MIS 583 Assignment 4: Self-supervised and transfer learning on CIFAR10

Before we start, please put your name and SID in following format:
: LASTNAME Firstname, ?00000000 // e.g.) 李晨愷 M114020035

Your Answer:
Hi I'm 陳昱逢, B092040016.

Google Colab Setup

Next we need to run a few commands to set up our environment on Google Colab. If you are running this notebook on a local machine you can skip this section.

Run the following cell to mount your Google Drive. Follow the link, sign in to your Google account (the same account you used to store this notebook!) and copy the authorization code into the text box that appears below.

In [ ]:
```
from google.colab import drive
drive.mount('/content/drive')
```

Data Setup (5 points)

The first thing to do is implement a dataset class to load rotated CIFAR10 images with matching labels. Since there is already a CIFAR10 dataset class implemented in `torchvision`, we will extend this class and modify the `__get_item__` method appropriately to load rotated images.

Each rotation label should be an integer in the set {0, 1, 2, 3} which correspond to rotations of 0, 90, 180, or 270 degrees respectively.

In [1]:
```
import torch
import torchvision
import torchvision.transforms as transforms
import numpy as np
import random


def rotate_img(img, rot):
    if rot == 0: # 0 degrees rotation
        return img
    ###########################################################################
    #        TODO: Implement rotate_img() - return the rotated img
    ###########################################################################
    elif rot == 1:
        return transforms.functional.rotate(img, angle = 90)
    elif rot == 2:
        return transforms.functional.rotate(img, angle = 180)
    elif rot == 3:
        return transforms.functional.rotate(img, angle = 270)
    else:
        raise ValueError('rotation should be 0, 90, 180, or 270 degrees')

    ###########################################################################
    #                             End of your code
    ###########################################################################

class CIFAR10Rotation(torchvision.datasets.CIFAR10):

    def __init__(self, root, train, download, transform) -> None:
        super().__init__(root=root, train=train, download=download, trans

    def __len__(self):
        return len(self.data)

    def __getitem__(self, index: int):
        image, cls_label = super().__getitem__(index)

        # randomly select image rotation
        rotation_label = random.choice([0, 1, 2, 3])
        image_rotated = rotate_img(image, rotation_label)

        rotation_label = torch.tensor(rotation_label).long()
        return image, image_rotated, rotation_label, torch.tensor(cls_lab
```

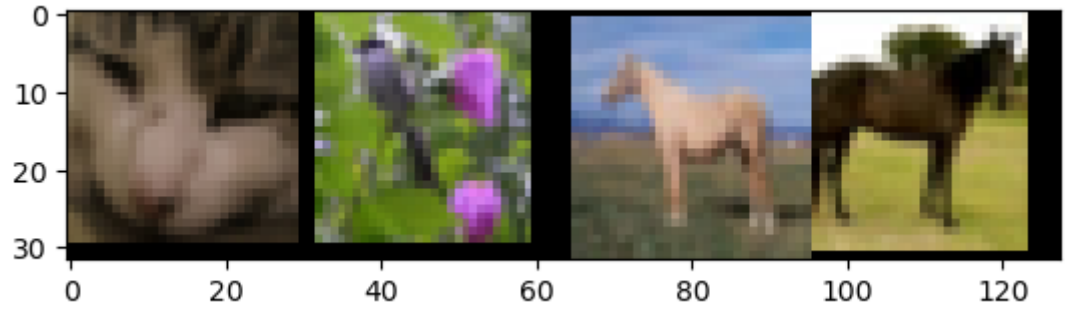
In [2]:
```
transform_train = transforms.Compose([
    transforms.RandomCrop(32, padding=4),
    transforms.RandomHorizontalFlip(),
    transforms.ToTensor(),
    transforms.Normalize((0.4914, 0.4822, 0.4465), (0.2023, 0.1994, 0.201
])

transform_test = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize((0.4914, 0.4822, 0.4465), (0.2023, 0.1994, 0.201
])

batch_size = 128

trainset = CIFAR10Rotation(root='./data', train=True,
                                        download=True, transform=transfor
trainloader = torch.utils.data.DataLoader(trainset, batch_size=batch_size
                                          shuffle=True, num_workers=2)

testset = CIFAR10Rotation(root='./data', train=False,
                                       download=True, transform=transform
testloader = torch.utils.data.DataLoader(testset, batch_size=batch_size,
                                         shuffle=False, num_workers=2)
```

```
Files already downloaded and verified
Files already downloaded and verified
```

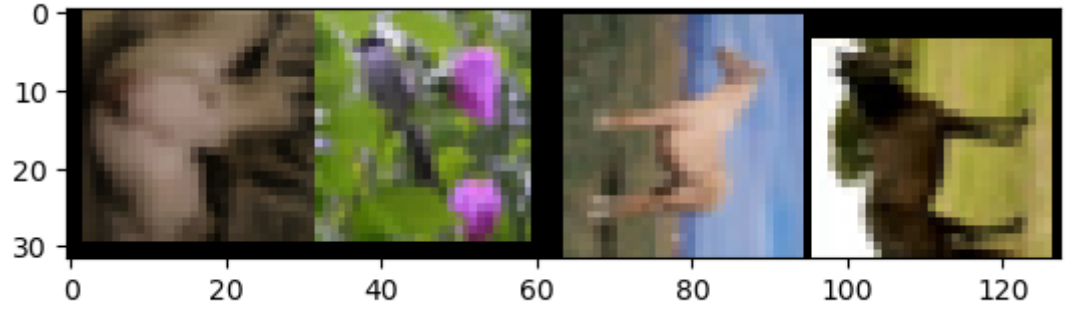
Show some example images and rotated images with labels:

In [3]:
```
import matplotlib.pyplot as plt

classes = ('plane', 'car', 'bird', 'cat',
           'deer', 'dog', 'frog', 'horse', 'ship', 'truck')

rot_classes = ('0', '90', '180', '270')


def imshow(img):
    # unnormalize
    img = transforms.Normalize((0, 0, 0), (1/0.2023, 1/0.1994, 1/0.2010))
    img = transforms.Normalize((-0.4914, -0.4822, -0.4465), (1, 1, 1))(im
    npimg = img.numpy()
    plt.imshow(np.transpose(npimg, (1, 2, 0)))
    plt.show()


dataiter = iter(trainloader)
images, rot_images, rot_labels, labels = next(dataiter)

# print images and rotated images
img_grid = imshow(torchvision.utils.make_grid(images[:4], padding=0))
print('Class labels: ', ' '.join(f'{classes[labels[j]]:5s}' for j in rang
img_grid = imshow(torchvision.utils.make_grid(rot_images[:4], padding=0))
print('Rotation labels: ', ' '.join(f'{rot_classes[rot_labels[j]]:5s}' fo
```

```
Clipping input data to the valid range for imshow with RGB data ([0..1] f
or floats or [0..255] for integers).
```



```
Clipping input data to the valid range for imshow with RGB data ([0..1] f
or floats or [0..255] for integers).
Class labels:  cat   bird  horse horse
```



```
Rotation labels:  270   0     270   90
```

Evaluation code

In [3]:

```
import time

def run_test(net, testloader, criterion, task):
    correct = 0
    total = 0
    avg_test_loss = 0.0
    # since we're not training, we don't need to calculate the gradients
    with torch.no_grad():
        for images, images_rotated, labels, cls_labels in testloader:
            if task == 'rotation':
              images, labels = images_rotated.to(device), labels.to(devic
            elif task == 'classification':
              images, labels = images.to(device), cls_labels.to(device)
            ########################################################################
            # TODO: Calculate outputs by running images through the netwo
            # The class with the highest energy is what we choose as pred
            ########################################################################
            outputs = net(images)
            _, predicted = torch.max(outputs, 1)
            total += labels.size(0)
            correct += (predicted == labels).sum().item()
            ########################################################################
            #                               End of your code
            ########################################################################
            avg_test_loss += criterion(outputs, labels)  / len(testloader
    print('TESTING:')
    print(f'Accuracy of the network on the 10000 test images: {100 * corr
    print(f'Average loss on the 10000 test images: {avg_test_loss:.3f}')
    return 100 * correct / total
```

In [4]:
```
def adjust_learning_rate(optimizer, epoch, init_lr, decay_epochs=30):
    """Sets the learning rate to the initial LR decayed by 10 every 30 ep
    lr = init_lr * (0.1 ** (epoch // decay_epochs))
    for param_group in optimizer.param_groups:
        param_group['lr'] = lr
```

Train a ResNet18 on the rotation task (9 points)

In this section, we will train a ResNet18 model **from scratch** on the rotation task. The input is a rotated image and the model predicts the rotation label. See the Data Setup section for details.

In [5]:
```
device = 'cuda' if torch.cuda.is_available() else 'cpu'
device
```

Out[5]:
```
'cuda'
```

Notice: You should not use pretrained weights from ImageNet.

In [7]:
```
import torch.nn as nn
import torch.nn.functional as F

from torchvision.models import resnet18

net = resnet18(weights = None, num_classes=4) # Do not modify this line.
net = net.to(device)
print(net) # print your model and check the num_classes is correct
```

```
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_runn
ing_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ce
il_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), paddin
g=(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=Fals
e)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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=4, bias=True)
)
```

In [8]:
```
import torch.nn as nn
import torch.optim as optim
################################################################################
# TODO: Define loss and optmizer functions
# Try any loss or optimizer function and learning rate to get better resu
# hint: torch.nn and torch.optim
################################################################################
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(net.parameters(), lr=0.001, weight_decay=0.01)
################################################################################
#                                End of your code
################################################################################
criterion = criterion.to(device)
```

In [9]:
```
# Both the self-supervised rotation task and supervised CIFAR10 classific
# trained with the CrossEntropyLoss, so we can use the training loop code

def train(net, criterion, optimizer, num_epochs, decay_epochs, init_lr, t
    test_acc = 0
    for epoch in range(num_epochs):  # loop over the dataset multiple tim

        running_loss = 0.0
        running_correct = 0.0
        running_total = 0.0
        start_time = time.time()

        net.train()

        for i, (imgs, imgs_rotated, rotation_label, cls_label) in enumera
            adjust_learning_rate(optimizer, epoch, init_lr, decay_epochs)
            ################################################################
            # TODO: Set the data to the correct device; Different task wi
            # TODO: Zero the parameter gradients
            # TODO: forward + backward + optimize
            # TODO: Get predicted results
            ################################################################
            if task == 'rotation':
                images, labels = imgs_rotated.to(device), rotation_label.
            elif task == 'classification':
                images, labels = imgs.to(device), cls_label.to(device)

            optimizer.zero_grad()

            outputs = net(images)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()

            _, predicted = torch.max(outputs, 1)

            ################################################################
            #                                End of your code
            ################################################################


            # print statistics
            print_freq = 100
            running_loss += loss.item()

            # calc acc
            running_total += labels.size(0)
            running_correct += (predicted == labels).sum().item()

            if i % print_freq == (print_freq - 1):    # print every 2000
                print(f'[{epoch + 1}, {i + 1:5d}] loss: {running_loss / p
                running_loss, running_correct, running_total = 0.0, 0.0,
                start_time = time.time()
        ################################################################
        # TODO: Run the run_test() function after each epoch; Set the mod
        ################################################################
        net.eval()
        test_acc = run_test(net, testloader, criterion,task)
        ################################################################
        #                              End of your code
        ################################################################

    print('Finished Training')
```

```
    print('Finished Training')
    return test_acc
```

In [10]:
```
train(net, criterion, optimizer, num_epochs=45, decay_epochs=15, init_lr=
################################
#     TODO: Save the model     #
################################
torch.save(net.state_dict(), 'rotation_model.pt')
################################
#      End of your code        #
################################
```

```
/home/vllab/anaconda3/lib/python3.11/site-packages/torch/nn/modules/conv.
py:456: UserWarning: Applied workaround for CuDNN issue, install nvrtc.so
(Triggered internally at /opt/conda/conda-bld/pytorch_1695392026823/work/
aten/src/ATen/native/cudnn/Conv_v8.cpp:80.)
  return F.conv2d(input, weight, bias, self.stride,
```

```
[1,   100] loss: 1.649 acc: 29.00 time: 4.14
[1,   200] loss: 1.301 acc: 41.64 time: 2.77
[1,   300] loss: 1.194 acc: 46.05 time: 2.78
TESTING:
Accuracy of the network on the 10000 test images: 50.63 %
Average loss on the 10000 test images: 1.313
[2,   100] loss: 1.118 acc: 50.91 time: 2.77
[2,   200] loss: 1.111 acc: 51.48 time: 2.60
[2,   300] loss: 1.094 acc: 52.77 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 55.89 %
Average loss on the 10000 test images: 1.030
[3,   100] loss: 1.064 acc: 54.26 time: 2.73
[3,   200] loss: 1.042 acc: 55.39 time: 2.61
[3,   300] loss: 1.035 acc: 55.77 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 56.44 %
Average loss on the 10000 test images: 1.043
[4,   100] loss: 1.004 acc: 57.41 time: 2.88
[4,   200] loss: 0.986 acc: 58.11 time: 2.74
[4,   300] loss: 0.986 acc: 58.12 time: 2.80
TESTING:
Accuracy of the network on the 10000 test images: 59.86 %
Average loss on the 10000 test images: 0.950
[5,   100] loss: 0.967 acc: 59.59 time: 2.81
[5,   200] loss: 0.961 acc: 60.04 time: 2.61
[5,   300] loss: 0.937 acc: 60.81 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 61.61 %
Average loss on the 10000 test images: 0.934
[6,   100] loss: 0.940 acc: 60.54 time: 2.80
[6,   200] loss: 0.916 acc: 61.95 time: 2.63
[6,   300] loss: 0.919 acc: 61.72 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 64.14 %
Average loss on the 10000 test images: 0.868
[7,   100] loss: 0.907 acc: 62.20 time: 2.77
[7,   200] loss: 0.896 acc: 62.71 time: 2.64
[7,   300] loss: 0.883 acc: 63.32 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 63.81 %
Average loss on the 10000 test images: 0.882
[8,   100] loss: 0.887 acc: 63.20 time: 2.73
[8,   200] loss: 0.872 acc: 63.20 time: 2.58
[8,   300] loss: 0.878 acc: 63.50 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 63.62 %
Average loss on the 10000 test images: 0.864
[9,   100] loss: 0.855 acc: 64.77 time: 2.72
[9,   200] loss: 0.872 acc: 63.70 time: 2.63
[9,   300] loss: 0.845 acc: 65.00 time: 2.85
TESTING:
Accuracy of the network on the 10000 test images: 65.19 %
Average loss on the 10000 test images: 0.845
[10,   100] loss: 0.848 acc: 65.39 time: 2.84
[10,   200] loss: 0.826 acc: 66.37 time: 2.72
[10,   300] loss: 0.835 acc: 65.17 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 67.10 %
Average loss on the 10000 test images: 0.801
[11,   100] loss: 0.832 acc: 65.88 time: 2.75
[11,   200] loss: 0.825 acc: 65.79 time: 2.63
[11,   300] loss: 0.817 acc: 66.78 time: 2.63
```

```
TESTING:
Accuracy of the network on the 10000 test images: 67.99 %
Average loss on the 10000 test images: 0.799
[12,   100] loss: 0.804 acc: 67.10 time: 2.76
[12,   200] loss: 0.803 acc: 67.44 time: 2.64
[12,   300] loss: 0.798 acc: 67.67 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 68.53 %
Average loss on the 10000 test images: 0.774
[13,   100] loss: 0.777 acc: 68.54 time: 2.78
[13,   200] loss: 0.794 acc: 67.61 time: 2.62
[13,   300] loss: 0.786 acc: 67.88 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 68.65 %
Average loss on the 10000 test images: 0.762
[14,   100] loss: 0.771 acc: 68.75 time: 2.83
[14,   200] loss: 0.779 acc: 68.42 time: 2.78
[14,   300] loss: 0.771 acc: 68.95 time: 2.78
TESTING:
Accuracy of the network on the 10000 test images: 70.46 %
Average loss on the 10000 test images: 0.734
[15,   100] loss: 0.753 acc: 69.47 time: 2.96
[15,   200] loss: 0.751 acc: 70.08 time: 2.76
[15,   300] loss: 0.760 acc: 69.52 time: 2.89
TESTING:
Accuracy of the network on the 10000 test images: 70.03 %
Average loss on the 10000 test images: 0.739
[16,   100] loss: 0.719 acc: 71.27 time: 2.93
[16,   200] loss: 0.682 acc: 72.64 time: 2.76
[16,   300] loss: 0.669 acc: 73.10 time: 2.82
TESTING:
Accuracy of the network on the 10000 test images: 74.80 %
Average loss on the 10000 test images: 0.636
[17,   100] loss: 0.657 acc: 74.10 time: 3.00
[17,   200] loss: 0.659 acc: 74.09 time: 2.70
[17,   300] loss: 0.658 acc: 73.31 time: 2.79
TESTING:
Accuracy of the network on the 10000 test images: 75.47 %
Average loss on the 10000 test images: 0.623
[18,   100] loss: 0.654 acc: 73.89 time: 2.90
[18,   200] loss: 0.657 acc: 73.98 time: 2.85
[18,   300] loss: 0.629 acc: 75.28 time: 2.80
TESTING:
Accuracy of the network on the 10000 test images: 75.71 %
Average loss on the 10000 test images: 0.618
[19,   100] loss: 0.649 acc: 74.02 time: 2.92
[19,   200] loss: 0.637 acc: 74.84 time: 2.82
[19,   300] loss: 0.636 acc: 74.56 time: 2.83
TESTING:
Accuracy of the network on the 10000 test images: 76.09 %
Average loss on the 10000 test images: 0.607
[20,   100] loss: 0.638 acc: 74.63 time: 2.84
[20,   200] loss: 0.630 acc: 75.04 time: 2.61
[20,   300] loss: 0.616 acc: 75.68 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 76.00 %
Average loss on the 10000 test images: 0.605
[21,   100] loss: 0.626 acc: 75.27 time: 2.76
[21,   200] loss: 0.622 acc: 75.58 time: 2.63
[21,   300] loss: 0.608 acc: 76.37 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 76.87 %
Average loss on the 10000 test images: 0.592
```

```
[22,   100] loss: 0.615 acc: 75.85 time: 2.74
[22,   200] loss: 0.618 acc: 75.55 time: 2.63
[22,   300] loss: 0.611 acc: 75.98 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 76.50 %
Average loss on the 10000 test images: 0.587
[23,   100] loss: 0.593 acc: 76.96 time: 2.73
[23,   200] loss: 0.606 acc: 76.04 time: 2.69
[23,   300] loss: 0.604 acc: 76.69 time: 2.84
TESTING:
Accuracy of the network on the 10000 test images: 77.04 %
Average loss on the 10000 test images: 0.583
[24,   100] loss: 0.596 acc: 76.95 time: 2.84
[24,   200] loss: 0.593 acc: 76.59 time: 2.63
[24,   300] loss: 0.602 acc: 76.66 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 76.75 %
Average loss on the 10000 test images: 0.588
[25,   100] loss: 0.598 acc: 76.41 time: 2.78
[25,   200] loss: 0.586 acc: 76.97 time: 2.63
[25,   300] loss: 0.596 acc: 76.75 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 77.29 %
Average loss on the 10000 test images: 0.576
[26,   100] loss: 0.576 acc: 77.37 time: 2.74
[26,   200] loss: 0.596 acc: 76.66 time: 2.63
[26,   300] loss: 0.598 acc: 76.53 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 77.38 %
Average loss on the 10000 test images: 0.572
[27,   100] loss: 0.588 acc: 76.59 time: 2.79
[27,   200] loss: 0.593 acc: 76.76 time: 2.63
[27,   300] loss: 0.587 acc: 77.00 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 77.41 %
Average loss on the 10000 test images: 0.565
[28,   100] loss: 0.593 acc: 77.06 time: 2.77
[28,   200] loss: 0.579 acc: 77.34 time: 2.62
[28,   300] loss: 0.576 acc: 77.33 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 77.66 %
Average loss on the 10000 test images: 0.564
[29,   100] loss: 0.588 acc: 76.77 time: 2.75
[29,   200] loss: 0.573 acc: 77.84 time: 2.64
[29,   300] loss: 0.568 acc: 77.84 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 77.27 %
Average loss on the 10000 test images: 0.565
[30,   100] loss: 0.560 acc: 78.27 time: 2.77
[30,   200] loss: 0.563 acc: 77.93 time: 2.65
[30,   300] loss: 0.570 acc: 77.69 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 77.66 %
Average loss on the 10000 test images: 0.562
[31,   100] loss: 0.558 acc: 78.41 time: 2.74
[31,   200] loss: 0.554 acc: 78.16 time: 2.65
[31,   300] loss: 0.557 acc: 78.23 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 78.34 %
Average loss on the 10000 test images: 0.544
[32,   100] loss: 0.552 acc: 78.33 time: 2.74
[32,   200] loss: 0.549 acc: 78.38 time: 2.65
[32,   300] loss: 0.552 acc: 78.62 time: 2.66
```

```
TESTING:
Accuracy of the network on the 10000 test images: 78.70 %
Average loss on the 10000 test images: 0.551
[33,   100] loss: 0.553 acc: 78.50 time: 2.75
[33,   200] loss: 0.551 acc: 78.26 time: 2.64
[33,   300] loss: 0.555 acc: 78.53 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 78.03 %
Average loss on the 10000 test images: 0.554
[34,   100] loss: 0.544 acc: 78.63 time: 2.75
[34,   200] loss: 0.553 acc: 78.48 time: 2.62
[34,   300] loss: 0.554 acc: 78.35 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 78.55 %
Average loss on the 10000 test images: 0.546
[35,   100] loss: 0.554 acc: 78.53 time: 2.77
[35,   200] loss: 0.556 acc: 78.08 time: 2.63
[35,   300] loss: 0.549 acc: 78.38 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 78.71 %
Average loss on the 10000 test images: 0.540
[36,   100] loss: 0.549 acc: 78.66 time: 2.78
[36,   200] loss: 0.547 acc: 78.91 time: 2.63
[36,   300] loss: 0.552 acc: 78.57 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 78.56 %
Average loss on the 10000 test images: 0.547
[37,   100] loss: 0.541 acc: 79.07 time: 2.75
[37,   200] loss: 0.548 acc: 78.59 time: 2.64
[37,   300] loss: 0.559 acc: 78.54 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 78.47 %
Average loss on the 10000 test images: 0.542
[38,   100] loss: 0.546 acc: 78.66 time: 2.74
[38,   200] loss: 0.552 acc: 78.66 time: 2.64
[38,   300] loss: 0.535 acc: 79.23 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 78.58 %
Average loss on the 10000 test images: 0.544
[39,   100] loss: 0.554 acc: 78.12 time: 2.74
[39,   200] loss: 0.546 acc: 78.54 time: 2.62
[39,   300] loss: 0.541 acc: 78.98 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 78.58 %
Average loss on the 10000 test images: 0.545
[40,   100] loss: 0.546 acc: 78.73 time: 2.74
[40,   200] loss: 0.542 acc: 78.88 time: 2.81
[40,   300] loss: 0.550 acc: 78.92 time: 2.75
TESTING:
Accuracy of the network on the 10000 test images: 78.77 %
Average loss on the 10000 test images: 0.539
[41,   100] loss: 0.544 acc: 78.93 time: 2.93
[41,   200] loss: 0.550 acc: 78.80 time: 2.70
[41,   300] loss: 0.544 acc: 78.87 time: 2.81
TESTING:
Accuracy of the network on the 10000 test images: 78.67 %
Average loss on the 10000 test images: 0.541
[42,   100] loss: 0.536 acc: 78.93 time: 2.92
[42,   200] loss: 0.554 acc: 78.81 time: 2.78
[42,   300] loss: 0.533 acc: 79.23 time: 2.78
TESTING:
Accuracy of the network on the 10000 test images: 78.56 %
Average loss on the 10000 test images: 0.548
```

```
[43,   100] loss: 0.561 acc: 77.83 time: 2.91
[43,   200] loss: 0.535 acc: 78.91 time: 2.81
[43,   300] loss: 0.538 acc: 78.90 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 78.67 %
Average loss on the 10000 test images: 0.538
[44,   100] loss: 0.540 acc: 79.04 time: 2.94
[44,   200] loss: 0.542 acc: 78.95 time: 2.68
[44,   300] loss: 0.544 acc: 78.87 time: 2.80
TESTING:
Accuracy of the network on the 10000 test images: 78.78 %
Average loss on the 10000 test images: 0.543
[45,   100] loss: 0.538 acc: 78.91 time: 2.90
[45,   200] loss: 0.538 acc: 79.22 time: 2.79
[45,   300] loss: 0.545 acc: 78.92 time: 2.78
TESTING:
Accuracy of the network on the 10000 test images: 78.99 %
Average loss on the 10000 test images: 0.539
Finished Training
```

Fine-tuning on the pre-trained model (9 points)

In this section, we will load the ResNet18 model pre-trained on the rotation task and fine-tune on the classification task. We will freeze all previous layers except for the 'layer4' block and 'fc' layer.

Then we will use the trained model from rotation task as the pretrained weights. Notice, you should not use the pretrained weights from ImageNet.

In [11]:
```python
import torch.nn as nn
import torch.nn.functional as F

from torchvision.models import resnet18

################################################
#     TODO: Load the pre-trained ResNet18 model     #
################################################
ckpt = torch.load('rotation_model.pt')
net = resnet18(weights = None, num_classes = 4)
net.load_state_dict(ckpt)
num_classes=10
net.fc = torch.nn.Linear(net.fc.in_features, num_classes)
net = net.to(device)
print(net) # print your model and check the num_classes is correct
################################################
#                End of your code                  #
################################################
```

```
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_runn
ing_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ce
il_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), paddin
g=(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=Fals
e)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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=10, bias=True)
)
```

In [12]:
```
################################################################################
#   TODO: Freeze all previous layers; only keep the 'layer4' block and 'f
################################################################################
for name, param in net.named_parameters():
    if 'layer4' not in name and 'fc' not in name:
        param.requires_grad = False
################################################################################
#                                                End of your code
################################################################################
```

In [13]:
```
# Print all the trainable parameters
params_to_update = net.parameters()
print("Params to learn:")
params_to_update = []
for name,param in net.named_parameters():
    if param.requires_grad == True:
        params_to_update.append(param)
        print("\t",name)
```

```
Params to learn:
	 layer4.0.conv1.weight
	 layer4.0.bn1.weight
	 layer4.0.bn1.bias
	 layer4.0.conv2.weight
	 layer4.0.bn2.weight
	 layer4.0.bn2.bias
	 layer4.0.downsample.0.weight
	 layer4.0.downsample.1.weight
	 layer4.0.downsample.1.bias
	 layer4.1.conv1.weight
	 layer4.1.bn1.weight
	 layer4.1.bn1.bias
	 layer4.1.conv2.weight
	 layer4.1.bn2.weight
	 layer4.1.bn2.bias
	 fc.weight
	 fc.bias
```

In [14]:
```
# TODO: Define criterion and optimizer
# Note that your optimizer only needs to update the parameters that are t
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(filter(lambda x: x.requires_grad, net.parameters(
```

In [15]:
```
train(net, criterion, optimizer, num_epochs=20, decay_epochs=10, init_lr=
```

```
[1,   100] loss: 1.719 acc: 35.77 time: 2.88
[1,   200] loss: 1.448 acc: 46.83 time: 2.62
[1,   300] loss: 1.394 acc: 49.17 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 53.14 %
Average loss on the 10000 test images: 1.302
[2,   100] loss: 1.345 acc: 50.95 time: 2.78
[2,   200] loss: 1.325 acc: 51.64 time: 2.68
[2,   300] loss: 1.308 acc: 52.34 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 55.44 %
Average loss on the 10000 test images: 1.238
[3,   100] loss: 1.299 acc: 52.71 time: 2.73
[3,   200] loss: 1.268 acc: 54.27 time: 2.61
[3,   300] loss: 1.279 acc: 54.37 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 54.42 %
Average loss on the 10000 test images: 1.278
[4,   100] loss: 1.268 acc: 53.99 time: 2.74
[4,   200] loss: 1.255 acc: 54.99 time: 2.63
[4,   300] loss: 1.260 acc: 54.08 time: 2.56
TESTING:
Accuracy of the network on the 10000 test images: 56.69 %
Average loss on the 10000 test images: 1.199
[5,   100] loss: 1.245 acc: 55.09 time: 2.77
[5,   200] loss: 1.242 acc: 55.00 time: 2.65
[5,   300] loss: 1.244 acc: 54.87 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 56.74 %
Average loss on the 10000 test images: 1.193
[6,   100] loss: 1.226 acc: 55.60 time: 2.76
[6,   200] loss: 1.248 acc: 54.84 time: 2.62
[6,   300] loss: 1.234 acc: 55.84 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 57.18 %
Average loss on the 10000 test images: 1.197
[7,   100] loss: 1.218 acc: 56.13 time: 2.75
[7,   200] loss: 1.219 acc: 56.06 time: 2.65
[7,   300] loss: 1.212 acc: 56.40 time: 2.68
TESTING:
Accuracy of the network on the 10000 test images: 57.48 %
Average loss on the 10000 test images: 1.189
[8,   100] loss: 1.195 acc: 56.74 time: 2.78
[8,   200] loss: 1.209 acc: 56.26 time: 2.63
[8,   300] loss: 1.208 acc: 57.01 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 57.91 %
Average loss on the 10000 test images: 1.177
[9,   100] loss: 1.204 acc: 56.90 time: 2.86
[9,   200] loss: 1.195 acc: 56.80 time: 2.66
[9,   300] loss: 1.215 acc: 56.38 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 57.54 %
Average loss on the 10000 test images: 1.181
[10,   100] loss: 1.190 acc: 57.02 time: 2.85
[10,   200] loss: 1.194 acc: 56.66 time: 2.70
[10,   300] loss: 1.191 acc: 56.84 time: 2.71
TESTING:
Accuracy of the network on the 10000 test images: 57.90 %
Average loss on the 10000 test images: 1.197
[11,   100] loss: 1.164 acc: 57.83 time: 2.78
[11,   200] loss: 1.128 acc: 59.03 time: 2.65
[11,   300] loss: 1.130 acc: 59.47 time: 2.60
```

```
TESTING:
Accuracy of the network on the 10000 test images: 60.79 %
Average loss on the 10000 test images: 1.110
[12,   100] loss: 1.125 acc: 59.31 time: 2.78
[12,   200] loss: 1.108 acc: 60.25 time: 2.64
[12,   300] loss: 1.123 acc: 59.41 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 60.84 %
Average loss on the 10000 test images: 1.098
[13,   100] loss: 1.100 acc: 60.16 time: 2.74
[13,   200] loss: 1.112 acc: 59.99 time: 2.58
[13,   300] loss: 1.127 acc: 59.17 time: 2.57
TESTING:
Accuracy of the network on the 10000 test images: 61.13 %
Average loss on the 10000 test images: 1.089
[14,   100] loss: 1.118 acc: 59.12 time: 2.72
[14,   200] loss: 1.102 acc: 60.34 time: 2.59
[14,   300] loss: 1.109 acc: 60.02 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 61.12 %
Average loss on the 10000 test images: 1.091
[15,   100] loss: 1.100 acc: 60.63 time: 2.77
[15,   200] loss: 1.094 acc: 60.45 time: 2.64
[15,   300] loss: 1.112 acc: 60.16 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 61.27 %
Average loss on the 10000 test images: 1.086
[16,   100] loss: 1.098 acc: 59.87 time: 2.71
[16,   200] loss: 1.111 acc: 59.70 time: 2.60
[16,   300] loss: 1.107 acc: 59.52 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 61.50 %
Average loss on the 10000 test images: 1.090
[17,   100] loss: 1.083 acc: 60.89 time: 2.71
[17,   200] loss: 1.095 acc: 60.27 time: 2.62
[17,   300] loss: 1.091 acc: 60.48 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 61.61 %
Average loss on the 10000 test images: 1.084
[18,   100] loss: 1.088 acc: 60.52 time: 2.74
[18,   200] loss: 1.089 acc: 60.45 time: 2.64
[18,   300] loss: 1.084 acc: 60.90 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 61.18 %
Average loss on the 10000 test images: 1.086
[19,   100] loss: 1.094 acc: 60.85 time: 2.77
[19,   200] loss: 1.078 acc: 61.28 time: 2.59
[19,   300] loss: 1.088 acc: 60.70 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 61.87 %
Average loss on the 10000 test images: 1.077
[20,   100] loss: 1.080 acc: 61.37 time: 2.81
[20,   200] loss: 1.095 acc: 59.96 time: 2.78
[20,   300] loss: 1.087 acc: 60.75 time: 2.72
TESTING:
Accuracy of the network on the 10000 test images: 62.09 %
Average loss on the 10000 test images: 1.072
Finished Training
```

Out[15]:
```
62.09
```

Fine-tuning on the randomly initialized model (9 points)

In this section, we will randomly initialize a ResNet18 model and fine-tune on the classification task. We will freeze all previous layers except for the 'layer4' block and 'fc' layer.

In [16]:
```
import torch.nn as nn
import torch.nn.functional as F

from torchvision.models import resnet18
################################################
# TODO: Randomly initialize a ResNet18 model    #
################################################
net = resnet18(weights=None, num_classes= 10)  ### not sure
net = net.to(device)
print(net) # print your model and check the num_classes is correct
################################################
#              End of your code                 #
################################################
```

```
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_runn
ing_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ce
il_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), paddin
g=(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=Fals
e)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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=10, bias=True)
)
```

In [17]:
```
################################################################################
# TODO: Freeze all previous layers; only keep the 'layer4' block and 'fc'
# To do this, you should set requires_grad=False for the frozen layers.
################################################################################
for name, param in net.named_parameters():
    if 'layer4' not in name and 'fc' not in name:
        param.requires_grad = False
################################################################################
#                                                End of your code
################################################################################
```

In [18]:
```
# Print all the trainable parameters
params_to_update = net.parameters()
print("Params to learn:")
params_to_update = []
for name,param in net.named_parameters():
    if param.requires_grad == True:
        params_to_update.append(param)
        print("\t",name)
```

```
Params to learn:
	 layer4.0.conv1.weight
	 layer4.0.bn1.weight
	 layer4.0.bn1.bias
	 layer4.0.conv2.weight
	 layer4.0.bn2.weight
	 layer4.0.bn2.bias
	 layer4.0.downsample.0.weight
	 layer4.0.downsample.1.weight
	 layer4.0.downsample.1.bias
	 layer4.1.conv1.weight
	 layer4.1.bn1.weight
	 layer4.1.bn1.bias
	 layer4.1.conv2.weight
	 layer4.1.bn2.weight
	 layer4.1.bn2.bias
	 fc.weight
	 fc.bias
```

In [19]:
```
# TODO: Define criterion and optimizer
# Note that your optimizer only needs to update the parameters that are t
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(filter(lambda x: x.requires_grad, net.parameters(
```

In [20]:
```
train(net, criterion, optimizer, num_epochs=20, decay_epochs=10, init_lr=
```

```
[1,   100] loss: 2.220 acc: 25.75 time: 2.82
[1,   200] loss: 1.931 acc: 31.19 time: 2.69
[1,   300] loss: 1.854 acc: 32.55 time: 2.81
TESTING:
Accuracy of the network on the 10000 test images: 36.04 %
Average loss on the 10000 test images: 1.774
[2,   100] loss: 1.798 acc: 35.19 time: 2.84
[2,   200] loss: 1.779 acc: 35.55 time: 2.63
[2,   300] loss: 1.775 acc: 35.39 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 39.19 %
Average loss on the 10000 test images: 1.676
[3,   100] loss: 1.757 acc: 36.02 time: 2.75
[3,   200] loss: 1.742 acc: 37.20 time: 2.59
[3,   300] loss: 1.735 acc: 36.70 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 40.46 %
Average loss on the 10000 test images: 1.652
[4,   100] loss: 1.716 acc: 37.57 time: 2.75
[4,   200] loss: 1.718 acc: 38.16 time: 2.67
[4,   300] loss: 1.709 acc: 38.20 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 41.21 %
Average loss on the 10000 test images: 1.633
[5,   100] loss: 1.685 acc: 39.00 time: 2.71
[5,   200] loss: 1.706 acc: 38.41 time: 2.59
[5,   300] loss: 1.691 acc: 39.02 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 41.86 %
Average loss on the 10000 test images: 1.629
[6,   100] loss: 1.690 acc: 39.12 time: 2.84
[6,   200] loss: 1.674 acc: 38.95 time: 2.75
[6,   300] loss: 1.682 acc: 39.20 time: 2.72
TESTING:
Accuracy of the network on the 10000 test images: 41.13 %
Average loss on the 10000 test images: 1.650
[7,   100] loss: 1.680 acc: 38.66 time: 2.78
[7,   200] loss: 1.682 acc: 38.99 time: 2.64
[7,   300] loss: 1.672 acc: 40.47 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 42.03 %
Average loss on the 10000 test images: 1.608
[8,   100] loss: 1.660 acc: 40.71 time: 2.73
[8,   200] loss: 1.667 acc: 40.28 time: 2.62
[8,   300] loss: 1.658 acc: 40.01 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 41.97 %
Average loss on the 10000 test images: 1.627
[9,   100] loss: 1.642 acc: 40.86 time: 2.76
[9,   200] loss: 1.652 acc: 40.70 time: 2.69
[9,   300] loss: 1.656 acc: 40.60 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 42.06 %
Average loss on the 10000 test images: 1.609
[10,   100] loss: 1.644 acc: 40.25 time: 2.77
[10,   200] loss: 1.645 acc: 41.09 time: 2.66
[10,   300] loss: 1.647 acc: 40.73 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 42.89 %
Average loss on the 10000 test images: 1.600
[11,   100] loss: 1.617 acc: 41.85 time: 2.76
[11,   200] loss: 1.605 acc: 42.04 time: 2.63
[11,   300] loss: 1.579 acc: 43.24 time: 2.62
```

```
TESTING:
Accuracy of the network on the 10000 test images: 44.42 %
Average loss on the 10000 test images: 1.554
[12,   100] loss: 1.571 acc: 42.93 time: 2.76
[12,   200] loss: 1.585 acc: 42.97 time: 2.67
[12,   300] loss: 1.579 acc: 43.45 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 44.88 %
Average loss on the 10000 test images: 1.540
[13,   100] loss: 1.567 acc: 43.74 time: 2.91
[13,   200] loss: 1.563 acc: 43.39 time: 2.67
[13,   300] loss: 1.587 acc: 43.23 time: 2.68
TESTING:
Accuracy of the network on the 10000 test images: 45.31 %
Average loss on the 10000 test images: 1.532
[14,   100] loss: 1.562 acc: 43.34 time: 2.74
[14,   200] loss: 1.557 acc: 43.89 time: 2.67
[14,   300] loss: 1.568 acc: 43.19 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 45.20 %
Average loss on the 10000 test images: 1.528
[15,   100] loss: 1.565 acc: 44.11 time: 2.74
[15,   200] loss: 1.559 acc: 43.84 time: 2.62
[15,   300] loss: 1.568 acc: 43.77 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 45.36 %
Average loss on the 10000 test images: 1.526
[16,   100] loss: 1.568 acc: 43.97 time: 2.70
[16,   200] loss: 1.542 acc: 45.43 time: 2.60
[16,   300] loss: 1.552 acc: 44.12 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 45.37 %
Average loss on the 10000 test images: 1.524
[17,   100] loss: 1.543 acc: 44.28 time: 2.78
[17,   200] loss: 1.539 acc: 44.80 time: 2.66
[17,   300] loss: 1.554 acc: 44.37 time: 2.58
TESTING:
Accuracy of the network on the 10000 test images: 45.31 %
Average loss on the 10000 test images: 1.518
[18,   100] loss: 1.538 acc: 44.55 time: 2.76
[18,   200] loss: 1.546 acc: 44.57 time: 2.66
[18,   300] loss: 1.554 acc: 44.12 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 45.82 %
Average loss on the 10000 test images: 1.515
[19,   100] loss: 1.553 acc: 43.59 time: 2.72
[19,   200] loss: 1.528 acc: 45.02 time: 2.63
[19,   300] loss: 1.541 acc: 44.60 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 45.53 %
Average loss on the 10000 test images: 1.511
[20,   100] loss: 1.533 acc: 44.84 time: 2.74
[20,   200] loss: 1.544 acc: 44.27 time: 2.60
[20,   300] loss: 1.542 acc: 44.72 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 45.31 %
Average loss on the 10000 test images: 1.516
Finished Training
```

Out[20]:
```
45.31
```

Supervised training on the pre-trained model (9 points)

In this section, we will load the ResNet18 model pre-trained on the rotation task and re-train the whole model on the classification task.

Then we will use the trained model from rotation task as the pretrained weights. Notice, you should not use the pretrained weights from ImageNet.

In [21]:
```
import torch.nn as nn
import torch.nn.functional as F

from torchvision.models import resnet18

########################################################
#     TODO: Load the pre-trained ResNet18 model     #
########################################################
ckpt = torch.load('rotation_model.pt')
net = resnet18(weights = None, num_classes = 4)
net.load_state_dict(ckpt)
num_classes=10
net.fc = torch.nn.Linear(net.fc.in_features, num_classes)
net = net.to(device)
print(net) # print your model and check the num_classes is correct
########################################################
#                End of your code                      #
########################################################
```

```
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_runn
ing_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ce
il_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), paddin
g=(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=Fals
e)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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=10, bias=True)
)
```

In [22]:
```
# TODO: Define criterion and optimizer
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(net.parameters(),lr=3e-4)
```

In [23]:
```
train(net, criterion, optimizer, num_epochs=20, decay_epochs=10, init_lr=
```

```
[1,   100] loss: 1.482 acc: 45.45 time: 2.77
[1,   200] loss: 1.170 acc: 58.62 time: 2.65
[1,   300] loss: 1.073 acc: 62.38 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 64.69 %
Average loss on the 10000 test images: 1.020
[2,   100] loss: 0.968 acc: 65.83 time: 2.71
[2,   200] loss: 0.915 acc: 67.48 time: 2.69
[2,   300] loss: 0.895 acc: 68.64 time: 2.82
TESTING:
Accuracy of the network on the 10000 test images: 67.42 %
Average loss on the 10000 test images: 0.958
[3,   100] loss: 0.839 acc: 70.97 time: 2.85
[3,   200] loss: 0.833 acc: 71.14 time: 2.79
[3,   300] loss: 0.830 acc: 71.56 time: 2.82
TESTING:
Accuracy of the network on the 10000 test images: 69.20 %
Average loss on the 10000 test images: 0.918
[4,   100] loss: 0.777 acc: 72.96 time: 2.76
[4,   200] loss: 0.766 acc: 73.50 time: 2.65
[4,   300] loss: 0.747 acc: 74.21 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 74.80 %
Average loss on the 10000 test images: 0.730
[5,   100] loss: 0.706 acc: 75.91 time: 2.74
[5,   200] loss: 0.711 acc: 75.16 time: 2.64
[5,   300] loss: 0.713 acc: 75.38 time: 2.59
TESTING:
Accuracy of the network on the 10000 test images: 75.07 %
Average loss on the 10000 test images: 0.740
[6,   100] loss: 0.679 acc: 76.84 time: 2.73
[6,   200] loss: 0.675 acc: 76.74 time: 2.62
[6,   300] loss: 0.660 acc: 77.45 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 74.90 %
Average loss on the 10000 test images: 0.738
[7,   100] loss: 0.645 acc: 77.92 time: 2.75
[7,   200] loss: 0.633 acc: 78.17 time: 2.66
[7,   300] loss: 0.638 acc: 78.09 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 76.59 %
Average loss on the 10000 test images: 0.695
[8,   100] loss: 0.610 acc: 78.63 time: 2.80
[8,   200] loss: 0.616 acc: 78.96 time: 2.79
[8,   300] loss: 0.623 acc: 78.05 time: 2.76
TESTING:
Accuracy of the network on the 10000 test images: 76.31 %
Average loss on the 10000 test images: 0.711
[9,   100] loss: 0.590 acc: 79.64 time: 2.78
[9,   200] loss: 0.614 acc: 79.00 time: 2.66
[9,   300] loss: 0.603 acc: 79.34 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 76.87 %
Average loss on the 10000 test images: 0.669
[10,   100] loss: 0.582 acc: 80.04 time: 2.75
[10,   200] loss: 0.580 acc: 80.20 time: 2.63
[10,   300] loss: 0.588 acc: 80.15 time: 2.71
TESTING:
Accuracy of the network on the 10000 test images: 78.88 %
Average loss on the 10000 test images: 0.621
[11,   100] loss: 0.488 acc: 83.27 time: 2.76
[11,   200] loss: 0.460 acc: 83.94 time: 2.80
[11,   300] loss: 0.440 acc: 84.83 time: 2.79
```

```
TESTING:
Accuracy of the network on the 10000 test images: 83.01 %
Average loss on the 10000 test images: 0.501
[12,   100] loss: 0.430 acc: 85.08 time: 2.96
[12,   200] loss: 0.406 acc: 86.16 time: 2.80
[12,   300] loss: 0.424 acc: 85.23 time: 2.82
TESTING:
Accuracy of the network on the 10000 test images: 83.48 %
Average loss on the 10000 test images: 0.491
[13,   100] loss: 0.400 acc: 86.34 time: 2.76
[13,   200] loss: 0.414 acc: 85.64 time: 2.67
[13,   300] loss: 0.394 acc: 86.44 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 83.55 %
Average loss on the 10000 test images: 0.484
[14,   100] loss: 0.398 acc: 86.15 time: 2.75
[14,   200] loss: 0.395 acc: 86.31 time: 2.65
[14,   300] loss: 0.397 acc: 86.16 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 83.70 %
Average loss on the 10000 test images: 0.483
[15,   100] loss: 0.376 acc: 86.36 time: 2.73
[15,   200] loss: 0.371 acc: 87.11 time: 2.64
[15,   300] loss: 0.386 acc: 86.74 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 83.93 %
Average loss on the 10000 test images: 0.471
[16,   100] loss: 0.380 acc: 86.81 time: 2.77
[16,   200] loss: 0.361 acc: 87.62 time: 2.65
[16,   300] loss: 0.364 acc: 87.15 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 84.00 %
Average loss on the 10000 test images: 0.478
[17,   100] loss: 0.374 acc: 86.96 time: 2.93
[17,   200] loss: 0.371 acc: 86.94 time: 2.81
[17,   300] loss: 0.353 acc: 87.52 time: 2.78
TESTING:
Accuracy of the network on the 10000 test images: 84.01 %
Average loss on the 10000 test images: 0.482
[18,   100] loss: 0.347 acc: 87.98 time: 2.91
[18,   200] loss: 0.357 acc: 87.71 time: 2.80
[18,   300] loss: 0.367 acc: 87.55 time: 2.73
TESTING:
Accuracy of the network on the 10000 test images: 84.17 %
Average loss on the 10000 test images: 0.473
[19,   100] loss: 0.348 acc: 87.87 time: 2.87
[19,   200] loss: 0.349 acc: 88.12 time: 2.65
[19,   300] loss: 0.337 acc: 87.91 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 84.34 %
Average loss on the 10000 test images: 0.467
[20,   100] loss: 0.336 acc: 88.30 time: 2.75
[20,   200] loss: 0.340 acc: 88.45 time: 2.62
[20,   300] loss: 0.346 acc: 87.88 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 84.11 %
Average loss on the 10000 test images: 0.471
Finished Training
```

Out[23]:
```
84.11
```

Supervised training on the randomly initialized model (9 points)

In this section, we will randomly initialize a ResNet18 model and re-train the whole model on the classification task.

In [24]:
```
import torch.nn as nn
import torch.nn.functional as F

from torchvision.models import resnet18

################################################
# TODO: Randomly initialize a ResNet18 model    #
################################################
net = resnet18(weights= None, num_classes=10)
net = net.to(device)
print(net) # print your model and check the num_classes is correct
################################################
#              End of your code                 #
################################################
```

```
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_runn
ing_stats=True)
  (relu): ReLU(inplace=True)
  (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ce
il_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), paddin
g=(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=Fals
e)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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), paddin
g=(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), paddin
g=(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=Fal
se)
        (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), paddin
g=(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), paddin
g=(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=10, bias=True)
)
```

In [25]:
```
# TODO: Define criterion and optimizer
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(net.parameters(),lr=3e-4)
```

In [26]:
```
train(net, criterion, optimizer, num_epochs=20, decay_epochs=10, init_lr=
```

```
[1,   100] loss: 2.257 acc: 22.14 time: 2.80
[1,   200] loss: 1.836 acc: 31.90 time: 2.66
[1,   300] loss: 1.722 acc: 36.92 time: 2.68
TESTING:
Accuracy of the network on the 10000 test images: 40.66 %
Average loss on the 10000 test images: 1.578
[2,   100] loss: 1.561 acc: 42.39 time: 2.73
[2,   200] loss: 1.469 acc: 45.92 time: 2.81
[2,   300] loss: 1.400 acc: 48.48 time: 2.81
TESTING:
Accuracy of the network on the 10000 test images: 53.12 %
Average loss on the 10000 test images: 1.298
[3,   100] loss: 1.297 acc: 52.70 time: 2.80
[3,   200] loss: 1.224 acc: 56.20 time: 2.64
[3,   300] loss: 1.181 acc: 57.67 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 58.44 %
Average loss on the 10000 test images: 1.165
[4,   100] loss: 1.119 acc: 59.87 time: 2.75
[4,   200] loss: 1.095 acc: 60.70 time: 2.65
[4,   300] loss: 1.064 acc: 62.37 time: 2.69
TESTING:
Accuracy of the network on the 10000 test images: 64.70 %
Average loss on the 10000 test images: 0.996
[5,   100] loss: 1.004 acc: 64.07 time: 2.90
[5,   200] loss: 0.960 acc: 66.20 time: 2.75
[5,   300] loss: 0.948 acc: 66.87 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 67.68 %
Average loss on the 10000 test images: 0.932
[6,   100] loss: 0.904 acc: 67.96 time: 2.77
[6,   200] loss: 0.908 acc: 68.38 time: 2.62
[6,   300] loss: 0.886 acc: 68.59 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 71.11 %
Average loss on the 10000 test images: 0.826
[7,   100] loss: 0.819 acc: 71.36 time: 2.74
[7,   200] loss: 0.826 acc: 71.52 time: 2.64
[7,   300] loss: 0.839 acc: 70.82 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 73.02 %
Average loss on the 10000 test images: 0.797
[8,   100] loss: 0.788 acc: 72.46 time: 2.77
[8,   200] loss: 0.766 acc: 73.08 time: 2.67
[8,   300] loss: 0.777 acc: 73.78 time: 2.83
TESTING:
Accuracy of the network on the 10000 test images: 72.91 %
Average loss on the 10000 test images: 0.791
[9,   100] loss: 0.751 acc: 73.36 time: 2.92
[9,   200] loss: 0.742 acc: 73.60 time: 2.86
[9,   300] loss: 0.744 acc: 74.44 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 74.54 %
Average loss on the 10000 test images: 0.731
[10,   100] loss: 0.714 acc: 75.21 time: 2.86
[10,   200] loss: 0.716 acc: 75.21 time: 2.87
[10,   300] loss: 0.696 acc: 75.77 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 76.78 %
Average loss on the 10000 test images: 0.681
[11,   100] loss: 0.588 acc: 79.66 time: 2.91
[11,   200] loss: 0.581 acc: 80.03 time: 2.77
[11,   300] loss: 0.546 acc: 80.88 time: 2.79
```

```
TESTING:
Accuracy of the network on the 10000 test images: 80.76 %
Average loss on the 10000 test images: 0.566
[12,   100] loss: 0.536 acc: 81.68 time: 2.86
[12,   200] loss: 0.532 acc: 81.62 time: 2.75
[12,   300] loss: 0.515 acc: 82.01 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 81.08 %
Average loss on the 10000 test images: 0.553
[13,   100] loss: 0.507 acc: 82.56 time: 2.93
[13,   200] loss: 0.514 acc: 81.83 time: 2.73
[13,   300] loss: 0.498 acc: 82.53 time: 2.81
TESTING:
Accuracy of the network on the 10000 test images: 81.39 %
Average loss on the 10000 test images: 0.549
[14,   100] loss: 0.490 acc: 82.95 time: 2.77
[14,   200] loss: 0.499 acc: 82.45 time: 2.67
[14,   300] loss: 0.508 acc: 82.35 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 81.24 %
Average loss on the 10000 test images: 0.547
[15,   100] loss: 0.470 acc: 83.95 time: 2.79
[15,   200] loss: 0.471 acc: 83.23 time: 2.62
[15,   300] loss: 0.487 acc: 83.03 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 81.84 %
Average loss on the 10000 test images: 0.531
[16,   100] loss: 0.473 acc: 83.44 time: 2.79
[16,   200] loss: 0.455 acc: 84.04 time: 2.61
[16,   300] loss: 0.478 acc: 83.34 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 81.97 %
Average loss on the 10000 test images: 0.532
[17,   100] loss: 0.446 acc: 84.33 time: 2.80
[17,   200] loss: 0.472 acc: 83.71 time: 2.61
[17,   300] loss: 0.464 acc: 84.13 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 82.29 %
Average loss on the 10000 test images: 0.527
[18,   100] loss: 0.454 acc: 84.35 time: 2.78
[18,   200] loss: 0.450 acc: 84.48 time: 2.71
[18,   300] loss: 0.438 acc: 84.76 time: 2.77
TESTING:
Accuracy of the network on the 10000 test images: 82.17 %
Average loss on the 10000 test images: 0.522
[19,   100] loss: 0.442 acc: 84.83 time: 2.83
[19,   200] loss: 0.433 acc: 85.14 time: 2.65
[19,   300] loss: 0.434 acc: 84.71 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 82.43 %
Average loss on the 10000 test images: 0.520
[20,   100] loss: 0.419 acc: 85.37 time: 2.78
[20,   200] loss: 0.428 acc: 85.04 time: 2.60
[20,   300] loss: 0.429 acc: 85.09 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 82.33 %
Average loss on the 10000 test images: 0.523
Finished Training
```

Out[26]:
```
82.33
```

Write report (37 points)

本次作業主要有3個tasks需要大家完成，在A4.pdf中有希望大家達成的baseline **(不能低於baseline最多2%，沒有達到不會給全部分數)**，report的撰寫請大家根據以下要求完成，就請大家將嘗試的結果寫在report裡，祝大家順利!

1. (13 points) Train a ResNet18 on the Rotation task and report the test performance. Discuss why such a task helps in learning features that are generalizable to other visual tasks.

2. (12 points) Initializing from the Rotation model or from random weights, fine-tune only the weights of the final block of convolutional layers and linear layer on the supervised CIFAR10 classification task. Report the test results and compare the performance of these two models. Provide your observations and insights. You can also discuss how the performance of pre-trained models affects downstream tasks, the performance of fine-tuning different numbers of layers, and so on.

3. (12 points) Initializing from the Rotation model or from random weights, train the full network on the supervised CIFAR10 classification task. Report the test results and compare the performance of these two models. Provide your observations and insights.

Extra Credit (13 points)

上面基本的code跟report最高可以拿到87分，這個加分部分並沒有要求同學們一定要做，若同學們想要獲得更高的分數可以根據以下的加分要求來獲得加分。

- In Figure 5(b) from the Gidaris et al. paper, the authors show a plot of CIFAR10 classification performance vs. number of training examples per category for a supervised CIFAR10 model vs. a RotNet model with the final layers fine-tuned on CIFAR10. The plot shows that pre-training on the Rotation task can be advantageous when only a small amount of labeled data is available. Using your RotNet fine-tuning code and supervised CIFAR10 training code from the main assignment, try to create a similar plot by performing supervised fine-tuning/training on only a subset of CIFAR10.
- Use a more advanced model than ResNet18 to try to get higher accuracy on the rotation prediction task, as well as for transfer to supervised CIFAR10 classification.

- If you have a good amount of compute at your disposal, try to train a rotation prediction model on the larger ImageNette dataset (still smaller than ImageNet, though).

- plot supervised v.s. fine-tuning when trained on only a subset of CIFAR10

In [27]:
```
import matplotlib.pyplot as plt


def get_data_subset(dataset, num_examples_per_class):
    # Obtain all possible classes from the dataset
    classes = np.unique(np.array(dataset.targets))

    # Placeholder for indices to extract for the subset
    indices = []

    # Loop over each class and randomly select num_examples_per_class ind
    for cls in classes:
        cls_indices = np.where(np.array(dataset.targets) == cls)[0]
        cls_subset_indices = np.random.choice(cls_indices, num_examples_p
        indices.extend(cls_subset_indices)

    # Use Subset to create a new dataset from the selected indices
    subset_dataset = torch.utils.data.Subset(dataset, indices)

    return subset_dataset



# Number of samples per class for subsetting the CIFAR10 dataset
samples_per_class = [20, 100, 400, 1000, 5000]

fine_tune_accuracies = []
supervised_accuracies = []

for spc in samples_per_class:
    # Get a subset of CIFAR10 data
    trainset_subset = get_data_subset(trainset, spc)
    trainloader = torch.utils.data.DataLoader(trainset_subset, batch_size

    ckpt = torch.load('rotation_model.pt')
    net = resnet18(weights = None, num_classes = 4)
    net.load_state_dict(ckpt)
    num_classes=10
    net.fc = torch.nn.Linear(net.fc.in_features, num_classes)
    net = net.to(device)

    for name, param in net.named_parameters():
        if 'layer4' not in name and 'fc' not in name:
            param.requires_grad = False

    criterion = nn.CrossEntropyLoss()
    optimizer = optim.AdamW(filter(lambda x: x.requires_grad, net.paramet

    test_acc = train(net, criterion, optimizer, num_epochs=20, decay_epoc

    fine_tune_accuracies.append(test_acc)




    ckpt = torch.load('rotation_model.pt')
    net2 = resnet18(weights = None, num_classes = 4)
    net2.load_state_dict(ckpt)
    num_classes=10
    net2.fc = torch.nn.Linear(net2.fc.in_features, num_classes)
    net2 = net2.to(device)

    criterion = nn.CrossEntropyLoss()
```

```
    criterion = nn.CrossEntropyLoss()
    optimizer = optim.AdamW(net2.parameters(),lr=3e-4)

    test2_acc = train(net2, criterion, optimizer, num_epochs=20, decay_ep
    supervised_accuracies.append(test2_acc)


# Plot the results
plt.plot(samples_per_class, fine_tune_accuracies, label='Fine-tuned')
plt.plot(samples_per_class, supervised_accuracies, label='Supervised')
plt.xlabel('Number of Training Examples per Class')
plt.ylabel('Accuracy')
plt.legend()
plt.show()
```

```
TESTING:
Accuracy of the network on the 10000 test images: 13.42 %
Average loss on the 10000 test images: 2.221
TESTING:
Accuracy of the network on the 10000 test images: 13.94 %
Average loss on the 10000 test images: 2.241
TESTING:
Accuracy of the network on the 10000 test images: 15.03 %
Average loss on the 10000 test images: 2.213
TESTING:
Accuracy of the network on the 10000 test images: 19.77 %
Average loss on the 10000 test images: 2.158
TESTING:
Accuracy of the network on the 10000 test images: 22.97 %
Average loss on the 10000 test images: 2.107
TESTING:
Accuracy of the network on the 10000 test images: 25.64 %
Average loss on the 10000 test images: 2.045
TESTING:
Accuracy of the network on the 10000 test images: 27.61 %
Average loss on the 10000 test images: 1.993
TESTING:
Accuracy of the network on the 10000 test images: 27.41 %
Average loss on the 10000 test images: 1.980
TESTING:
Accuracy of the network on the 10000 test images: 27.72 %
Average loss on the 10000 test images: 1.976
TESTING:
Accuracy of the network on the 10000 test images: 26.94 %
Average loss on the 10000 test images: 2.020
TESTING:
Accuracy of the network on the 10000 test images: 27.66 %
Average loss on the 10000 test images: 1.997
TESTING:
Accuracy of the network on the 10000 test images: 28.20 %
Average loss on the 10000 test images: 1.982
TESTING:
Accuracy of the network on the 10000 test images: 28.63 %
Average loss on the 10000 test images: 1.963
TESTING:
Accuracy of the network on the 10000 test images: 28.88 %
Average loss on the 10000 test images: 1.954
TESTING:
Accuracy of the network on the 10000 test images: 29.15 %
Average loss on the 10000 test images: 1.949
TESTING:
Accuracy of the network on the 10000 test images: 29.63 %
Average loss on the 10000 test images: 1.935
TESTING:
```

```
Accuracy of the network on the 10000 test images: 29.85 %
Average loss on the 10000 test images: 1.931
TESTING:
Accuracy of the network on the 10000 test images: 29.78 %
Average loss on the 10000 test images: 1.930
TESTING:
Accuracy of the network on the 10000 test images: 29.81 %
Average loss on the 10000 test images: 1.936
TESTING:
Accuracy of the network on the 10000 test images: 29.89 %
Average loss on the 10000 test images: 1.937
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 14.92 %
Average loss on the 10000 test images: 2.170
TESTING:
Accuracy of the network on the 10000 test images: 17.15 %
Average loss on the 10000 test images: 2.445
TESTING:
Accuracy of the network on the 10000 test images: 18.49 %
Average loss on the 10000 test images: 2.514
TESTING:
Accuracy of the network on the 10000 test images: 24.22 %
Average loss on the 10000 test images: 2.263
TESTING:
Accuracy of the network on the 10000 test images: 26.22 %
Average loss on the 10000 test images: 2.244
TESTING:
Accuracy of the network on the 10000 test images: 31.08 %
Average loss on the 10000 test images: 2.100
TESTING:
Accuracy of the network on the 10000 test images: 38.05 %
Average loss on the 10000 test images: 1.902
TESTING:
Accuracy of the network on the 10000 test images: 37.40 %
Average loss on the 10000 test images: 1.982
TESTING:
Accuracy of the network on the 10000 test images: 36.57 %
Average loss on the 10000 test images: 2.207
TESTING:
Accuracy of the network on the 10000 test images: 37.18 %
Average loss on the 10000 test images: 2.449
TESTING:
Accuracy of the network on the 10000 test images: 38.12 %
Average loss on the 10000 test images: 2.381
TESTING:
Accuracy of the network on the 10000 test images: 38.69 %
Average loss on the 10000 test images: 2.316
TESTING:
Accuracy of the network on the 10000 test images: 39.75 %
Average loss on the 10000 test images: 2.271
TESTING:
Accuracy of the network on the 10000 test images: 40.27 %
Average loss on the 10000 test images: 2.242
TESTING:
Accuracy of the network on the 10000 test images: 40.68 %
Average loss on the 10000 test images: 2.229
TESTING:
Accuracy of the network on the 10000 test images: 41.03 %
Average loss on the 10000 test images: 2.216
TESTING:
Accuracy of the network on the 10000 test images: 41.35 %
Average loss on the 10000 test images: 2.214
```

```
TESTING:
Accuracy of the network on the 10000 test images: 41.47 %
Average loss on the 10000 test images: 2.202
TESTING:
Accuracy of the network on the 10000 test images: 41.52 %
Average loss on the 10000 test images: 2.207
TESTING:
Accuracy of the network on the 10000 test images: 41.61 %
Average loss on the 10000 test images: 2.211
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 15.83 %
Average loss on the 10000 test images: 2.180
TESTING:
Accuracy of the network on the 10000 test images: 22.31 %
Average loss on the 10000 test images: 2.059
TESTING:
Accuracy of the network on the 10000 test images: 26.05 %
Average loss on the 10000 test images: 2.048
TESTING:
Accuracy of the network on the 10000 test images: 28.51 %
Average loss on the 10000 test images: 2.002
TESTING:
Accuracy of the network on the 10000 test images: 36.67 %
Average loss on the 10000 test images: 1.723
TESTING:
Accuracy of the network on the 10000 test images: 35.99 %
Average loss on the 10000 test images: 1.786
TESTING:
Accuracy of the network on the 10000 test images: 39.48 %
Average loss on the 10000 test images: 1.682
TESTING:
Accuracy of the network on the 10000 test images: 40.94 %
Average loss on the 10000 test images: 1.623
TESTING:
Accuracy of the network on the 10000 test images: 43.05 %
Average loss on the 10000 test images: 1.594
TESTING:
Accuracy of the network on the 10000 test images: 43.41 %
Average loss on the 10000 test images: 1.584
TESTING:
Accuracy of the network on the 10000 test images: 44.19 %
Average loss on the 10000 test images: 1.552
TESTING:
Accuracy of the network on the 10000 test images: 45.20 %
Average loss on the 10000 test images: 1.530
TESTING:
Accuracy of the network on the 10000 test images: 45.61 %
Average loss on the 10000 test images: 1.533
TESTING:
Accuracy of the network on the 10000 test images: 45.83 %
Average loss on the 10000 test images: 1.527
TESTING:
Accuracy of the network on the 10000 test images: 45.80 %
Average loss on the 10000 test images: 1.530
TESTING:
Accuracy of the network on the 10000 test images: 45.96 %
Average loss on the 10000 test images: 1.520
TESTING:
Accuracy of the network on the 10000 test images: 45.97 %
Average loss on the 10000 test images: 1.514
TESTING:
Accuracy of the network on the 10000 test images: 45.95 %
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Average loss on the 10000 test images: 1.513
TESTING:
Accuracy of the network on the 10000 test images: 46.09 %
Average loss on the 10000 test images: 1.509
TESTING:
Accuracy of the network on the 10000 test images: 45.85 %
Average loss on the 10000 test images: 1.508
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 28.33 %
Average loss on the 10000 test images: 2.230
TESTING:
Accuracy of the network on the 10000 test images: 41.23 %
Average loss on the 10000 test images: 1.701
TESTING:
Accuracy of the network on the 10000 test images: 41.95 %
Average loss on the 10000 test images: 1.644
TESTING:
Accuracy of the network on the 10000 test images: 43.07 %
Average loss on the 10000 test images: 1.745
TESTING:
Accuracy of the network on the 10000 test images: 47.05 %
Average loss on the 10000 test images: 1.596
TESTING:
Accuracy of the network on the 10000 test images: 49.55 %
Average loss on the 10000 test images: 1.488
TESTING:
Accuracy of the network on the 10000 test images: 50.89 %
Average loss on the 10000 test images: 1.486
TESTING:
Accuracy of the network on the 10000 test images: 51.82 %
Average loss on the 10000 test images: 1.494
TESTING:
Accuracy of the network on the 10000 test images: 47.96 %
Average loss on the 10000 test images: 1.747
TESTING:
Accuracy of the network on the 10000 test images: 50.57 %
Average loss on the 10000 test images: 1.686
TESTING:
Accuracy of the network on the 10000 test images: 54.50 %
Average loss on the 10000 test images: 1.469
TESTING:
Accuracy of the network on the 10000 test images: 55.68 %
Average loss on the 10000 test images: 1.397
TESTING:
Accuracy of the network on the 10000 test images: 55.69 %
Average loss on the 10000 test images: 1.387
TESTING:
Accuracy of the network on the 10000 test images: 55.82 %
Average loss on the 10000 test images: 1.394
TESTING:
Accuracy of the network on the 10000 test images: 55.89 %
Average loss on the 10000 test images: 1.410
TESTING:
Accuracy of the network on the 10000 test images: 55.74 %
Average loss on the 10000 test images: 1.428
TESTING:
Accuracy of the network on the 10000 test images: 55.87 %
Average loss on the 10000 test images: 1.434
TESTING:
Accuracy of the network on the 10000 test images: 55.71 %
Average loss on the 10000 test images: 1.444
TESTING:
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Accuracy of the network on the 10000 test images: 55.90 %
Average loss on the 10000 test images: 1.454
TESTING:
Accuracy of the network on the 10000 test images: 55.86 %
Average loss on the 10000 test images: 1.472
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 31.90 %
Average loss on the 10000 test images: 1.892
TESTING:
Accuracy of the network on the 10000 test images: 42.05 %
Average loss on the 10000 test images: 1.573
TESTING:
Accuracy of the network on the 10000 test images: 45.35 %
Average loss on the 10000 test images: 1.496
TESTING:
Accuracy of the network on the 10000 test images: 46.00 %
Average loss on the 10000 test images: 1.513
TESTING:
Accuracy of the network on the 10000 test images: 47.81 %
Average loss on the 10000 test images: 1.433
TESTING:
Accuracy of the network on the 10000 test images: 49.62 %
Average loss on the 10000 test images: 1.409
TESTING:
Accuracy of the network on the 10000 test images: 48.91 %
Average loss on the 10000 test images: 1.415
TESTING:
Accuracy of the network on the 10000 test images: 49.77 %
Average loss on the 10000 test images: 1.415
TESTING:
Accuracy of the network on the 10000 test images: 50.91 %
Average loss on the 10000 test images: 1.378
TESTING:
Accuracy of the network on the 10000 test images: 50.83 %
Average loss on the 10000 test images: 1.390
TESTING:
Accuracy of the network on the 10000 test images: 53.80 %
Average loss on the 10000 test images: 1.304
TESTING:
Accuracy of the network on the 10000 test images: 54.14 %
Average loss on the 10000 test images: 1.297
TESTING:
Accuracy of the network on the 10000 test images: 53.86 %
Average loss on the 10000 test images: 1.295
TESTING:
Accuracy of the network on the 10000 test images: 53.93 %
Average loss on the 10000 test images: 1.297
TESTING:
Accuracy of the network on the 10000 test images: 54.49 %
Average loss on the 10000 test images: 1.293
TESTING:
Accuracy of the network on the 10000 test images: 54.60 %
Average loss on the 10000 test images: 1.286
TESTING:
Accuracy of the network on the 10000 test images: 54.68 %
Average loss on the 10000 test images: 1.287
TESTING:
Accuracy of the network on the 10000 test images: 54.56 %
Average loss on the 10000 test images: 1.288
TESTING:
Accuracy of the network on the 10000 test images: 54.31 %
Average loss on the 10000 test images: 1.288
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TESTING:
Accuracy of the network on the 10000 test images: 54.62 %
Average loss on the 10000 test images: 1.287
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 43.84 %
Average loss on the 10000 test images: 1.518
TESTING:
Accuracy of the network on the 10000 test images: 52.35 %
Average loss on the 10000 test images: 1.358
TESTING:
Accuracy of the network on the 10000 test images: 54.45 %
Average loss on the 10000 test images: 1.273
TESTING:
Accuracy of the network on the 10000 test images: 57.55 %
Average loss on the 10000 test images: 1.267
TESTING:
Accuracy of the network on the 10000 test images: 57.38 %
Average loss on the 10000 test images: 1.291
TESTING:
Accuracy of the network on the 10000 test images: 58.31 %
Average loss on the 10000 test images: 1.264
TESTING:
Accuracy of the network on the 10000 test images: 63.06 %
Average loss on the 10000 test images: 1.081
TESTING:
Accuracy of the network on the 10000 test images: 58.20 %
Average loss on the 10000 test images: 1.240
TESTING:
Accuracy of the network on the 10000 test images: 61.87 %
Average loss on the 10000 test images: 1.180
TESTING:
Accuracy of the network on the 10000 test images: 60.94 %
Average loss on the 10000 test images: 1.212
TESTING:
Accuracy of the network on the 10000 test images: 66.76 %
Average loss on the 10000 test images: 0.995
TESTING:
Accuracy of the network on the 10000 test images: 67.41 %
Average loss on the 10000 test images: 0.997
TESTING:
Accuracy of the network on the 10000 test images: 67.33 %
Average loss on the 10000 test images: 1.004
TESTING:
Accuracy of the network on the 10000 test images: 67.07 %
Average loss on the 10000 test images: 1.007
TESTING:
Accuracy of the network on the 10000 test images: 67.52 %
Average loss on the 10000 test images: 1.015
TESTING:
Accuracy of the network on the 10000 test images: 67.56 %
Average loss on the 10000 test images: 1.017
TESTING:
Accuracy of the network on the 10000 test images: 67.55 %
Average loss on the 10000 test images: 1.029
TESTING:
Accuracy of the network on the 10000 test images: 68.01 %
Average loss on the 10000 test images: 1.024
TESTING:
Accuracy of the network on the 10000 test images: 68.01 %
Average loss on the 10000 test images: 1.050
TESTING:
Accuracy of the network on the 10000 test images: 67.87 %
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Average loss on the 10000 test images: 1.040
Finished Training
TESTING:
Accuracy of the network on the 10000 test images: 42.88 %
Average loss on the 10000 test images: 1.566
TESTING:
Accuracy of the network on the 10000 test images: 48.02 %
Average loss on the 10000 test images: 1.432
TESTING:
Accuracy of the network on the 10000 test images: 49.50 %
Average loss on the 10000 test images: 1.398
TESTING:
Accuracy of the network on the 10000 test images: 52.12 %
Average loss on the 10000 test images: 1.338
TESTING:
Accuracy of the network on the 10000 test images: 52.69 %
Average loss on the 10000 test images: 1.323
TESTING:
Accuracy of the network on the 10000 test images: 53.29 %
Average loss on the 10000 test images: 1.301
TESTING:
Accuracy of the network on the 10000 test images: 54.37 %
Average loss on the 10000 test images: 1.274
TESTING:
Accuracy of the network on the 10000 test images: 54.63 %
Average loss on the 10000 test images: 1.264
TESTING:
Accuracy of the network on the 10000 test images: 53.19 %
Average loss on the 10000 test images: 1.344
TESTING:
Accuracy of the network on the 10000 test images: 54.49 %
Average loss on the 10000 test images: 1.269
TESTING:
Accuracy of the network on the 10000 test images: 57.14 %
Average loss on the 10000 test images: 1.212
TESTING:
Accuracy of the network on the 10000 test images: 57.11 %
Average loss on the 10000 test images: 1.216
TESTING:
Accuracy of the network on the 10000 test images: 57.24 %
Average loss on the 10000 test images: 1.210
TESTING:
Accuracy of the network on the 10000 test images: 57.52 %
Average loss on the 10000 test images: 1.200
TESTING:
Accuracy of the network on the 10000 test images: 57.89 %
Average loss on the 10000 test images: 1.207
TESTING:
Accuracy of the network on the 10000 test images: 57.68 %
Average loss on the 10000 test images: 1.206
TESTING:
Accuracy of the network on the 10000 test images: 57.92 %
Average loss on the 10000 test images: 1.200
TESTING:
Accuracy of the network on the 10000 test images: 57.69 %
Average loss on the 10000 test images: 1.201
TESTING:
Accuracy of the network on the 10000 test images: 57.53 %
Average loss on the 10000 test images: 1.201
TESTING:
Accuracy of the network on the 10000 test images: 57.18 %
Average loss on the 10000 test images: 1.214
Finished Training
```

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TESTING:
Accuracy of the network on the 10000 test images: 50.72 %
Average loss on the 10000 test images: 1.339
TESTING:
Accuracy of the network on the 10000 test images: 60.04 %
Average loss on the 10000 test images: 1.118
TESTING:
Accuracy of the network on the 10000 test images: 59.12 %
Average loss on the 10000 test images: 1.187
TESTING:
Accuracy of the network on the 10000 test images: 61.91 %
Average loss on the 10000 test images: 1.155
TESTING:
Accuracy of the network on the 10000 test images: 65.90 %
Average loss on the 10000 test images: 0.980
TESTING:
Accuracy of the network on the 10000 test images: 63.75 %
Average loss on the 10000 test images: 1.093
TESTING:
Accuracy of the network on the 10000 test images: 67.09 %
Average loss on the 10000 test images: 0.984
TESTING:
Accuracy of the network on the 10000 test images: 67.65 %
Average loss on the 10000 test images: 0.960
TESTING:
Accuracy of the network on the 10000 test images: 71.08 %
Average loss on the 10000 test images: 0.869
TESTING:
Accuracy of the network on the 10000 test images: 66.16 %
Average loss on the 10000 test images: 1.010
TESTING:
Accuracy of the network on the 10000 test images: 73.00 %
Average loss on the 10000 test images: 0.799
TESTING:
Accuracy of the network on the 10000 test images: 73.59 %
Average loss on the 10000 test images: 0.786
TESTING:
Accuracy of the network on the 10000 test images: 73.75 %
Average loss on the 10000 test images: 0.786
TESTING:
Accuracy of the network on the 10000 test images: 73.78 %
Average loss on the 10000 test images: 0.789
TESTING:
Accuracy of the network on the 10000 test images: 74.19 %
Average loss on the 10000 test images: 0.783
TESTING:
Accuracy of the network on the 10000 test images: 74.19 %
Average loss on the 10000 test images: 0.786
TESTING:
Accuracy of the network on the 10000 test images: 73.96 %
Average loss on the 10000 test images: 0.790
TESTING:
Accuracy of the network on the 10000 test images: 74.09 %
Average loss on the 10000 test images: 0.788
TESTING:
Accuracy of the network on the 10000 test images: 74.30 %
Average loss on the 10000 test images: 0.791
TESTING:
Accuracy of the network on the 10000 test images: 74.50 %
Average loss on the 10000 test images: 0.785
Finished Training
[1,   100] loss: 1.702 acc: 37.01 time: 2.80
[1,   200] loss: 1.458 acc: 45.76 time: 2.77
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[1,   300] loss: 1.388 acc: 49.88 time: 2.76
TESTING:
Accuracy of the network on the 10000 test images: 52.29 %
Average loss on the 10000 test images: 1.328
[2,   100] loss: 1.342 acc: 51.27 time: 2.89
[2,   200] loss: 1.320 acc: 52.30 time: 2.68
[2,   300] loss: 1.313 acc: 53.05 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 54.88 %
Average loss on the 10000 test images: 1.262
[3,   100] loss: 1.289 acc: 53.81 time: 2.75
[3,   200] loss: 1.280 acc: 53.94 time: 2.61
[3,   300] loss: 1.293 acc: 53.07 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 55.87 %
Average loss on the 10000 test images: 1.233
[4,   100] loss: 1.262 acc: 54.32 time: 2.78
[4,   200] loss: 1.278 acc: 54.08 time: 2.65
[4,   300] loss: 1.258 acc: 54.33 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 56.78 %
Average loss on the 10000 test images: 1.214
[5,   100] loss: 1.233 acc: 55.42 time: 2.81
[5,   200] loss: 1.265 acc: 53.98 time: 2.73
[5,   300] loss: 1.254 acc: 54.98 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 56.29 %
Average loss on the 10000 test images: 1.225
[6,   100] loss: 1.226 acc: 55.57 time: 2.80
[6,   200] loss: 1.240 acc: 55.55 time: 2.67
[6,   300] loss: 1.239 acc: 55.30 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 57.00 %
Average loss on the 10000 test images: 1.208
[7,   100] loss: 1.223 acc: 55.70 time: 2.76
[7,   200] loss: 1.218 acc: 56.32 time: 2.66
[7,   300] loss: 1.229 acc: 55.88 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 56.42 %
Average loss on the 10000 test images: 1.209
[8,   100] loss: 1.220 acc: 55.22 time: 2.92
[8,   200] loss: 1.203 acc: 56.66 time: 2.81
[8,   300] loss: 1.201 acc: 57.29 time: 2.71
TESTING:
Accuracy of the network on the 10000 test images: 57.76 %
Average loss on the 10000 test images: 1.179
[9,   100] loss: 1.215 acc: 55.86 time: 2.79
[9,   200] loss: 1.197 acc: 56.92 time: 2.68
[9,   300] loss: 1.211 acc: 56.55 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 57.05 %
Average loss on the 10000 test images: 1.217
[10,   100] loss: 1.199 acc: 56.49 time: 2.81
[10,   200] loss: 1.189 acc: 57.23 time: 2.70
[10,   300] loss: 1.205 acc: 56.95 time: 2.69
TESTING:
Accuracy of the network on the 10000 test images: 58.46 %
Average loss on the 10000 test images: 1.167
[11,   100] loss: 1.169 acc: 57.66 time: 2.81
[11,   200] loss: 1.136 acc: 59.12 time: 2.66
[11,   300] loss: 1.138 acc: 58.74 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 60.84 %
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Average loss on the 10000 test images: 1.097
[12,   100] loss: 1.118 acc: 59.61 time: 2.71
[12,   200] loss: 1.103 acc: 59.99 time: 2.66
[12,   300] loss: 1.125 acc: 59.98 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 60.70 %
Average loss on the 10000 test images: 1.099
[13,   100] loss: 1.099 acc: 60.25 time: 2.82
[13,   200] loss: 1.105 acc: 59.83 time: 2.67
[13,   300] loss: 1.109 acc: 60.23 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 61.13 %
Average loss on the 10000 test images: 1.092
[14,   100] loss: 1.117 acc: 59.99 time: 2.79
[14,   200] loss: 1.106 acc: 60.23 time: 2.65
[14,   300] loss: 1.112 acc: 60.66 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 61.17 %
Average loss on the 10000 test images: 1.089
[15,   100] loss: 1.101 acc: 59.91 time: 2.86
[15,   200] loss: 1.114 acc: 59.73 time: 2.79
[15,   300] loss: 1.108 acc: 60.18 time: 2.83
TESTING:
Accuracy of the network on the 10000 test images: 61.01 %
Average loss on the 10000 test images: 1.088
[16,   100] loss: 1.110 acc: 59.51 time: 2.92
[16,   200] loss: 1.097 acc: 60.21 time: 2.77
[16,   300] loss: 1.099 acc: 60.34 time: 2.69
TESTING:
Accuracy of the network on the 10000 test images: 61.41 %
Average loss on the 10000 test images: 1.080
[17,   100] loss: 1.095 acc: 60.45 time: 2.77
[17,   200] loss: 1.108 acc: 60.08 time: 2.66
[17,   300] loss: 1.098 acc: 60.41 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 61.44 %
Average loss on the 10000 test images: 1.080
[18,   100] loss: 1.097 acc: 60.66 time: 2.75
[18,   200] loss: 1.080 acc: 61.18 time: 2.65
[18,   300] loss: 1.095 acc: 60.70 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 61.38 %
Average loss on the 10000 test images: 1.085
[19,   100] loss: 1.096 acc: 60.55 time: 2.79
[19,   200] loss: 1.088 acc: 60.58 time: 2.65
[19,   300] loss: 1.104 acc: 60.19 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 61.62 %
Average loss on the 10000 test images: 1.081
[20,   100] loss: 1.073 acc: 61.02 time: 2.77
[20,   200] loss: 1.098 acc: 60.93 time: 2.66
[20,   300] loss: 1.100 acc: 60.27 time: 2.77
TESTING:
Accuracy of the network on the 10000 test images: 61.55 %
Average loss on the 10000 test images: 1.077
Finished Training
[1,   100] loss: 1.479 acc: 45.66 time: 2.97
[1,   200] loss: 1.153 acc: 59.60 time: 2.73
[1,   300] loss: 1.070 acc: 62.20 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 64.99 %
Average loss on the 10000 test images: 1.026
[2,   100] loss: 0.949 acc: 66.68 time: 2.80
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[2,   200] loss: 0.939 acc: 66.94 time: 2.73
[2,   300] loss: 0.897 acc: 68.40 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 71.30 %
Average loss on the 10000 test images: 0.824
[3,   100] loss: 0.840 acc: 70.80 time: 2.78
[3,   200] loss: 0.821 acc: 71.36 time: 2.67
[3,   300] loss: 0.823 acc: 71.23 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 72.60 %
Average loss on the 10000 test images: 0.818
[4,   100] loss: 0.756 acc: 73.92 time: 2.80
[4,   200] loss: 0.761 acc: 73.80 time: 2.68
[4,   300] loss: 0.761 acc: 73.88 time: 2.68
TESTING:
Accuracy of the network on the 10000 test images: 73.41 %
Average loss on the 10000 test images: 0.764
[5,   100] loss: 0.716 acc: 75.04 time: 2.88
[5,   200] loss: 0.726 acc: 75.20 time: 2.88
[5,   300] loss: 0.700 acc: 75.48 time: 2.72
TESTING:
Accuracy of the network on the 10000 test images: 74.68 %
Average loss on the 10000 test images: 0.757
[6,   100] loss: 0.682 acc: 76.41 time: 2.94
[6,   200] loss: 0.669 acc: 76.66 time: 2.76
[6,   300] loss: 0.669 acc: 77.27 time: 2.76
TESTING:
Accuracy of the network on the 10000 test images: 75.49 %
Average loss on the 10000 test images: 0.727
[7,   100] loss: 0.636 acc: 78.27 time: 2.81
[7,   200] loss: 0.646 acc: 77.25 time: 2.78
[7,   300] loss: 0.638 acc: 77.95 time: 2.83
TESTING:
Accuracy of the network on the 10000 test images: 73.85 %
Average loss on the 10000 test images: 0.786
[8,   100] loss: 0.630 acc: 78.48 time: 2.90
[8,   200] loss: 0.627 acc: 78.62 time: 2.80
[8,   300] loss: 0.620 acc: 78.23 time: 2.84
TESTING:
Accuracy of the network on the 10000 test images: 77.00 %
Average loss on the 10000 test images: 0.683
[9,   100] loss: 0.573 acc: 80.14 time: 2.79
[9,   200] loss: 0.591 acc: 79.68 time: 2.67
[9,   300] loss: 0.597 acc: 79.35 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 78.59 %
Average loss on the 10000 test images: 0.636
[10,   100] loss: 0.576 acc: 80.08 time: 2.82
[10,   200] loss: 0.585 acc: 80.03 time: 2.60
[10,   300] loss: 0.577 acc: 80.66 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 79.40 %
Average loss on the 10000 test images: 0.612
[11,   100] loss: 0.488 acc: 82.88 time: 2.95
[11,   200] loss: 0.467 acc: 83.79 time: 2.73
[11,   300] loss: 0.447 acc: 84.68 time: 2.82
TESTING:
Accuracy of the network on the 10000 test images: 82.87 %
Average loss on the 10000 test images: 0.500
[12,   100] loss: 0.433 acc: 85.14 time: 2.99
[12,   200] loss: 0.428 acc: 85.28 time: 2.67
[12,   300] loss: 0.418 acc: 85.43 time: 2.68
TESTING:
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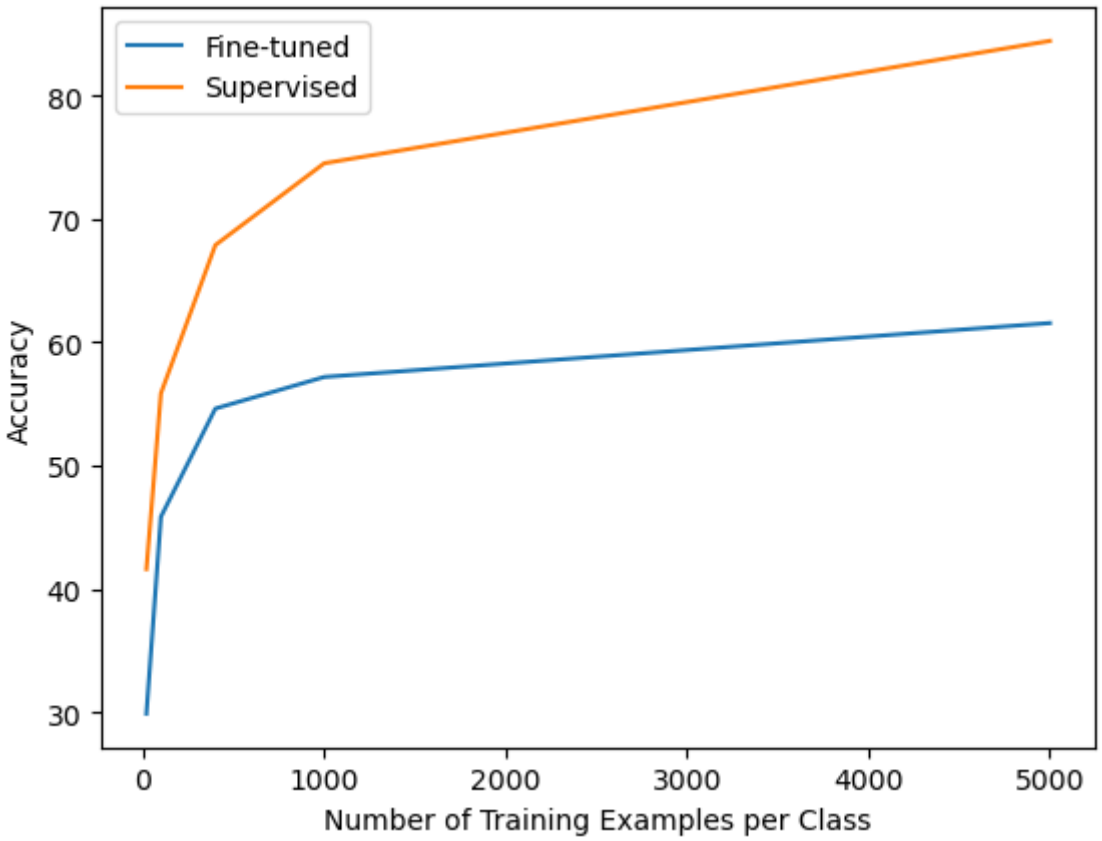
Accuracy of the network on the 10000 test images: 83.60 %
Average loss on the 10000 test images: 0.488
[13,   100] loss: 0.401 acc: 86.20 time: 2.79
[13,   200] loss: 0.406 acc: 86.24 time: 2.62
[13,   300] loss: 0.406 acc: 85.98 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 83.46 %
Average loss on the 10000 test images: 0.483
[14,   100] loss: 0.397 acc: 86.35 time: 2.81
[14,   200] loss: 0.401 acc: 86.01 time: 2.63
[14,   300] loss: 0.384 acc: 86.79 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 83.80 %
Average loss on the 10000 test images: 0.483
[15,   100] loss: 0.386 acc: 86.58 time: 2.96
[15,   200] loss: 0.387 acc: 86.47 time: 2.83
[15,   300] loss: 0.372 acc: 87.33 time: 2.86
TESTING:
Accuracy of the network on the 10000 test images: 83.95 %
Average loss on the 10000 test images: 0.479
[16,   100] loss: 0.378 acc: 87.11 time: 2.95
[16,   200] loss: 0.390 acc: 86.57 time: 2.75
[16,   300] loss: 0.361 acc: 87.30 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 84.04 %
Average loss on the 10000 test images: 0.479
[17,   100] loss: 0.370 acc: 87.32 time: 2.82
[17,   200] loss: 0.359 acc: 87.51 time: 2.67
[17,   300] loss: 0.364 acc: 87.52 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 84.12 %
Average loss on the 10000 test images: 0.477
[18,   100] loss: 0.358 acc: 87.30 time: 2.78
[18,   200] loss: 0.364 acc: 87.27 time: 2.67
[18,   300] loss: 0.354 acc: 87.80 time: 2.70
TESTING:
Accuracy of the network on the 10000 test images: 84.32 %
Average loss on the 10000 test images: 0.470
[19,   100] loss: 0.343 acc: 88.00 time: 2.78
[19,   200] loss: 0.361 acc: 87.38 time: 2.65
[19,   300] loss: 0.355 acc: 87.54 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 83.96 %
Average loss on the 10000 test images: 0.478
[20,   100] loss: 0.341 acc: 88.37 time: 2.79
[20,   200] loss: 0.343 acc: 88.11 time: 2.61
[20,   300] loss: 0.350 acc: 87.98 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 84.42 %
Average loss on the 10000 test images: 0.477
Finished Training
```



- More Advanced model than ResNet18

In [28]:
```
import torch.nn as nn
import torch.nn.functional as F
from torchvision.models import densenet121

ad_model = densenet121(weights = None, num_classes=4)
ad_model = ad_model.to(device)

criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(ad_model.parameters(), lr=0.001, weight_decay=0.0
criterion = criterion.to(device)


train(ad_model, criterion, optimizer, num_epochs=45, decay_epochs=15, ini
torch.save(ad_model.state_dict(), 'ad_rotation_model.pt')



print("="*20,"supervised CIFAR10","="*20)


ckpt = torch.load('ad_rotation_model.pt')
ad_model = densenet121(weights = None, num_classes = 4)
ad_model.load_state_dict(ckpt)
num_classes=10
ad_model.classifier = nn.Linear(ad_model.classifier.in_features, num_clas
ad_model = ad_model.to(device)

criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(ad_model.parameters(),lr=3e-4)

train(ad_model, criterion, optimizer, num_epochs=20, decay_epochs=10, ini
```

```
[1,   100] loss: 1.632 acc: 28.70 time: 6.01
[1,   200] loss: 1.328 acc: 39.38 time: 5.19
[1,   300] loss: 1.272 acc: 43.46 time: 5.67
TESTING:
Accuracy of the network on the 10000 test images: 47.72 %
Average loss on the 10000 test images: 1.177
[2,   100] loss: 1.191 acc: 45.80 time: 5.86
[2,   200] loss: 1.189 acc: 45.72 time: 5.29
[2,   300] loss: 1.160 acc: 47.49 time: 5.34
TESTING:
Accuracy of the network on the 10000 test images: 51.26 %
Average loss on the 10000 test images: 1.102
[3,   100] loss: 1.139 acc: 49.41 time: 5.97
[3,   200] loss: 1.097 acc: 52.77 time: 5.84
[3,   300] loss: 1.082 acc: 53.91 time: 5.84
TESTING:
Accuracy of the network on the 10000 test images: 57.12 %
Average loss on the 10000 test images: 1.030
[4,   100] loss: 1.035 acc: 55.84 time: 5.63
[4,   200] loss: 1.018 acc: 56.63 time: 5.29
[4,   300] loss: 1.016 acc: 56.94 time: 5.32
TESTING:
Accuracy of the network on the 10000 test images: 58.20 %
Average loss on the 10000 test images: 0.980
[5,   100] loss: 0.982 acc: 58.55 time: 5.44
[5,   200] loss: 0.982 acc: 58.09 time: 5.27
[5,   300] loss: 0.964 acc: 59.02 time: 5.32
TESTING:
Accuracy of the network on the 10000 test images: 60.68 %
Average loss on the 10000 test images: 0.942
[6,   100] loss: 0.952 acc: 60.23 time: 5.42
[6,   200] loss: 0.937 acc: 60.44 time: 5.53
[6,   300] loss: 0.937 acc: 60.84 time: 5.97
TESTING:
Accuracy of the network on the 10000 test images: 60.81 %
Average loss on the 10000 test images: 0.915
[7,   100] loss: 0.925 acc: 61.04 time: 5.62
[7,   200] loss: 0.907 acc: 62.05 time: 5.30
[7,   300] loss: 0.919 acc: 61.12 time: 5.30
TESTING:
Accuracy of the network on the 10000 test images: 61.61 %
Average loss on the 10000 test images: 0.935
[8,   100] loss: 0.903 acc: 62.55 time: 5.55
[8,   200] loss: 0.906 acc: 62.17 time: 5.34
[8,   300] loss: 0.887 acc: 62.77 time: 5.33
TESTING:
Accuracy of the network on the 10000 test images: 63.37 %
Average loss on the 10000 test images: 0.894
[9,   100] loss: 0.882 acc: 62.91 time: 5.54
[9,   200] loss: 0.873 acc: 63.38 time: 5.77
[9,   300] loss: 0.870 acc: 63.50 time: 5.86
TESTING:
Accuracy of the network on the 10000 test images: 65.69 %
Average loss on the 10000 test images: 0.835
[10,   100] loss: 0.855 acc: 64.16 time: 5.94
[10,   200] loss: 0.863 acc: 64.27 time: 5.83
[10,   300] loss: 0.836 acc: 65.65 time: 5.89
TESTING:
Accuracy of the network on the 10000 test images: 67.32 %
Average loss on the 10000 test images: 0.796
[11,   100] loss: 0.830 acc: 65.68 time: 5.46
[11,   200] loss: 0.834 acc: 65.30 time: 5.32
[11,   300] loss: 0.823 acc: 65.94 time: 5.26
```

```
TESTING:
Accuracy of the network on the 10000 test images: 67.33 %
Average loss on the 10000 test images: 0.810
[12,   100] loss: 0.815 acc: 66.41 time: 5.55
[12,   200] loss: 0.811 acc: 66.20 time: 5.42
[12,   300] loss: 0.801 acc: 67.34 time: 5.30
TESTING:
Accuracy of the network on the 10000 test images: 68.78 %
Average loss on the 10000 test images: 0.774
[13,   100] loss: 0.783 acc: 68.02 time: 5.53
[13,   200] loss: 0.781 acc: 67.74 time: 5.56
[13,   300] loss: 0.794 acc: 67.39 time: 5.82
TESTING:
Accuracy of the network on the 10000 test images: 68.81 %
Average loss on the 10000 test images: 0.755
[14,   100] loss: 0.775 acc: 68.21 time: 6.04
[14,   200] loss: 0.774 acc: 68.16 time: 5.86
[14,   300] loss: 0.764 acc: 68.91 time: 5.82
TESTING:
Accuracy of the network on the 10000 test images: 69.88 %
Average loss on the 10000 test images: 0.737
[15,   100] loss: 0.761 acc: 68.82 time: 5.47
[15,   200] loss: 0.746 acc: 69.89 time: 5.30
[15,   300] loss: 0.745 acc: 69.79 time: 5.35
TESTING:
Accuracy of the network on the 10000 test images: 71.26 %
Average loss on the 10000 test images: 0.724
[16,   100] loss: 0.708 acc: 71.58 time: 5.55
[16,   200] loss: 0.670 acc: 73.05 time: 5.35
[16,   300] loss: 0.662 acc: 73.48 time: 5.43
TESTING:
Accuracy of the network on the 10000 test images: 74.28 %
Average loss on the 10000 test images: 0.645
[17,   100] loss: 0.648 acc: 74.13 time: 5.93
[17,   200] loss: 0.658 acc: 73.79 time: 5.81
[17,   300] loss: 0.659 acc: 73.59 time: 5.35
TESTING:
Accuracy of the network on the 10000 test images: 74.32 %
Average loss on the 10000 test images: 0.636
[18,   100] loss: 0.642 acc: 74.69 time: 5.51
[18,   200] loss: 0.631 acc: 74.60 time: 5.28
[18,   300] loss: 0.640 acc: 73.75 time: 5.27
TESTING:
Accuracy of the network on the 10000 test images: 75.48 %
Average loss on the 10000 test images: 0.617
[19,   100] loss: 0.632 acc: 74.87 time: 5.46
[19,   200] loss: 0.633 acc: 74.95 time: 5.31
[19,   300] loss: 0.626 acc: 74.93 time: 5.32
TESTING:
Accuracy of the network on the 10000 test images: 75.43 %
Average loss on the 10000 test images: 0.616
[20,   100] loss: 0.613 acc: 75.76 time: 5.49
[20,   200] loss: 0.629 acc: 75.27 time: 5.33
[20,   300] loss: 0.625 acc: 74.95 time: 5.40
TESTING:
Accuracy of the network on the 10000 test images: 75.47 %
Average loss on the 10000 test images: 0.620
[21,   100] loss: 0.608 acc: 75.81 time: 5.94
[21,   200] loss: 0.620 acc: 75.24 time: 5.23
[21,   300] loss: 0.613 acc: 75.49 time: 5.22
TESTING:
Accuracy of the network on the 10000 test images: 76.18 %
Average loss on the 10000 test images: 0.603
```

```
[22,   100] loss: 0.613 acc: 75.52 time: 5.52
[22,   200] loss: 0.612 acc: 75.49 time: 5.29
[22,   300] loss: 0.608 acc: 75.38 time: 5.36
TESTING:
Accuracy of the network on the 10000 test images: 76.38 %
Average loss on the 10000 test images: 0.599
[23,   100] loss: 0.612 acc: 75.47 time: 6.07
[23,   200] loss: 0.589 acc: 76.80 time: 5.78
[23,   300] loss: 0.601 acc: 75.63 time: 5.47
TESTING:
Accuracy of the network on the 10000 test images: 76.31 %
Average loss on the 10000 test images: 0.600
[24,   100] loss: 0.601 acc: 76.10 time: 5.46
[24,   200] loss: 0.602 acc: 76.02 time: 5.31
[24,   300] loss: 0.584 acc: 76.59 time: 5.32
TESTING:
Accuracy of the network on the 10000 test images: 76.79 %
Average loss on the 10000 test images: 0.585
[25,   100] loss: 0.590 acc: 76.76 time: 5.48
[25,   200] loss: 0.593 acc: 76.52 time: 5.23
[25,   300] loss: 0.577 acc: 77.16 time: 5.34
TESTING:
Accuracy of the network on the 10000 test images: 77.23 %
Average loss on the 10000 test images: 0.578
[26,   100] loss: 0.582 acc: 77.11 time: 5.65
[26,   200] loss: 0.575 acc: 77.50 time: 5.33
[26,   300] loss: 0.593 acc: 76.30 time: 5.28
TESTING:
Accuracy of the network on the 10000 test images: 76.89 %
Average loss on the 10000 test images: 0.577
[27,   100] loss: 0.579 acc: 76.87 time: 5.49
[27,   200] loss: 0.577 acc: 77.73 time: 5.24
[27,   300] loss: 0.582 acc: 76.98 time: 5.12
TESTING:
Accuracy of the network on the 10000 test images: 77.43 %
Average loss on the 10000 test images: 0.569
[28,   100] loss: 0.583 acc: 76.98 time: 5.25
[28,   200] loss: 0.572 acc: 77.30 time: 5.04
[28,   300] loss: 0.573 acc: 77.24 time: 5.00
TESTING:
Accuracy of the network on the 10000 test images: 77.03 %
Average loss on the 10000 test images: 0.577
[29,   100] loss: 0.573 acc: 77.41 time: 5.24
[29,   200] loss: 0.554 acc: 78.19 time: 5.06
[29,   300] loss: 0.562 acc: 77.76 time: 5.04
TESTING:
Accuracy of the network on the 10000 test images: 77.77 %
Average loss on the 10000 test images: 0.562
[30,   100] loss: 0.559 acc: 78.16 time: 5.23
[30,   200] loss: 0.550 acc: 78.12 time: 5.05
[30,   300] loss: 0.567 acc: 77.80 time: 5.04
TESTING:
Accuracy of the network on the 10000 test images: 77.33 %
Average loss on the 10000 test images: 0.569
[31,   100] loss: 0.557 acc: 77.65 time: 5.25
[31,   200] loss: 0.542 acc: 78.62 time: 5.05
[31,   300] loss: 0.546 acc: 78.64 time: 5.04
TESTING:
Accuracy of the network on the 10000 test images: 77.91 %
Average loss on the 10000 test images: 0.564
[32,   100] loss: 0.561 acc: 77.85 time: 5.21
[32,   200] loss: 0.552 acc: 78.27 time: 5.02
[32,   300] loss: 0.536 acc: 78.88 time: 5.02
```

```
TESTING:
Accuracy of the network on the 10000 test images: 77.76 %
Average loss on the 10000 test images: 0.566
[33,   100] loss: 0.541 acc: 78.45 time: 5.22
[33,   200] loss: 0.540 acc: 78.91 time: 5.00
[33,   300] loss: 0.548 acc: 78.38 time: 5.03
TESTING:
Accuracy of the network on the 10000 test images: 77.89 %
Average loss on the 10000 test images: 0.563
[34,   100] loss: 0.534 acc: 79.15 time: 5.20
[34,   200] loss: 0.550 acc: 78.38 time: 5.00
[34,   300] loss: 0.537 acc: 78.98 time: 5.10
TESTING:
Accuracy of the network on the 10000 test images: 77.99 %
Average loss on the 10000 test images: 0.567
[35,   100] loss: 0.545 acc: 78.16 time: 5.29
[35,   200] loss: 0.537 acc: 78.95 time: 5.07
[35,   300] loss: 0.542 acc: 78.48 time: 5.03
TESTING:
Accuracy of the network on the 10000 test images: 78.36 %
Average loss on the 10000 test images: 0.557
[36,   100] loss: 0.540 acc: 78.86 time: 5.19
[36,   200] loss: 0.551 acc: 78.19 time: 5.00
[36,   300] loss: 0.542 acc: 78.36 time: 5.01
TESTING:
Accuracy of the network on the 10000 test images: 77.87 %
Average loss on the 10000 test images: 0.567
[37,   100] loss: 0.546 acc: 78.30 time: 5.19
[37,   200] loss: 0.541 acc: 78.86 time: 5.16
[37,   300] loss: 0.537 acc: 79.33 time: 5.10
TESTING:
Accuracy of the network on the 10000 test images: 78.66 %
Average loss on the 10000 test images: 0.552
[38,   100] loss: 0.528 acc: 79.11 time: 5.20
[38,   200] loss: 0.543 acc: 78.64 time: 5.02
[38,   300] loss: 0.533 acc: 79.06 time: 5.01
TESTING:
Accuracy of the network on the 10000 test images: 78.18 %
Average loss on the 10000 test images: 0.570
[39,   100] loss: 0.550 acc: 78.41 time: 5.20
[39,   200] loss: 0.537 acc: 78.70 time: 5.07
[39,   300] loss: 0.543 acc: 78.66 time: 5.01
TESTING:
Accuracy of the network on the 10000 test images: 78.63 %
Average loss on the 10000 test images: 0.550
[40,   100] loss: 0.538 acc: 78.87 time: 5.36
[40,   200] loss: 0.531 acc: 78.85 time: 5.03
[40,   300] loss: 0.534 acc: 78.70 time: 5.02
TESTING:
Accuracy of the network on the 10000 test images: 78.75 %
Average loss on the 10000 test images: 0.550
[41,   100] loss: 0.529 acc: 79.22 time: 5.26
[41,   200] loss: 0.541 acc: 78.94 time: 5.06
[41,   300] loss: 0.540 acc: 78.83 time: 5.07
TESTING:
Accuracy of the network on the 10000 test images: 78.16 %
Average loss on the 10000 test images: 0.556
[42,   100] loss: 0.519 acc: 80.08 time: 5.20
[42,   200] loss: 0.528 acc: 79.45 time: 5.04
[42,   300] loss: 0.539 acc: 78.95 time: 5.08
TESTING:
Accuracy of the network on the 10000 test images: 78.15 %
Average loss on the 10000 test images: 0.570
```

```
[43,   100] loss: 0.528 acc: 79.30 time: 5.25
[43,   200] loss: 0.543 acc: 78.54 time: 5.03
[43,   300] loss: 0.525 acc: 79.26 time: 5.08
TESTING:
Accuracy of the network on the 10000 test images: 78.53 %
Average loss on the 10000 test images: 0.544
[44,   100] loss: 0.535 acc: 78.84 time: 5.23
[44,   200] loss: 0.540 acc: 78.95 time: 5.06
[44,   300] loss: 0.534 acc: 78.95 time: 5.08
TESTING:
Accuracy of the network on the 10000 test images: 78.79 %
Average loss on the 10000 test images: 0.547
[45,   100] loss: 0.532 acc: 79.23 time: 5.26
[45,   200] loss: 0.530 acc: 78.55 time: 5.00
[45,   300] loss: 0.536 acc: 79.09 time: 5.07
TESTING:
Accuracy of the network on the 10000 test images: 78.78 %
Average loss on the 10000 test images: 0.547
Finished Training
==================== supervised CIFAR10 ====================
[1,   100] loss: 1.424 acc: 47.73 time: 5.30
[1,   200] loss: 1.133 acc: 59.06 time: 5.11
[1,   300] loss: 1.034 acc: 62.91 time: 5.13
TESTING:
Accuracy of the network on the 10000 test images: 66.61 %
Average loss on the 10000 test images: 0.953
[2,   100] loss: 0.931 acc: 66.73 time: 5.30
[2,   200] loss: 0.894 acc: 68.48 time: 5.12
[2,   300] loss: 0.864 acc: 69.48 time: 5.36
TESTING:
Accuracy of the network on the 10000 test images: 70.01 %
Average loss on the 10000 test images: 0.856
[3,   100] loss: 0.809 acc: 71.27 time: 5.78
[3,   200] loss: 0.786 acc: 72.57 time: 5.97
[3,   300] loss: 0.795 acc: 71.96 time: 5.84
TESTING:
Accuracy of the network on the 10000 test images: 71.46 %
Average loss on the 10000 test images: 0.829
[4,   100] loss: 0.729 acc: 74.48 time: 6.06
[4,   200] loss: 0.718 acc: 75.00 time: 5.77
[4,   300] loss: 0.722 acc: 75.01 time: 5.58
TESTING:
Accuracy of the network on the 10000 test images: 75.38 %
Average loss on the 10000 test images: 0.701
[5,   100] loss: 0.677 acc: 76.44 time: 5.53
[5,   200] loss: 0.684 acc: 75.96 time: 5.36
[5,   300] loss: 0.686 acc: 76.17 time: 5.39
TESTING:
Accuracy of the network on the 10000 test images: 74.29 %
Average loss on the 10000 test images: 0.757
[6,   100] loss: 0.644 acc: 77.63 time: 5.55
[6,   200] loss: 0.655 acc: 77.07 time: 5.90
[6,   300] loss: 0.629 acc: 78.09 time: 5.85
TESTING:
Accuracy of the network on the 10000 test images: 77.34 %
Average loss on the 10000 test images: 0.665
[7,   100] loss: 0.615 acc: 78.66 time: 5.55
[7,   200] loss: 0.614 acc: 78.35 time: 5.31
[7,   300] loss: 0.643 acc: 77.52 time: 5.34
TESTING:
Accuracy of the network on the 10000 test images: 77.04 %
Average loss on the 10000 test images: 0.684
[8,   100] loss: 0.578 acc: 80.16 time: 5.55
```

```
[8,   200] loss: 0.609 acc: 78.80 time: 5.34
[8,   300] loss: 0.601 acc: 79.17 time: 5.43
TESTING:
Accuracy of the network on the 10000 test images: 78.14 %
Average loss on the 10000 test images: 0.643
[9,   100] loss: 0.585 acc: 79.91 time: 6.09
[9,   200] loss: 0.558 acc: 80.88 time: 5.86
[9,   300] loss: 0.573 acc: 80.38 time: 5.91
TESTING:
Accuracy of the network on the 10000 test images: 79.00 %
Average loss on the 10000 test images: 0.626
[10,   100] loss: 0.551 acc: 80.76 time: 5.90
[10,   200] loss: 0.549 acc: 80.95 time: 5.95
[10,   300] loss: 0.556 acc: 80.84 time: 5.89
TESTING:
Accuracy of the network on the 10000 test images: 77.08 %
Average loss on the 10000 test images: 0.658
[11,   100] loss: 0.464 acc: 83.55 time: 5.59
[11,   200] loss: 0.437 acc: 85.20 time: 5.44
[11,   300] loss: 0.419 acc: 85.22 time: 5.38
TESTING:
Accuracy of the network on the 10000 test images: 83.89 %
Average loss on the 10000 test images: 0.469
[12,   100] loss: 0.390 acc: 86.22 time: 5.58
[12,   200] loss: 0.381 acc: 86.84 time: 5.33
[12,   300] loss: 0.399 acc: 85.81 time: 5.28
TESTING:
Accuracy of the network on the 10000 test images: 84.21 %
Average loss on the 10000 test images: 0.462
[13,   100] loss: 0.372 acc: 86.98 time: 5.56
[13,   200] loss: 0.368 acc: 87.05 time: 5.30
[13,   300] loss: 0.369 acc: 86.78 time: 5.60
TESTING:
Accuracy of the network on the 10000 test images: 84.51 %
Average loss on the 10000 test images: 0.456
[14,   100] loss: 0.361 acc: 87.69 time: 5.74
[14,   200] loss: 0.359 acc: 87.48 time: 5.43
[14,   300] loss: 0.364 acc: 87.29 time: 5.34
TESTING:
Accuracy of the network on the 10000 test images: 84.55 %
Average loss on the 10000 test images: 0.457
[15,   100] loss: 0.344 acc: 88.04 time: 5.58
[15,   200] loss: 0.370 acc: 86.91 time: 5.40
[15,   300] loss: 0.342 acc: 87.93 time: 5.38
TESTING:
Accuracy of the network on the 10000 test images: 84.72 %
Average loss on the 10000 test images: 0.456
[16,   100] loss: 0.331 acc: 88.34 time: 5.54
[16,   200] loss: 0.341 acc: 88.28 time: 5.38
[16,   300] loss: 0.354 acc: 87.94 time: 5.35
TESTING:
Accuracy of the network on the 10000 test images: 84.57 %
Average loss on the 10000 test images: 0.455
[17,   100] loss: 0.321 acc: 88.93 time: 5.68
[17,   200] loss: 0.333 acc: 88.32 time: 5.39
[17,   300] loss: 0.346 acc: 87.80 time: 5.83
TESTING:
Accuracy of the network on the 10000 test images: 84.78 %
Average loss on the 10000 test images: 0.454
[18,   100] loss: 0.329 acc: 88.59 time: 5.45
[18,   200] loss: 0.329 acc: 88.45 time: 5.32
[18,   300] loss: 0.332 acc: 88.50 time: 5.35
TESTING:
```

```
Accuracy of the network on the 10000 test images: 85.23 %
Average loss on the 10000 test images: 0.450
[19,   100] loss: 0.304 acc: 89.17 time: 5.53
[19,   200] loss: 0.316 acc: 88.85 time: 5.32
[19,   300] loss: 0.312 acc: 89.16 time: 5.30
TESTING:
Accuracy of the network on the 10000 test images: 84.90 %
Average loss on the 10000 test images: 0.454
[20,   100] loss: 0.310 acc: 89.16 time: 6.04
[20,   200] loss: 0.302 acc: 89.34 time: 5.68
[20,   300] loss: 0.311 acc: 89.03 time: 5.89
TESTING:
Accuracy of the network on the 10000 test images: 84.85 %
Average loss on the 10000 test images: 0.456
Finished Training
```

Out[28]:
```
84.85
```

- Train rotation prediction model on imagenette

In [29]:
```
import tarfile

# Path to the downloaded .tgz file
tgz_path = "imagenette2-160.tgz"
# Directory where you want to extract the dataset
extract_path = "./imagenette2"

# Extract the .tgz file
with tarfile.open(tgz_path, "r:gz") as tar:
    tar.extractall(path=extract_path)

print(f"Extracted to {extract_path}")
```

```
Extracted to ./imagenette2
```

In [22]:
```
import os
for res in os.walk('./imagenette2/imagenette2/train/'):
    print(res)
```

```
('./imagenette2/imagenette2/train/', ['n02979186', 'n01440764', 'n0300068
4', 'n03888257', 'n03445777', 'n03394916', 'n02102040', 'n03028079', 'n03
417042', 'n03425413'], [])
('./imagenette2/imagenette2/train/n02979186', [], ['n02979186_20733.JPEG
', 'n02979186_1897.JPEG', 'n02979186_5043.JPEG', 'n02979186_2854.JPEG', '
ILSVRC2012_val_00012468.JPEG', 'n02979186_18456.JPEG', 'n02979186_10874.J
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', 'n02979186_15085.JPEG', 'n02979186_21218.JPEG', 'n02979186_5695.JPEG',
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', 'n03425413_16864.JPEG', 'n03425413_14508.JPEG', 'n03425413_21508.JPEG
']
```

In [66]:

```
imagenette_transform_train = transforms.Compose([
    transforms.Resize((320, 320)), # Resize the image
    transforms.RandomCrop(288),
    transforms.RandomHorizontalFlip(),
    transforms.ToTensor(),
    transforms.Normalize((0.4914, 0.4822, 0.4465), (0.2023, 0.1994, 0.201
])

imagenette_transform_val = transforms.Compose([
    transforms.Resize((288, 288)), # Resize the image
    transforms.ToTensor(),
    transforms.Normalize((0.4914, 0.4822, 0.4465), (0.2023, 0.1994, 0.201

])
```

In [67]:
```
import os
from PIL import Image
from torchvision.datasets import VisionDataset
import torch

class ImageNetteRotation(VisionDataset):

    def __init__(self, root,train ,transform=None):
        super().__init__(root, transform=transform)

        root = root+train
        # folder structure of 'imagenette/imagenette2-160/train' and 'ima
        self.images = []
        self.labels = []

        for dirname, _, filenames in os.walk(root):
            for filename in filenames:
                if filename.endswith('.JPEG'):
                    self.images.append(os.path.join(dirname, filename))
                    # In ImageNette, class labels are encoded in the dire
                    self.labels.append(dirname.split('/')[-1])

    def __len__(self):
        return len(self.images)

    def __getitem__(self, index):
        img_path = self.images[index]
        img = Image.open(img_path).convert('RGB')

        # Apply the transformation if specified
        if self.transform:
            img = self.transform(img)

        # Randomly select image rotation
        rotation_label = random.choice([0, 1, 2, 3])
        img_rotated = rotate_img(img, rotation_label)

        # Convert the class label to a numerical format
        cls_label = self._class_to_index(self.labels[index])

        rotation_label = torch.tensor(rotation_label).long()
        return img, img_rotated, rotation_label, torch.tensor(cls_label).

    def _class_to_index(self, class_name):
        # This could be a dictionary mapping from class names to numbers
        class_to_idx = {'n01440764': 0, 'n02102040': 1, 'n02979186': 2, '
        return class_to_idx[class_name]

# Example usage
root_dir = './imagenette2/imagenette2-160/'  # Or './imagenette/val' for

batch_size = 64

imagenette_train_rotation_dataset = ImageNetteRotation(root=root_dir,trai
imagenette_trainloader = torch.utils.data.DataLoader(imagenette_train_rot


imagenette_val_rotation_dataset = ImageNetteRotation(root=root_dir,train
imagenette_valloader = torch.utils.data.DataLoader(imagenette_val_rotatio
```

In [68]:
```
print(len(imagenette_train_rotation_dataset))
print(len(imagenette_val_rotation_dataset))
print(imagenette_train_rotation_dataset.labels[0])
print(imagenette_train_rotation_dataset._class_to_index(imagenette_train_
```

```
9469
3925
n02979186
2
```

In [69]:
```
import time

def imagenette_run_test(net, imagenette_valloader, criterion, task):
    correct = 0
    total = 0
    avg_test_loss = 0.0
    # since we're not training, we don't need to calculate the gradients
    with torch.no_grad():
        for images, images_rotated, labels, cls_labels in imagenette_vall
            torch.cuda.empty_cache()

            if task == 'rotation':
              images, labels = images_rotated.to(device), labels.to(devic
            elif task == 'classification':
              images, labels = images.to(device), cls_labels.to(device)
            ################################################################
            # TODO: Calculate outputs by running images through the netwo
            # The class with the highest energy is what we choose as pred
            ################################################################
            outputs = net(images)
            _, predicted = torch.max(outputs, 1)
            total += labels.size(0)
            correct += (predicted == labels).sum().item()
            ################################################################
            #                               End of your code
            ################################################################
            avg_test_loss += criterion(outputs, labels)  / len(imagenette
    print('evaluating on imagenette validation set:')
    print('Accuracy of the network on the 3925 validation images:', f'{10
    print('Average loss on the 3925 validation images:', f'{avg_test_loss
    return 100 * correct / total



def imagenette_train(net, criterion, optimizer, num_epochs, decay_epochs,
    test_acc = 0
    for epoch in range(num_epochs):  # loop over the dataset multiple tim
        torch.cuda.empty_cache()

        running_loss = 0.0
        running_correct = 0.0
        running_total = 0.0
        start_time = time.time()

        net.train()

        for i, (imgs, imgs_rotated, rotation_label, cls_label) in enumera
            torch.cuda.empty_cache()

            adjust_learning_rate(optimizer, epoch, init_lr, decay_epochs)
            ################################################################
            # TODO: Set the data to the correct device; Different task wi
            # TODO: Zero the parameter gradients
            # TODO: forward + backward + optimize
            # TODO: Get predicted results
            ################################################################
            if task == 'rotation':
                images, labels = imgs_rotated.to(device), rotation_label.
            elif task == 'classification':
                images, labels = imgs.to(device), cls_label.to(device)

            optimizer.zero_grad()
```

```
            outputs = net(images)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()

            _, predicted = torch.max(outputs, 1)

            ########################################################################
            #                                End of your code
            ########################################################################


            # print statistics
            print_freq = 35
            running_loss += loss.item()

            # calc acc
            running_total += labels.size(0)
            running_correct += (predicted == labels).sum().item()

            if i % print_freq == (print_freq - 1):    # print every 2000
                print(f'[{epoch + 1}, {i + 1:5d}] loss: {running_loss / p
                running_loss, running_correct, running_total = 0.0, 0.0,
                start_time = time.time()
        ########################################################################
        # TODO: Run the run_test() function after each epoch; Set the mod
        ########################################################################
        net.eval()
        test_acc = imagenette_run_test(net, imagenette_valloader, criteri
        ########################################################################
        #                               End of your code
        ########################################################################

    print('Finished Training')
    return test_acc
```

In [70]:

```
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
from torchvision.models import resnet18


net = resnet18(weights = None, num_classes=4) # Do not modify this line.
net = net.to(device)


criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(net.parameters(), lr=3e-4, weight_decay=0.01)
criterion = criterion.to(device)

imagenette_train(net, criterion, optimizer, num_epochs=45, decay_epochs=1

torch.save(net.state_dict(),'rotation_trained_on_imagenette_model.pt')


### supervised training on the pre-trained model
ckpt = torch.load('rotation_trained_on_imagenette_model.pt')
net = resnet18(weights = None, num_classes = 4)
net.load_state_dict(ckpt)
num_classes=10
net.fc = torch.nn.Linear(net.fc.in_features, num_classes)
net = net.to(device)
```

```
criterion = nn.CrossEntropyLoss()
optimizer = optim.AdamW(net.parameters(),lr=3e-4)

train(net, criterion, optimizer, num_epochs=20, decay_epochs=10, init_lr=
```

```
Average loss on the 3925 validation images: 1.400
[2,    35] loss: 1.407 acc: 27.10 time: 6.99
[2,    70] loss: 1.384 acc: 28.97 time: 6.69
[2,   105] loss: 1.360 acc: 32.19 time: 6.69
[2,   140] loss: 1.298 acc: 38.57 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 40.89 %
Average loss on the 3925 validation images: 1.279
[3,    35] loss: 1.262 acc: 41.74 time: 7.01
[3,    70] loss: 1.253 acc: 42.32 time: 6.68
[3,   105] loss: 1.228 acc: 43.93 time: 6.68
[3,   140] loss: 1.225 acc: 43.84 time: 6.70
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 44.99 %
Average loss on the 3925 validation images: 1.197
[4,    35] loss: 1.210 acc: 45.40 time: 7.02
[4,    70] loss: 1.203 acc: 43.93 time: 6.71
[4,   105] loss: 1.201 acc: 44.82 time: 6.71
[4,   140] loss: 1.202 acc: 45.45 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 44.66 %
Average loss on the 3925 validation images: 1.204
[5,    35] loss: 1.199 acc: 44.91 time: 7.04
[5,    70] loss: 1.212 acc: 44.51 time: 6.72
[5,   105] loss: 1.183 acc: 45.31 time: 6.71
[5,   140] loss: 1.183 acc: 45.18 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 47.03 %
Average loss on the 3925 validation images: 1.178
[6,    35] loss: 1.193 acc: 46.38 time: 7.07
[6,    70] loss: 1.169 acc: 46.61 time: 6.71
[6,   105] loss: 1.188 acc: 44.82 time: 6.72
[6,   140] loss: 1.182 acc: 46.07 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.33 %
Average loss on the 3925 validation images: 1.146
[7,    35] loss: 1.156 acc: 47.59 time: 7.02
[7,    70] loss: 1.189 acc: 45.71 time: 6.72
[7,   105] loss: 1.150 acc: 46.83 time: 6.72
[7,   140] loss: 1.162 acc: 46.47 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 47.39 %
Average loss on the 3925 validation images: 1.190
[8,    35] loss: 1.162 acc: 46.70 time: 7.00
[8,    70] loss: 1.179 acc: 46.12 time: 6.71
[8,   105] loss: 1.167 acc: 46.74 time: 6.71
[8,   140] loss: 1.158 acc: 46.43 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 46.80 %
Average loss on the 3925 validation images: 1.153
[9,    35] loss: 1.163 acc: 46.43 time: 7.04
[9,    70] loss: 1.160 acc: 46.21 time: 6.71
[9,   105] loss: 1.156 acc: 48.08 time: 6.71
[9,   140] loss: 1.172 acc: 46.38 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 45.25 %
Average loss on the 3925 validation images: 1.186
```

```
[10,    35] loss: 1.158 acc: 46.74 time: 7.05
[10,    70] loss: 1.163 acc: 46.29 time: 6.72
[10,   105] loss: 1.141 acc: 48.75 time: 6.72
[10,   140] loss: 1.140 acc: 48.39 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.84 %
Average loss on the 3925 validation images: 1.161
[11,    35] loss: 1.131 acc: 49.46 time: 7.02
[11,    70] loss: 1.166 acc: 47.19 time: 6.71
[11,   105] loss: 1.145 acc: 48.75 time: 6.72
[11,   140] loss: 1.142 acc: 48.39 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.38 %
Average loss on the 3925 validation images: 1.147
[12,    35] loss: 1.138 acc: 48.75 time: 7.02
[12,    70] loss: 1.144 acc: 48.08 time: 6.71
[12,   105] loss: 1.165 acc: 45.31 time: 6.71
[12,   140] loss: 1.119 acc: 49.60 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.66 %
Average loss on the 3925 validation images: 1.127
[13,    35] loss: 1.116 acc: 49.46 time: 7.04
[13,    70] loss: 1.112 acc: 50.00 time: 6.72
[13,   105] loss: 1.140 acc: 48.79 time: 6.72
[13,   140] loss: 1.169 acc: 47.50 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.20 %
Average loss on the 3925 validation images: 1.153
[14,    35] loss: 1.114 acc: 50.85 time: 7.02
[14,    70] loss: 1.153 acc: 47.54 time: 6.71
[14,   105] loss: 1.138 acc: 47.68 time: 6.72
[14,   140] loss: 1.138 acc: 49.38 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 48.99 %
Average loss on the 3925 validation images: 1.127
[15,    35] loss: 1.128 acc: 48.44 time: 7.04
[15,    70] loss: 1.128 acc: 48.93 time: 6.72
[15,   105] loss: 1.152 acc: 47.86 time: 6.72
[15,   140] loss: 1.111 acc: 49.96 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 47.52 %
Average loss on the 3925 validation images: 1.153
[16,    35] loss: 1.080 acc: 52.41 time: 7.04
[16,    70] loss: 1.103 acc: 50.76 time: 6.72
[16,   105] loss: 1.125 acc: 49.60 time: 6.72
[16,   140] loss: 1.096 acc: 50.89 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 53.02 %
Average loss on the 3925 validation images: 1.077
[17,    35] loss: 1.094 acc: 51.61 time: 7.01
[17,    70] loss: 1.078 acc: 52.10 time: 6.72
[17,   105] loss: 1.085 acc: 51.74 time: 6.71
[17,   140] loss: 1.079 acc: 51.21 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 53.86 %
Average loss on the 3925 validation images: 1.069
[18,    35] loss: 1.103 acc: 50.49 time: 7.04
[18,    70] loss: 1.046 acc: 52.72 time: 6.73
[18,   105] loss: 1.073 acc: 52.50 time: 6.72
[18,   140] loss: 1.064 acc: 52.50 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 54.57 %
Average loss on the 3925 validation images: 1.061
```

```
[19,    35] loss: 1.057 acc: 54.96 time: 7.04
[19,    70] loss: 1.057 acc: 53.48 time: 6.69
[19,   105] loss: 1.093 acc: 51.74 time: 6.69
[19,   140] loss: 1.036 acc: 54.87 time: 6.70
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 53.40 %
Average loss on the 3925 validation images: 1.073
[20,    35] loss: 1.055 acc: 52.32 time: 7.03
[20,    70] loss: 1.063 acc: 53.57 time: 6.70
[20,   105] loss: 1.076 acc: 52.46 time: 6.70
[20,   140] loss: 1.044 acc: 54.51 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 54.55 %
Average loss on the 3925 validation images: 1.050
[21,    35] loss: 1.071 acc: 53.17 time: 7.03
[21,    70] loss: 1.045 acc: 54.69 time: 6.71
[21,   105] loss: 1.043 acc: 54.82 time: 6.72
[21,   140] loss: 1.050 acc: 53.66 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 54.22 %
Average loss on the 3925 validation images: 1.043
[22,    35] loss: 1.059 acc: 53.35 time: 7.01
[22,    70] loss: 1.047 acc: 54.29 time: 6.71
[22,   105] loss: 1.041 acc: 54.73 time: 6.71
[22,   140] loss: 1.052 acc: 53.75 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 55.11 %
Average loss on the 3925 validation images: 1.037
[23,    35] loss: 1.042 acc: 55.09 time: 7.03
[23,    70] loss: 1.057 acc: 52.46 time: 6.71
[23,   105] loss: 1.017 acc: 55.67 time: 6.71
[23,   140] loss: 1.058 acc: 53.66 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 54.83 %
Average loss on the 3925 validation images: 1.048
[24,    35] loss: 1.020 acc: 56.88 time: 7.01
[24,    70] loss: 1.037 acc: 54.78 time: 6.71
[24,   105] loss: 1.020 acc: 57.19 time: 6.71
[24,   140] loss: 1.054 acc: 54.55 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 55.31 %
Average loss on the 3925 validation images: 1.026
[25,    35] loss: 1.041 acc: 54.51 time: 7.04
[25,    70] loss: 1.034 acc: 56.79 time: 6.72
[25,   105] loss: 1.007 acc: 55.98 time: 6.71
[25,   140] loss: 1.042 acc: 54.20 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 54.57 %
Average loss on the 3925 validation images: 1.044
[26,    35] loss: 1.012 acc: 55.04 time: 7.02
[26,    70] loss: 1.053 acc: 54.69 time: 6.70
[26,   105] loss: 1.025 acc: 56.07 time: 6.71
[26,   140] loss: 1.006 acc: 57.10 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 55.26 %
Average loss on the 3925 validation images: 1.031
[27,    35] loss: 1.017 acc: 56.65 time: 7.02
[27,    70] loss: 1.012 acc: 55.76 time: 6.71
[27,   105] loss: 1.028 acc: 54.96 time: 6.71
[27,   140] loss: 1.025 acc: 56.16 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 56.94 %
Average loss on the 3925 validation images: 1.010
```

```
[28,    35] loss: 1.011 acc: 57.01 time: 7.03
[28,    70] loss: 1.038 acc: 54.96 time: 6.71
[28,   105] loss: 1.011 acc: 56.83 time: 6.71
[28,   140] loss: 1.010 acc: 56.70 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 56.33 %
Average loss on the 3925 validation images: 1.018
[29,    35] loss: 1.017 acc: 57.01 time: 7.02
[29,    70] loss: 0.997 acc: 56.65 time: 6.71
[29,   105] loss: 0.997 acc: 57.10 time: 6.71
[29,   140] loss: 1.017 acc: 56.74 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 56.36 %
Average loss on the 3925 validation images: 1.028
[30,    35] loss: 0.994 acc: 58.08 time: 7.02
[30,    70] loss: 1.026 acc: 55.94 time: 6.73
[30,   105] loss: 0.998 acc: 57.72 time: 6.71
[30,   140] loss: 0.990 acc: 57.14 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 57.38 %
Average loss on the 3925 validation images: 0.999
[31,    35] loss: 0.980 acc: 57.28 time: 7.02
[31,    70] loss: 1.002 acc: 57.77 time: 6.71
[31,   105] loss: 0.963 acc: 60.13 time: 6.71
[31,   140] loss: 0.969 acc: 58.71 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 58.32 %
Average loss on the 3925 validation images: 0.986
[32,    35] loss: 0.972 acc: 58.62 time: 7.05
[32,    70] loss: 0.975 acc: 59.33 time: 6.72
[32,   105] loss: 0.936 acc: 61.16 time: 6.71
[32,   140] loss: 0.991 acc: 57.72 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 58.29 %
Average loss on the 3925 validation images: 0.978
[33,    35] loss: 0.959 acc: 60.62 time: 7.04
[33,    70] loss: 0.959 acc: 60.04 time: 6.71
[33,   105] loss: 0.973 acc: 59.91 time: 6.72
[33,   140] loss: 0.944 acc: 60.85 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 58.70 %
Average loss on the 3925 validation images: 0.973
[34,    35] loss: 0.960 acc: 59.33 time: 7.01
[34,    70] loss: 0.971 acc: 59.60 time: 6.71
[34,   105] loss: 0.957 acc: 60.62 time: 6.72
[34,   140] loss: 0.961 acc: 59.64 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.08 %
Average loss on the 3925 validation images: 0.972
[35,    35] loss: 0.958 acc: 59.96 time: 7.04
[35,    70] loss: 0.965 acc: 58.17 time: 6.71
[35,   105] loss: 0.940 acc: 60.49 time: 6.71
[35,   140] loss: 0.958 acc: 59.82 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.36 %
Average loss on the 3925 validation images: 0.964
[36,    35] loss: 0.934 acc: 61.12 time: 7.04
[36,    70] loss: 0.967 acc: 60.09 time: 6.71
[36,   105] loss: 0.949 acc: 60.27 time: 6.71
[36,   140] loss: 0.970 acc: 59.46 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.59 %
Average loss on the 3925 validation images: 0.971
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[37,    35] loss: 0.934 acc: 61.47 time: 7.02
[37,    70] loss: 0.963 acc: 60.04 time: 6.72
[37,   105] loss: 0.961 acc: 60.71 time: 6.72
[37,   140] loss: 0.956 acc: 60.27 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.26 %
Average loss on the 3925 validation images: 0.968
[38,    35] loss: 0.911 acc: 63.12 time: 7.01
[38,    70] loss: 0.939 acc: 61.07 time: 6.71
[38,   105] loss: 0.969 acc: 60.18 time: 6.71
[38,   140] loss: 0.957 acc: 59.78 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.77 %
Average loss on the 3925 validation images: 0.958
[39,    35] loss: 0.937 acc: 62.50 time: 7.04
[39,    70] loss: 0.933 acc: 60.45 time: 6.72
[39,   105] loss: 0.955 acc: 59.82 time: 6.72
[39,   140] loss: 0.944 acc: 61.07 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 60.46 %
Average loss on the 3925 validation images: 0.960
[40,    35] loss: 0.939 acc: 60.27 time: 7.02
[40,    70] loss: 0.936 acc: 60.49 time: 6.73
[40,   105] loss: 0.957 acc: 60.49 time: 6.72
[40,   140] loss: 0.936 acc: 61.16 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.95 %
Average loss on the 3925 validation images: 0.962
[41,    35] loss: 0.919 acc: 61.65 time: 7.01
[41,    70] loss: 0.957 acc: 60.54 time: 6.71
[41,   105] loss: 0.924 acc: 62.59 time: 6.72
[41,   140] loss: 0.954 acc: 60.58 time: 6.71
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.29 %
Average loss on the 3925 validation images: 0.964
[42,    35] loss: 0.929 acc: 62.01 time: 7.04
[42,    70] loss: 0.960 acc: 59.11 time: 6.73
[42,   105] loss: 0.930 acc: 61.92 time: 6.73
[42,   140] loss: 0.954 acc: 58.84 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.95 %
Average loss on the 3925 validation images: 0.957
[43,    35] loss: 0.929 acc: 60.94 time: 7.02
[43,    70] loss: 0.934 acc: 62.10 time: 6.72
[43,   105] loss: 0.950 acc: 59.15 time: 6.73
[43,   140] loss: 0.937 acc: 60.49 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 60.41 %
Average loss on the 3925 validation images: 0.954
[44,    35] loss: 0.943 acc: 59.96 time: 7.04
[44,    70] loss: 0.953 acc: 58.93 time: 6.73
[44,   105] loss: 0.911 acc: 62.32 time: 6.72
[44,   140] loss: 0.939 acc: 60.94 time: 6.73
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.54 %
Average loss on the 3925 validation images: 0.955
[45,    35] loss: 0.948 acc: 61.38 time: 7.04
[45,    70] loss: 0.938 acc: 60.71 time: 6.71
[45,   105] loss: 0.938 acc: 61.56 time: 6.71
[45,   140] loss: 0.927 acc: 62.63 time: 6.72
evaluating on imagenette validation set:
Accuracy of the network on the 3925 validation images: 59.72 %
Average loss on the 3925 validation images: 0.954
```

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Finished Training
[1,   100] loss: 1.864 acc: 29.45 time: 2.82
[1,   200] loss: 1.681 acc: 36.51 time: 2.68
[1,   300] loss: 1.565 acc: 41.14 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 43.02 %
Average loss on the 10000 test images: 1.567
[2,   100] loss: 1.419 acc: 47.49 time: 2.76
[2,   200] loss: 1.357 acc: 50.56 time: 2.59
[2,   300] loss: 1.286 acc: 53.70 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 55.80 %
Average loss on the 10000 test images: 1.236
[3,   100] loss: 1.176 acc: 57.63 time: 2.78
[3,   200] loss: 1.139 acc: 59.40 time: 2.62
[3,   300] loss: 1.098 acc: 61.08 time: 2.60
TESTING:
Accuracy of the network on the 10000 test images: 63.04 %
Average loss on the 10000 test images: 1.057
[4,   100] loss: 1.034 acc: 62.98 time: 2.75
[4,   200] loss: 1.024 acc: 63.80 time: 2.64
[4,   300] loss: 0.983 acc: 65.20 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 66.27 %
Average loss on the 10000 test images: 0.964
[5,   100] loss: 0.919 acc: 67.22 time: 2.77
[5,   200] loss: 0.938 acc: 66.91 time: 2.66
[5,   300] loss: 0.901 acc: 68.43 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 68.94 %
Average loss on the 10000 test images: 0.912
[6,   100] loss: 0.841 acc: 70.60 time: 2.76
[6,   200] loss: 0.874 acc: 69.73 time: 2.67
[6,   300] loss: 0.843 acc: 70.45 time: 2.68
TESTING:
Accuracy of the network on the 10000 test images: 70.97 %
Average loss on the 10000 test images: 0.836
[7,   100] loss: 0.813 acc: 71.49 time: 2.79
[7,   200] loss: 0.801 acc: 71.94 time: 2.63
[7,   300] loss: 0.808 acc: 71.84 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 74.20 %
Average loss on the 10000 test images: 0.747
[8,   100] loss: 0.778 acc: 73.02 time: 2.77
[8,   200] loss: 0.749 acc: 73.79 time: 2.63
[8,   300] loss: 0.753 acc: 73.78 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 72.59 %
Average loss on the 10000 test images: 0.794
[9,   100] loss: 0.720 acc: 75.12 time: 2.76
[9,   200] loss: 0.757 acc: 73.43 time: 2.64
[9,   300] loss: 0.727 acc: 74.58 time: 2.61
TESTING:
Accuracy of the network on the 10000 test images: 74.79 %
Average loss on the 10000 test images: 0.727
[10,   100] loss: 0.705 acc: 75.18 time: 2.81
[10,   200] loss: 0.694 acc: 76.12 time: 2.67
[10,   300] loss: 0.699 acc: 75.46 time: 2.64
TESTING:
Accuracy of the network on the 10000 test images: 75.24 %
Average loss on the 10000 test images: 0.722
[11,   100] loss: 0.619 acc: 78.84 time: 2.77
[11,   200] loss: 0.569 acc: 80.04 time: 2.66
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[11,   300] loss: 0.579 acc: 79.74 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 79.86 %
Average loss on the 10000 test images: 0.581
[12,   100] loss: 0.543 acc: 81.02 time: 2.78
[12,   200] loss: 0.539 acc: 81.33 time: 2.65
[12,   300] loss: 0.540 acc: 81.05 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 80.59 %
Average loss on the 10000 test images: 0.568
[13,   100] loss: 0.524 acc: 81.72 time: 2.76
[13,   200] loss: 0.535 acc: 81.21 time: 2.66
[13,   300] loss: 0.524 acc: 81.63 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 80.84 %
Average loss on the 10000 test images: 0.561
[14,   100] loss: 0.527 acc: 81.85 time: 2.80
[14,   200] loss: 0.518 acc: 81.80 time: 2.68
[14,   300] loss: 0.513 acc: 82.20 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 81.23 %
Average loss on the 10000 test images: 0.556
[15,   100] loss: 0.513 acc: 82.14 time: 2.80
[15,   200] loss: 0.495 acc: 82.59 time: 2.65
[15,   300] loss: 0.511 acc: 82.11 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 80.91 %
Average loss on the 10000 test images: 0.558
[16,   100] loss: 0.483 acc: 82.83 time: 2.78
[16,   200] loss: 0.499 acc: 82.36 time: 2.67
[16,   300] loss: 0.500 acc: 82.47 time: 2.65
TESTING:
Accuracy of the network on the 10000 test images: 81.40 %
Average loss on the 10000 test images: 0.554
[17,   100] loss: 0.486 acc: 82.94 time: 2.79
[17,   200] loss: 0.493 acc: 83.02 time: 2.66
[17,   300] loss: 0.500 acc: 82.61 time: 2.63
TESTING:
Accuracy of the network on the 10000 test images: 81.20 %
Average loss on the 10000 test images: 0.553
[18,   100] loss: 0.475 acc: 83.62 time: 2.81
[18,   200] loss: 0.484 acc: 83.00 time: 2.66
[18,   300] loss: 0.486 acc: 82.97 time: 2.62
TESTING:
Accuracy of the network on the 10000 test images: 81.52 %
Average loss on the 10000 test images: 0.544
[19,   100] loss: 0.472 acc: 83.51 time: 2.80
[19,   200] loss: 0.462 acc: 83.77 time: 2.68
[19,   300] loss: 0.477 acc: 83.25 time: 2.67
TESTING:
Accuracy of the network on the 10000 test images: 81.36 %
Average loss on the 10000 test images: 0.544
[20,   100] loss: 0.473 acc: 83.55 time: 2.78
[20,   200] loss: 0.459 acc: 83.97 time: 2.69
[20,   300] loss: 0.458 acc: 83.95 time: 2.66
TESTING:
Accuracy of the network on the 10000 test images: 81.97 %
Average loss on the 10000 test images: 0.536
Finished Training
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Out[70]:
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81.97
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