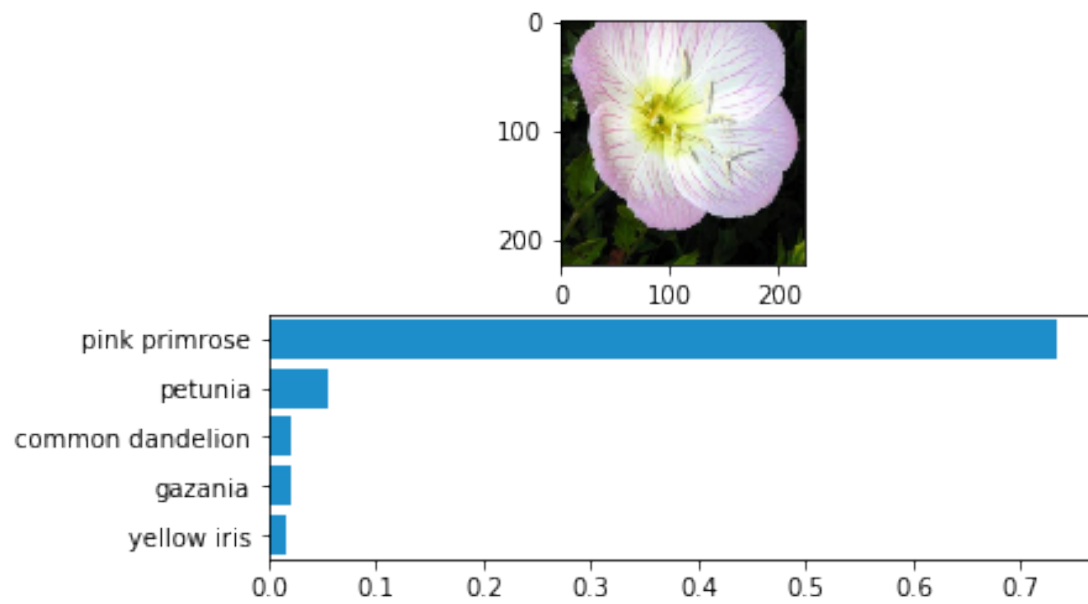
    # Make the predictions
    predictions, labels = predict(path, model)

    plt.subplot(2,1,2)
    sns.barplot(x=predictions, y=labels, color = '#0097e6');
    plt.show()

sanity_check()

```





In [ ]: