Assignment 3

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1. Getting started

[1]:
```
%matplotlib inline

import os
import numpy as np
import torch
from torch import nn
from torch.nn import functional as F
import torch.utils.data as td
import torchvision as tv
import pandas as pd
from PIL import Image
from matplotlib import pyplot as plt
```

[2]:
```
device = 'cuda' if torch.cuda.is_available() else 'cpu'
print(device)
```

```
cuda
```

2. Data Loader

Question 1

[3]:
```
dataset_root_dir = "/datasets/ee285f-public/caltech_ucsd_birds/"
```

Question 2

[4]:
```
class BirdsDataset(td.Dataset):

    def __init__(self, root_dir, mode="train", image_size=(224, 224)):
        super(BirdsDataset, self).__init__()
        self.image_size = image_size
        self.mode = mode
        self.data = pd.read_csv(os.path.join(root_dir, "%s.csv" % mode))
        self.images_dir = os.path.join(root_dir, "CUB_200_2011/images")
    def __len__(self):
        return  len(self.data)

    def __repr__(self):
        return"BirdsDataset(mode={}, image_size={})". \
            format(self.mode, self.image_size)

    def __getitem__(self, idx):
        img_path = os.path.join(self.images_dir, \
                                self.data.iloc[idx]['file_path'])
        bbox = self.data.iloc[idx][['x1','y1','x2','y2']]
        img = Image.open(img_path).convert('RGB')
        img = img.crop([bbox[0], bbox[1], bbox[2], bbox[3]])
        transform = tv.transforms.Compose([
        tv.transforms.Resize(self.image_size),
        tv.transforms.ToTensor(),
        tv.transforms.Normalize((0.5, 0.5, 0.5), (0.5, 0.5, 0.5))
        ])
        x = transform(img)
        d = self.data.iloc[idx]['class']
        return x, d

    def number_of_classes(self):
        return self.data['class'].max() + 1
```

Question 3

[5]:
```
def myimshow(image, ax=plt):
    image = image.to('cpu').numpy()
    image = np.moveaxis(image, [0, 1, 2], [2, 0, 1])
    image = (image + 1) / 2
    image[image < 0] = 0
    image[image > 1] = 1
    h = ax.imshow(image)
    ax.axis('off')
    return h
```

[6]:
```
train_set = BirdsDataset(dataset_root_dir)
x = train_set.__getitem__(10)
plt.figure()
myimshow(x[0])
print("Label of the image below :", x[1])
```

```
Label of the image below : 0
```

Question 4

[7]:
```
train_loader = td.DataLoader(train_set, batch_size=16, shuffle=True,␣
 ↪pin_memory=True)
print("Number of mini-batches :", len(train_loader))
```

```
Number of mini-batches : 47
```

The advantage of using pin_memory in a DataLoader is that it will automatically put the fetched data tensors in pinned memory and enables faster data transfer to CUDA-enabled GPUs.

Question 5

[8]:
```
for idx, mini_batch in enumerate(train_loader):
    if idx == 4:
        break
    plt.figure()
    myimshow(mini_batch[0][0])
    print("Label of image ", idx+1, " :", mini_batch[1][0])
```

```
Label of image  1  : tensor(15)
Label of image  2  : tensor(13)
Label of image  3  : tensor(17)
Label of image  4  : tensor(15)
```

Since, shuffle=True in train_loader. Everytime we display the first image of the four mini-batch we get four different images.

Question 6

[9]:
```
val_set = BirdsDataset(dataset_root_dir, mode = 'val')
val_loader = td.DataLoader(val_set, batch_size=16, pin_memory=True)
```

In DataLoader, shuffle is set to False by default. For validation, we need not shuffle the dataset because it is used to evaluate the performance of the network. For training, there may be similar datasets close to each other, so we shuffle the dataset for faster convergence.

3. Abstract Neural Network Model

[10]:
```
import nntools as nt
```

Question 7

[11]:
```
net = nt.NeuralNetwork()
```

```
        TypeErrorTraceback (most recent call last)

        <ipython-input-11-2b13b95b774d> in <module>
    ----> 1 net = nt.NeuralNetwork()


        TypeError: Can't instantiate abstract class NeuralNetwork with abstract␣
 ↪methods criterion, forward
```

We observe an error, because an abstract class does not implement forward and criterion and cannot be instantiated. The implementation of forward and criterion will depend on the specific type and architecture of neuralnetworks we are considering.

[12]:
```
class NNClassifier(nt.NeuralNetwork):

    def __init__(self):
        super(NNClassifier, self).__init__()
        self.cross_entropy = nn.CrossEntropyLoss()

    def criterion(self, y, d):
        return self.cross_entropy(y, d)
```

4. VGG-16 Transfer Learning

Question 8

[13]:
```
vgg = tv.models.vgg16_bn(pretrained=True)
```

[14]:
```
print(vgg)
print("Learnable parameters :")
for name, param in vgg.named_parameters():
    print(name, param.size(), param.requires_grad)
```

```
VGG(
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (4): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (14): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (15): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (18): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (21): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (22): ReLU(inplace=True)
    (23): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (24): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (25): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (26): ReLU(inplace=True)
    (27): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (28): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (29): ReLU(inplace=True)
    (30): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (31): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (32): ReLU(inplace=True)
    (33): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (34): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (35): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (36): ReLU(inplace=True)
    (37): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (38): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (39): ReLU(inplace=True)
    (40): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (41): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (42): ReLU(inplace=True)
    (43): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(7, 7))
  (classifier): Sequential(
    (0): Linear(in_features=25088, out_features=4096, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=4096, out_features=4096, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=4096, out_features=1000, bias=True)
  )
)
Learnable parameters :
features.0.weight torch.Size([64, 3, 3, 3]) True
features.0.bias torch.Size([64]) True
features.1.weight torch.Size([64]) True
features.1.bias torch.Size([64]) True
features.3.weight torch.Size([64, 64, 3, 3]) True
features.3.bias torch.Size([64]) True
features.4.weight torch.Size([64]) True
features.4.bias torch.Size([64]) True
features.7.weight torch.Size([128, 64, 3, 3]) True
features.7.bias torch.Size([128]) True
features.8.weight torch.Size([128]) True
features.8.bias torch.Size([128]) True
features.10.weight torch.Size([128, 128, 3, 3]) True
features.10.bias torch.Size([128]) True
features.11.weight torch.Size([128]) True
features.11.bias torch.Size([128]) True
features.14.weight torch.Size([256, 128, 3, 3]) True
features.14.bias torch.Size([256]) True
features.15.weight torch.Size([256]) True
features.15.bias torch.Size([256]) True
features.17.weight torch.Size([256, 256, 3, 3]) True
features.17.bias torch.Size([256]) True
features.18.weight torch.Size([256]) True
features.18.bias torch.Size([256]) True
features.20.weight torch.Size([256, 256, 3, 3]) True
features.20.bias torch.Size([256]) True
features.21.weight torch.Size([256]) True
features.21.bias torch.Size([256]) True
features.24.weight torch.Size([512, 256, 3, 3]) True
features.24.bias torch.Size([512]) True
features.25.weight torch.Size([512]) True
features.25.bias torch.Size([512]) True
features.27.weight torch.Size([512, 512, 3, 3]) True
features.27.bias torch.Size([512]) True
features.28.weight torch.Size([512]) True
features.28.bias torch.Size([512]) True
features.30.weight torch.Size([512, 512, 3, 3]) True
features.30.bias torch.Size([512]) True
features.31.weight torch.Size([512]) True
features.31.bias torch.Size([512]) True
features.34.weight torch.Size([512, 512, 3, 3]) True
features.34.bias torch.Size([512]) True
features.35.weight torch.Size([512]) True
features.35.bias torch.Size([512]) True
features.37.weight torch.Size([512, 512, 3, 3]) True
features.37.bias torch.Size([512]) True
features.38.weight torch.Size([512]) True
features.38.bias torch.Size([512]) True
features.40.weight torch.Size([512, 512, 3, 3]) True
features.40.bias torch.Size([512]) True
features.41.weight torch.Size([512]) True
features.41.bias torch.Size([512]) True
classifier.0.weight torch.Size([4096, 25088]) True
classifier.0.bias torch.Size([4096]) True
classifier.3.weight torch.Size([4096, 4096]) True
classifier.3.bias torch.Size([4096]) True
classifier.6.weight torch.Size([1000, 4096]) True
classifier.6.bias torch.Size([1000]) True
```

Question 9

[15]:
```
class VGG16Transfer(NNClassifier):

    def __init__(self, num_classes, fine_tuning=False):
        super(VGG16Transfer, self).__init__()
        vgg = tv.models.vgg16_bn(pretrained=True)
        for param in vgg.parameters():
            param.requires_grad = fine_tuning
        self.features = vgg.features
        self.avgpool = vgg.avgpool
        self.classifier = vgg.classifier
        num_ftrs = vgg.classifier[6].in_features
        self.classifier[6] = nn.Linear(num_ftrs, num_classes)

    def forward(self, x):
        x = self.features(x)
        x = self.avgpool(x)
        f = torch.flatten(x, 1)
        y = self.classifier(f)
        return y
```

Question 10

```
[16]: num_classes = train_set.number_of_classes()
print("Number of classes :", num_classes)
vgg16 = VGG16Transfer(num_classes)

print(vgg16)
print("Learnable parameters :" )
for name, param in vgg16.named_parameters():
    print(name, param.size(), param.requires_grad)
```

```
Number of classes : 20
VGG16Transfer(
  (cross_entropy): CrossEntropyLoss()
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU(inplace=True)
    (3): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (4): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU(inplace=True)
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU(inplace=True)
    (10): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (12): ReLU(inplace=True)
    (13): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
```

```
    (14): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (15): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (16): ReLU(inplace=True)
    (17): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (18): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (19): ReLU(inplace=True)
    (20): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (21): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (22): ReLU(inplace=True)
    (23): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (24): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (25): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (26): ReLU(inplace=True)
    (27): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (28): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (29): ReLU(inplace=True)
    (30): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (31): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (32): ReLU(inplace=True)
    (33): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (34): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (35): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (36): ReLU(inplace=True)
    (37): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (38): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (39): ReLU(inplace=True)
    (40): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (41): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (42): ReLU(inplace=True)
    (43): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(7, 7))
  (classifier): Sequential(
    (0): Linear(in_features=25088, out_features=4096, bias=True)
    (1): ReLU(inplace=True)
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=4096, out_features=4096, bias=True)
    (4): ReLU(inplace=True)
    (5): Dropout(p=0.5, inplace=False)
    (6): Linear(in_features=4096, out_features=20, bias=True)
  )
)
Learnable parameters :
classifier.6.weight torch.Size([20, 4096]) True
classifier.6.bias torch.Size([20]) True
```

5. Training experiment and checkpoints

Question 11

[17]:
```
class ClassificationStatsManager(nt.StatsManager):

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

    def init(self):
        super(ClassificationStatsManager, self).init()
        self.running_accuracy = 0

    def accumulate(self, loss, x, y, d):
        super(ClassificationStatsManager, self).accumulate(loss, x, y, d)
        _, l = torch.max(y, 1)
        self.running_accuracy += torch.mean((l == d).float())

    def summarize(self):
        loss = super(ClassificationStatsManager, self).summarize()
        accuracy = 100 * self.running_accuracy / self.number_update
        return {'loss': loss, 'accuracy': accuracy}
```

Question 12

self.net.eval() sets all layers to eval mode. Dropout and batch normalization (batchnorm) layers will work in evaluation mode instead of training mode. It is important that we change batchnorm layers to eval mode because in VGG16Transfer() we have a batchnorm layer.

We find in the documentation that batchnorm layer keeps a running estimate of the computed mean and variance during training. The default momentum of the running sum is kept at 0.1. But, in evaluation the computed mean and variance is used for normalization. Also during evaluation, we can reduce memory usage by deactivating autograd and can speed up the process.

Question 13

[18]:
```
lr = 1e-3
net = VGG16Transfer(num_classes)
net = net.to(device)
adam = torch.optim.Adam(net.parameters(), lr=lr)
```

```
stats_manager = ClassificationStatsManager()
exp1 = nt.Experiment(net, train_set, val_set, adam, stats_manager,
               output_dir="birdclass1", perform_validation_during_training=True)
```

Config.txt has the setting of the experiment, i.e., it contains the structure, parameters and hyper-parameters of the model, training set and validation set, Optimizer, StatsManager, BatchSize and PerformValidationDuringTraining.

In the nntools.py we see that after each epoch, there is a self.load() and self.save(). In the documentaion of torch.save(), we infer that checkpoint.pth.tar has the state of the experiment, i.e., it contains Net, Optimizer and History and a file name.

Question 14

[19]:
```
lr = 1e-4
net = VGG16Transfer(num_classes)
net = net.to(device)
adam = torch.optim.Adam(net.parameters(), lr=lr)
stats_manager = ClassificationStatsManager()
exp1 = nt.Experiment(net, train_set, val_set, adam, stats_manager,
               output_dir="birdclass1", perform_validation_during_training=True)
```

```
        ValueErrorTraceback (most recent call last)

        <ipython-input-19-498136cd4335> in <module>
          5 stats_manager = ClassificationStatsManager()
          6 exp1 = nt.Experiment(net, train_set, val_set, adam, stats_manager,
    ----> 7                output_dir="birdclass1",␣
↪perform_validation_during_training=True)


        /datasets/home/home-01/46/346/samansoo/nntools.py in __init__(self, net,␣
↪train_set, val_set, optimizer, stats_manager, output_dir, batch_size,␣
↪perform_validation_during_training)
        168                 if f.read()[:-1] != repr(self):
        169                     raise ValueError(
    --> 170                         "Cannot create this experiment: "
        171                         "I found a checkpoint conflicting with the␣
↪current setting.")
        172             self.load()


        ValueError: Cannot create this experiment: I found a checkpoint␣
↪conflicting with the current setting.
```

We have changed the learning rate from 1e-3 to 1e-4. Since learning rate is a setting of the model, it fails to load because there exist a conflict with the current setting.

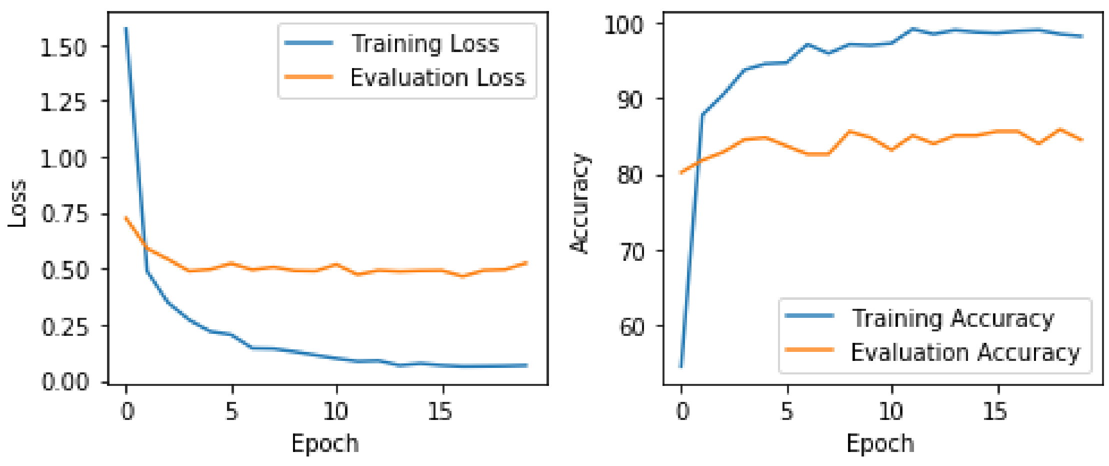
[20]:
```
lr = 1e-3
net = VGG16Transfer(num_classes)
net = net.to(device)
adam = torch.optim.Adam(net.parameters(), lr=lr)
stats_manager = ClassificationStatsManager()
exp1 = nt.Experiment(net, train_set, val_set, adam, stats_manager,
               output_dir="birdclass1", perform_validation_during_training=True)
```

Question 15

[21]:
```
def plot(exp, fig, axes):
    axes[0].clear()
    axes[1].clear()
    axes[0].plot([exp.history[k][0]['loss'] for k in range(exp.epoch)],
                 label="training loss")
    axes[0].plot([exp.history[k][1]['loss'] for k in range(exp.epoch)],
                 label="evaluation loss")

    axes[0].set_xlabel('Epoch')
    axes[0].set_ylabel('Loss')
    axes[0].legend(('Training Loss', 'Evaluation Loss'))

    axes[1].plot([exp.history[k][0]['accuracy'] for k in range(exp.epoch)],
                 label="training accuracy")
    axes[1].plot([exp.history[k][1]['accuracy'] for k in range(exp.epoch)],
                 label="evaluation accuracy")

    axes[1].set_xlabel('Epoch')
    axes[1].set_ylabel('Accuracy')
    axes[1].legend(('Training Accuracy', 'Evaluation Accuracy'))
    plt.tight_layout()
    fig.canvas.draw()
```

[22]:
```
fig, axes = plt.subplots(ncols=2, figsize=(7, 3))
exp1.run(num_epochs=20, plot=lambda exp: plot(exp, fig=fig, axes=axes))
```

```
Start/Continue training from epoch 20
Finish training for 20 epochs
```



6. ResNet18 Transfer Learning

Question 16

[23]:
```
resnet = tv.models.resnet18(pretrained=True)
```

[24]:
```
print(resnet)
print("Learnable Parameters :")
for name, param in resnet.named_parameters():
    print(name, param.size(), param.requires_grad)
```

```
ResNet(
  (conv1): Conv2d(3, 64, kernel_size=(7, 7), stride=(2, 2), padding=(3, 3),
bias=False)
  (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1,
ceil_mode=False)
  (layer1): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (1): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (layer2): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 128, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(64, 128, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (layer3): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(128, 256, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(128, 256, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (layer4): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(256, 512, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(256, 512, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
```

```
    )
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(1, 1))
  (fc): Linear(in_features=512, out_features=1000, bias=True)
)
Learnable Parameters :
conv1.weight torch.Size([64, 3, 7, 7]) True
bn1.weight torch.Size([64]) True
bn1.bias torch.Size([64]) True
layer1.0.conv1.weight torch.Size([64, 64, 3, 3]) True
layer1.0.bn1.weight torch.Size([64]) True
layer1.0.bn1.bias torch.Size([64]) True
layer1.0.conv2.weight torch.Size([64, 64, 3, 3]) True
layer1.0.bn2.weight torch.Size([64]) True
layer1.0.bn2.bias torch.Size([64]) True
layer1.1.conv1.weight torch.Size([64, 64, 3, 3]) True
layer1.1.bn1.weight torch.Size([64]) True
layer1.1.bn1.bias torch.Size([64]) True
layer1.1.conv2.weight torch.Size([64, 64, 3, 3]) True
layer1.1.bn2.weight torch.Size([64]) True
layer1.1.bn2.bias torch.Size([64]) True
layer2.0.conv1.weight torch.Size([128, 64, 3, 3]) True
layer2.0.bn1.weight torch.Size([128]) True
layer2.0.bn1.bias torch.Size([128]) True
layer2.0.conv2.weight torch.Size([128, 128, 3, 3]) True
layer2.0.bn2.weight torch.Size([128]) True
layer2.0.bn2.bias torch.Size([128]) True
layer2.0.downsample.0.weight torch.Size([128, 64, 1, 1]) True
layer2.0.downsample.1.weight torch.Size([128]) True
layer2.0.downsample.1.bias torch.Size([128]) True
layer2.1.conv1.weight torch.Size([128, 128, 3, 3]) True
layer2.1.bn1.weight torch.Size([128]) True
layer2.1.bn1.bias torch.Size([128]) True
layer2.1.conv2.weight torch.Size([128, 128, 3, 3]) True
layer2.1.bn2.weight torch.Size([128]) True
layer2.1.bn2.bias torch.Size([128]) True
layer3.0.conv1.weight torch.Size([256, 128, 3, 3]) True
layer3.0.bn1.weight torch.Size([256]) True
layer3.0.bn1.bias torch.Size([256]) True
layer3.0.conv2.weight torch.Size([256, 256, 3, 3]) True
layer3.0.bn2.weight torch.Size([256]) True
layer3.0.bn2.bias torch.Size([256]) True
layer3.0.downsample.0.weight torch.Size([256, 128, 1, 1]) True
layer3.0.downsample.1.weight torch.Size([256]) True
layer3.0.downsample.1.bias torch.Size([256]) True
layer3.1.conv1.weight torch.Size([256, 256, 3, 3]) True
layer3.1.bn1.weight torch.Size([256]) True
layer3.1.bn1.bias torch.Size([256]) True
```

```
layer3.1.conv2.weight torch.Size([256, 256, 3, 3]) True
layer3.1.bn2.weight torch.Size([256]) True
layer3.1.bn2.bias torch.Size([256]) True
layer4.0.conv1.weight torch.Size([512, 256, 3, 3]) True
layer4.0.bn1.weight torch.Size([512]) True
layer4.0.bn1.bias torch.Size([512]) True
layer4.0.conv2.weight torch.Size([512, 512, 3, 3]) True
layer4.0.bn2.weight torch.Size([512]) True
layer4.0.bn2.bias torch.Size([512]) True
layer4.0.downsample.0.weight torch.Size([512, 256, 1, 1]) True
layer4.0.downsample.1.weight torch.Size([512]) True
layer4.0.downsample.1.bias torch.Size([512]) True
layer4.1.conv1.weight torch.Size([512, 512, 3, 3]) True
layer4.1.bn1.weight torch.Size([512]) True
layer4.1.bn1.bias torch.Size([512]) True
layer4.1.conv2.weight torch.Size([512, 512, 3, 3]) True
layer4.1.bn2.weight torch.Size([512]) True
layer4.1.bn2.bias torch.Size([512]) True
fc.weight torch.Size([1000, 512]) True
fc.bias torch.Size([1000]) True
```

[25]:
```
class Resnet18Transfer(NNClassifier):

    def __init__(self, num_classes, fine_tuning=False):
        super(Resnet18Transfer, self).__init__()
        resnet = tv.models.resnet18(pretrained=True)
        for param in resnet.parameters():
            param.requires_grad = fine_tuning

        self.conv1 = resnet.conv1
        self.bn1 = resnet.bn1
        self.relu = resnet.relu
        self.maxpool = resnet.maxpool
        self.layer1 = resnet.layer1
        self.layer2 = resnet.layer2
        self.layer3 = resnet.layer3
        self.layer4 = resnet.layer4
        self.avgpool = resnet.avgpool
        self.fc = resnet.fc

        num_ftrs = self.fc.in_features
        self.fc = nn.Linear(num_ftrs, num_classes)

    def forward(self, x):
        x = self.conv1(x)
        x = self.bn1(x)
        x = self.relu(x)
        x = self.maxpool(x)
        x = self.layer1(x)
        x = self.layer2(x)
        x = self.layer3(x)
        x = self.layer4(x)
        x = self.avgpool(x)
        x = torch.flatten(x, 1)
        x = self.fc(x)
        return x
```

[26]:
```
resnet18 = Resnet18Transfer(num_classes)
print(resnet18)
print("Learnable Parameters :")
for name, param in resnet18.named_parameters():
    print(name, param.size(), param.requires_grad)
```

```
Resnet18Transfer(
  (cross_entropy): CrossEntropyLoss()
  (conv1): Conv2d(3, 64, kernel_size=(7, 7), stride=(2, 2), padding=(3, 3),
bias=False)
  (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1,
ceil_mode=False)
  (layer1): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (1): BasicBlock(
      (conv1): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1),
bias=False)
      (bn2): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
```

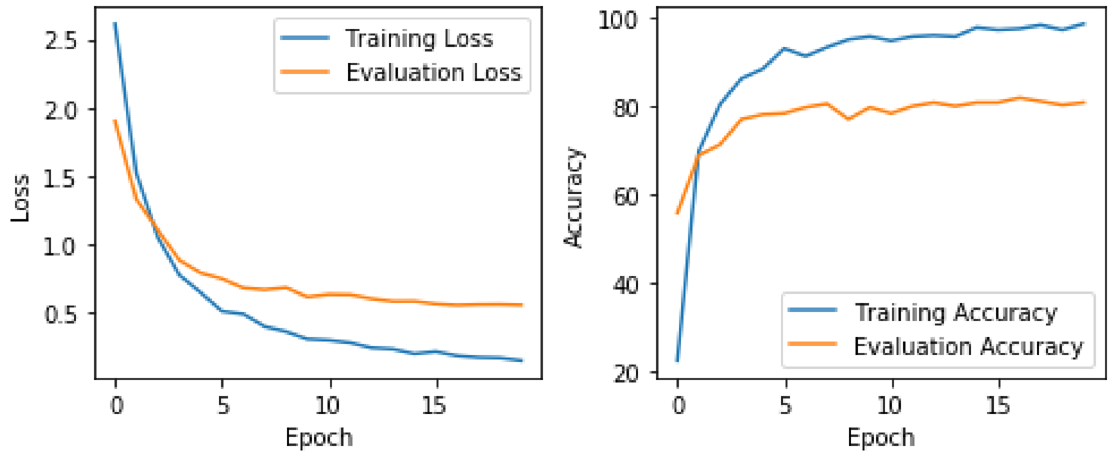
```
    )
  )
  (layer2): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(64, 128, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(64, 128, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (layer3): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(128, 256, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(128, 256, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (layer4): Sequential(
    (0): BasicBlock(
      (conv1): Conv2d(256, 512, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (downsample): Sequential(
        (0): Conv2d(256, 512, kernel_size=(1, 1), stride=(2, 2), bias=False)
        (1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      )
    )
    (1): BasicBlock(
      (conv1): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn1): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (relu): ReLU(inplace=True)
      (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), bias=False)
      (bn2): BatchNorm2d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(1, 1))
  (fc): Linear(in_features=512, out_features=20, bias=True)
)
Learnable Parameters :
fc.weight torch.Size([20, 512]) True
fc.bias torch.Size([20]) True
```

Question 17

```
[27]: lr2 = 1e-3
      net2 = Resnet18Transfer(num_classes)
      net2 = net2.to(device)
      adam2 = torch.optim.Adam(net2.parameters(), lr=lr2)
      stats_manager2 = ClassificationStatsManager()
      exp2 = nt.Experiment(net2, train_set, val_set, adam2, stats_manager2,
                     output_dir="birdclass2", perform_validation_during_training=True)
```

```
[28]: fig, axes = plt.subplots(ncols=2, figsize=(7, 3))
      exp2.run(num_epochs=20, plot=lambda exp: plot(exp, fig=fig, axes=axes))
```

```
Start/Continue training from epoch 20
Finish training for 20 epochs
```



Question 18

```
[29]: exp1.evaluate()
```

```
[29]: {'loss': 0.5238540965010938, 'accuracy': tensor(84.5109, device='cuda:0')}
```

```
[30]: exp2.evaluate()
```

```
[30]: {'loss': 0.5604417719270872, 'accuracy': tensor(80.7065, device='cuda:0')}
```

Accuracy of the Resnet18 architecture is 80.7065 % and the accuracy of VGG architecture is 84.5109%. Accuracy of Resnet is lesser despite having a deeper network than VGG is due to the limited dataset available to us.