Solution_Final_CP_2021

November 12, 2022

1 CP - Final - 2021

1.1 Instruction

- Modify this file to be Final-<Your FirstName-[First Letter of Last Name]>, e.g., Final-Chaklam-S.ipynb
- This exam is open-booked; open-internet.
- You ARE NOT allowed to use sklearn or pytorch libraries, unless stated.
- The completed exams shall be submitted at the Google Classroom
- All code should be **complemented with comments**, unless it's really obvious. **We reserve the privilege to give you zero for any part of the question where the benefit of doubt is not justified**

1.2 Examination Rules:

- You may leave the room temporarily with the approval and supervision of the proctors. No extra time will be added to the exam in such cases.
- You are required to turn on your webcam during the entire period of the exam time
- Students will be allowed to leave at the **earliest 45 minutes** after the exam has started
- **All work should belong to you**. A student should NOT engage in the following activities which proctors reserve the right to interpret any of such act as academic dishonesty without questioning:
  - Chatting with any human beings physically or via online methods
  - Plagiarism of any sort, i.e., copying from friends. **Both copee and copier shall be given a minimum penalty of zero mark for that particular question or the whole exam.**
- No make-up exams are allowed. Special considerations may be given upon a valid reason on unpredictable events such as accidents or serious sickness.

[ ]:
```
import numpy as np
import torch
import torchvision
import torchvision.datasets as datasets
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
import math
import matplotlib.pyplot as plt
from torch.utils.data import Dataset, DataLoader
```

```python
import random
from collections import Counter

from sklearn.model_selection import train_test_split
```

1. Generate a 4 class 2d-data with 70000 samples. (10 points)

- Class 0 data is sampled from a normal distribution with mean = 0, std = 1, size = (28,28)
- Class 1 data is sampled from a normal distribution with mean = 5, std = 1, size = (28,28)
- Class 2 data is sampled from a normal distribution with mean = 15, std = 1, size = (28,28)
- Class 3 data is sampled from a normal distribution with mean = 20, std = 1, size = (28,28)

The final shape of x should be (70000, 1, 28, 28) and y should be (70000,)

[ ]:
```python
class Dataset():
    def __init__(self, num_sample = 70000, num_classes = 4):
        self.num_sample = num_sample
        self.num_classes = num_classes
        self.x = torch.empty(self.num_sample,1,28,28)
        self.y = [int(random.randrange(0, self.num_classes)) for _ in␣
 ↪range(self.num_sample)]
        # print(Counter(self.y).keys())
        # print(Counter(self.y).values())
        self.y = torch.Tensor(self.y)
        print("X shape: ", self.x.shape, "y shape: ", self.y.shape)
        for i in range(self.num_sample):
            if self.y[i] == 0:
                self.x[i,:,:,:] = torch.normal(mean=0, std=1, size = (28,28))
            elif self.y[i] == 1:
                self.x[i,:,:,:] = torch.normal(mean=5, std=1, size = (28,28))
            elif self.y[i] == 2:
                self.x[i,:,:,:] = torch.normal(mean=15, std=1, size = (28,28))
            else:
                self.x[i,:,:,:] = torch.normal(mean=20, std=1, size = (28,28))

        self.len = self.x.shape[0]

    def __getitem__(self, index):
        return self.x[index], self.y[index]

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

In case you are unable to do question 1, Use the following lines of code to generate your data and continue with question 3. But be aware that no marks will be given to question 1 and question 2

[ ]:
```python
import torchvision
training_data = torchvision.datasets.MNIST('./data/', train=True, download=True,
```

```
                             transform=torchvision.transforms.Compose([
                               torchvision.transforms.ToTensor(),
                               torchvision.transforms.Normalize(
                                 (0.5,), (0.5,))
                             ]))

testing_data  = torchvision.datasets.MNIST('./data/', train=False,␣
 ↪download=True,
                             transform=torchvision.transforms.Compose([
                               torchvision.transforms.ToTensor(),
                               torchvision.transforms.Normalize(
                                 (0.5,), (0.5,))
                             ]))

datasets = {}
datasets['train'] = training_data
datasets['test'] = testing_data
```

2. Split your data into train and test with the split ratio of 0.2

```
[ ]: from torch.utils.data import Subset
def train_test_dataset(dataset, split=0.20):
    train_idx, test_idx = train_test_split(list(range(len(dataset))),␣
 ↪test_size=split)
    datasets = {}
    datasets['train'] = Subset(dataset, train_idx)
    datasets['test'] = Subset(dataset, test_idx)
    return datasets

dataset = Dataset(num_sample = 70000)
datasets = train_test_dataset(dataset, split = 1/7)
```

```
X shape:  torch.Size([70000, 1, 28, 28]) y shape:  torch.Size([70000])
```

3. Check the size of your train and test set

```
[ ]: print("Number of training samples: ",len(datasets['train']))
print("Number of testing samples: ",len(datasets['test']))
```

```
Number of training samples:  60000
Number of testing samples:  10000
```

4. Set up your train and test loader with a batch size of 32 and shuffle = True.

```
[ ]: batch_size = 32
train_loader = DataLoader(datasets['train'], batch_size=batch_size,␣
 ↪shuffle=True)
test_loader = DataLoader(datasets['test'], batch_size=batch_size, shuffle=True)
```

[ ]:
```python
loaders = {'train': train_loader, 'test': test_loader }
```

5. Check the shape of your batch. It should be [batchsize = 32, channel = 1, height = 28, width = 28]

[ ]:
```python
examples = enumerate(train_loader)
batch_idx, (example_data, example_targets) = next(examples)
```

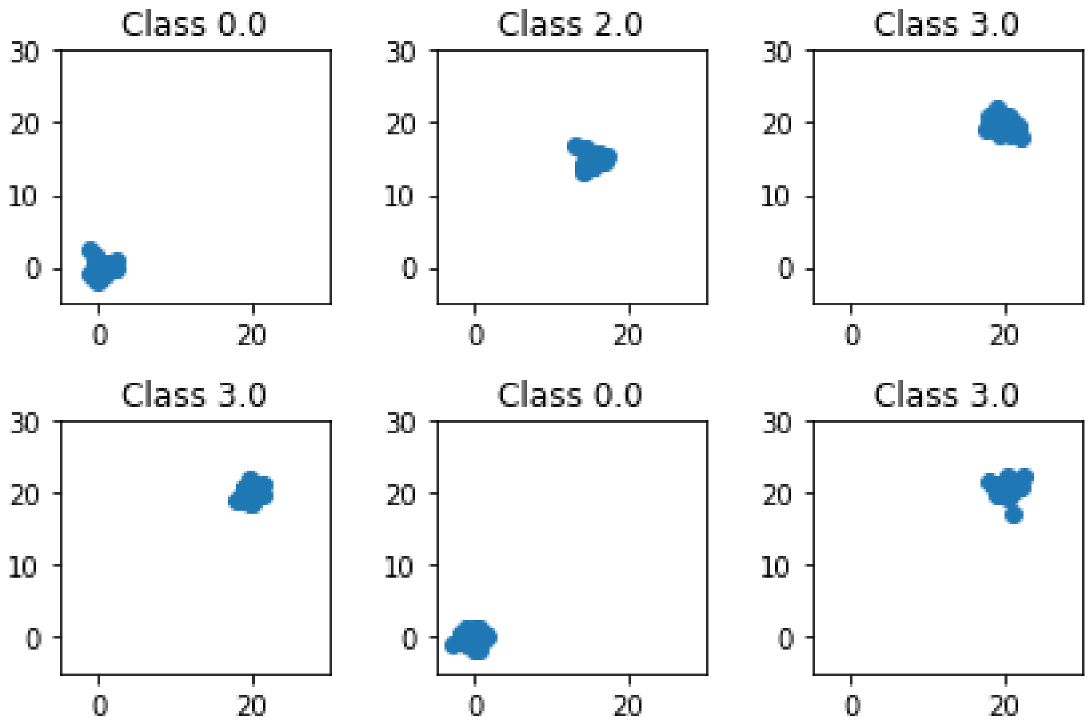
[ ]:
```python
example_data.shape
```

[ ]:
```
torch.Size([32, 1, 28, 28])
```

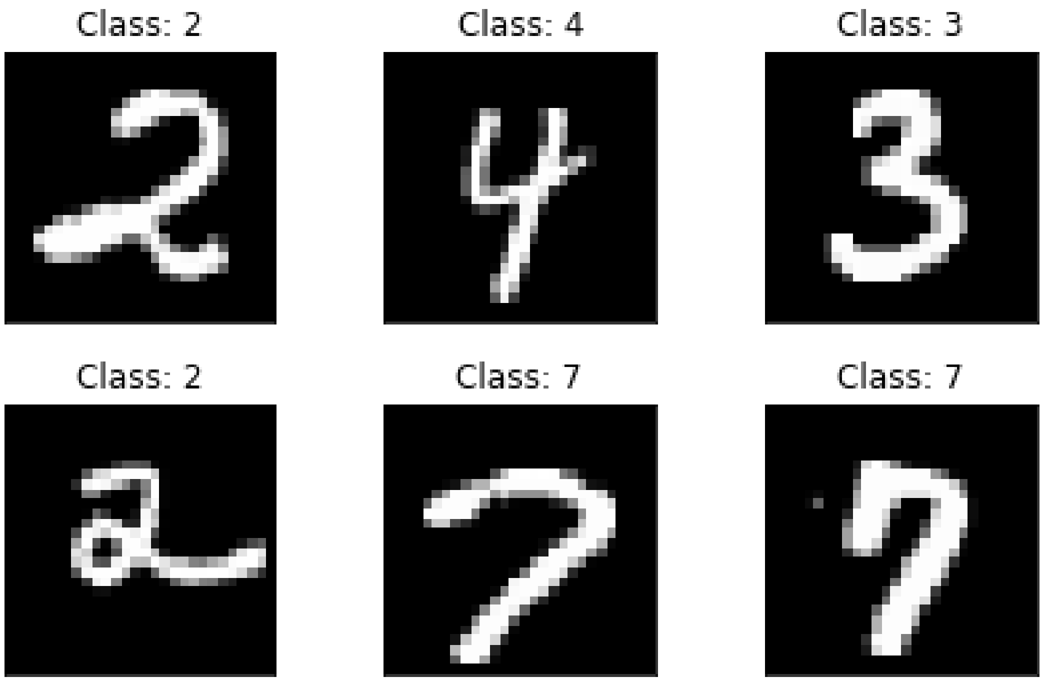
6. Plot 6 samples.

[ ]:
```python
fig = plt.figure()

def get_image(x, y):
    print(x.shape, y.shape)
    plt.tight_layout()
    plt.scatter(x[:,:,0],x[:,:,1])
    plt.title(f"Class {y}")
    plt.xlim([-5,30])
    plt.ylim([-5,30])

for i in range(len(dataset)):
    x, y = datasets['train'][i]
    ax = plt.subplot(2, 3, i + 1)
    ax.set_title('Sample #{}'.format(i))
    get_image(x,y)
    if i == 5:
        plt.show()
        break
```

```
torch.Size([1, 28, 28]) torch.Size([])
torch.Size([1, 28, 28]) torch.Size([])
torch.Size([1, 28, 28]) torch.Size([])
torch.Size([1, 28, 28]) torch.Size([])
torch.Size([1, 28, 28]) torch.Size([])
torch.Size([1, 28, 28]) torch.Size([])
```



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

fig = plt.figure()
for i in range(6):
  plt.subplot(2,3,i+1)
  plt.tight_layout()
  plt.imshow(example_data[i][0], cmap='gray', interpolation='none')
  plt.title("Class: {}".format(example_targets[i]))
  plt.xticks([])
  plt.yticks([])
```



7. Configure your device.

[ ]:
```
# Device configuration
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
device
```

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

8. Define your class called Net with the following layers

- cnn2d layer 1 with in_channel = 1, out_channel = 10, kernel size of 5, dropout of p = 0.5 maxpool and relu as its activation function
- cnn2d layer 2 with in_channel = 10, out_channel = 20, kernel size of 5, dropout of p = 0.5 maxpool and relu as its activation function
- linear layer with output of 25
- lstm with num_layer = 2 and set hidden size to be num_classes

[ ]:
```
class Net(nn.Module):
    def __init__(self, num_class, num_layers, num_classes):
        super(Net, self).__init__()
        # CNN2d
        self.num_classes = num_classes
        self.conv1 = nn.Conv2d(1, 10, kernel_size=5)
        self.conv1_drop = nn.Dropout2d(p = 0.5)
        self.conv2 = nn.Conv2d(10, 20, kernel_size=5)
```

```
        self.conv2_drop = nn.Dropout2d(p = 0.5)
        self.fc1 = nn.Linear(320, 25)

        #LSTM
        self.hidden_size = num_classes
        self.num_layers = num_layers
        self.input_size = 5
        self.sequence_length = 5

        self.lstm = nn.LSTM(self.input_size, self.hidden_size, self.num_layers,␣
↪batch_first=True)

    def forward(self, x):
        x = F.relu(F.max_pool2d(self.conv1_drop(self.conv1(x)), 2))
        x = F.relu(F.max_pool2d(self.conv2_drop(self.conv2(x)), 2))
        x = x.view(-1, 320)
        x = F.relu(self.fc1(x))
        x = F.dropout(x, training=self.training)
        # out = x
        h0 = torch.zeros(self.num_layers, x.size(0), self.hidden_size).
↪to(device)
        c0 = torch.zeros(self.num_layers, x.size(0), self.hidden_size).
↪to(device)

        x = x.reshape(-1, self.sequence_length, self.input_size).to(device)
        out, hidden = self.lstm(x, (h0, c0))  # out: tensor of shape␣
↪(batch_size, seq_length, hidden_size)
        out = out[:, -1, :]
        return out
```

9. Create an model object with num_layers = 2, hidden_size = 64, num_classes = 4

If you use MNIST hidden_size and num_classes = 10

[ ]:
```
num_layers = 2
num_classes = 4
model = Net(num_classes, num_layers, num_classes).to(device)
print(model)
```

```
Net(
  (conv1): Conv2d(1, 10, kernel_size=(5, 5), stride=(1, 1))
  (conv1_drop): Dropout2d(p=0.5, inplace=False)
  (conv2): Conv2d(10, 20, kernel_size=(5, 5), stride=(1, 1))
  (conv2_drop): Dropout2d(p=0.5, inplace=False)
  (fc1): Linear(in_features=320, out_features=25, bias=True)
  (lstm): LSTM(5, 4, num_layers=2, batch_first=True)
)
```

10. Define an appropriate loss function for classification of this dataset

```
[ ]: loss_func = nn.CrossEntropyLoss()
```

11. Define your optimizer as Adam with learning rate of 0.001.

```
[ ]: from torch import optim
     learning_rate = 0.001
     optimizer = optim.Adam(model.parameters(), lr = learning_rate)
```

12. Train your model with n_epoch = 3

```
[ ]: def train(num_epochs, model, loaders):
         print(f"num_epochs: {num_epochs}")
         print(f"model: {model}")
         print(f"loaders['train']: {loaders['train']}")
         print("Started epoch: ")
         losses = []
         accs = []
         model.train()
         total_step = len(loaders['train'])
         for epoch in range(num_epochs):
             correct = 0
             total = 0
             loss = 0
             for i, (inputs, targets) in enumerate(loaders['train']):
                 inputs = inputs.to(device)
                 targets = targets.to(device)

                 # Forward pass
                 outputs = model(inputs)
                 _, predicted = torch.max(outputs.data, 1)
                 total = total + targets.size(0)
                 correct = correct + (predicted == targets).sum().item()

                 loss = loss_func(outputs, targets.long())
                 loss += loss

                 # Backward and optimize
                 optimizer.zero_grad()
                 loss.backward()
                 optimizer.step()

                 if (i+1) % 100 == 0:
                     print ('Epoch [{}/{}], Step [{}/{}], Loss: {:.4f}'
                            .format(epoch + 1, num_epochs, i + 1, total_step, loss.
      ↪item()))
```

```python
        accs.append(100 * correct / total)
        losses.append(loss / total)
    print("Done!")
    return losses, accs
```

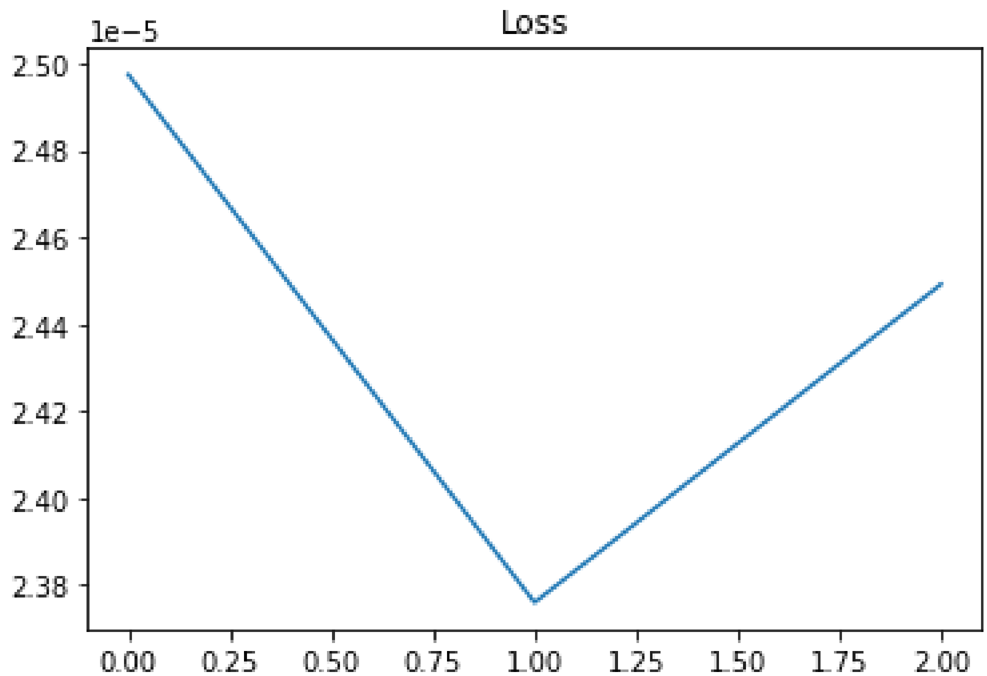
[ ]:
```python
num_epochs = 3
losses, accs = train(num_epochs, model, loaders)
```

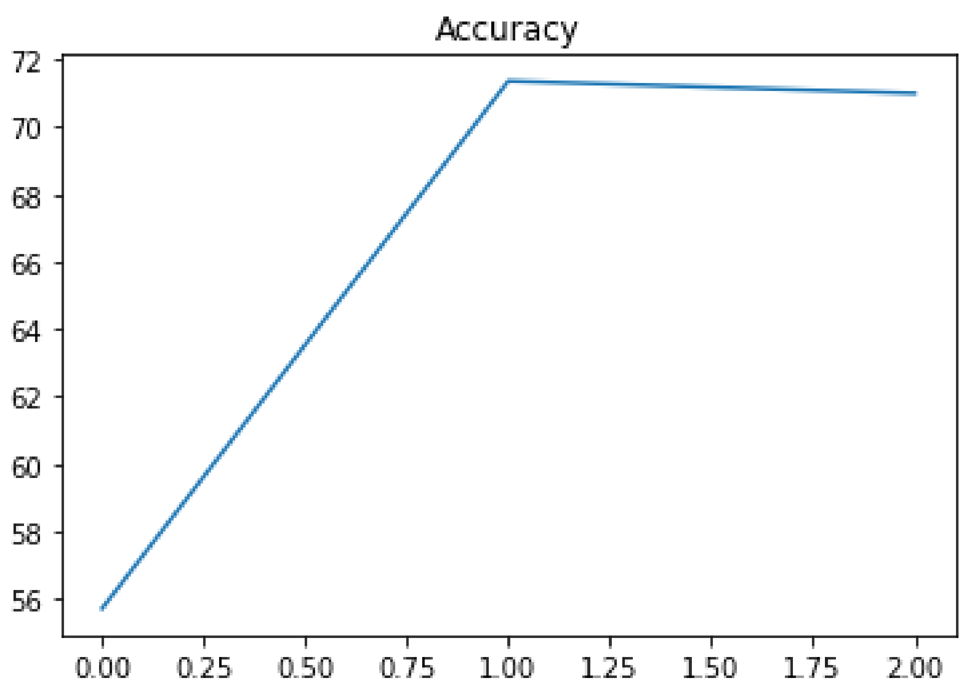
```
num_epochs: 3
model: Net(
  (conv1): Conv2d(1, 10, kernel_size=(5, 5), stride=(1, 1))
  (conv1_drop): Dropout2d(p=0.5, inplace=False)
  (conv2): Conv2d(10, 20, kernel_size=(5, 5), stride=(1, 1))
  (conv2_drop): Dropout2d(p=0.5, inplace=False)
  (fc1): Linear(in_features=320, out_features=25, bias=True)
  (lstm): LSTM(5, 4, num_layers=2, batch_first=True)
)
loaders['train']: <torch.utils.data.dataloader.DataLoader object at
0x7f22db1c3350>
Started epoch:
Epoch [1/3], Step [100/1875], Loss: 2.7407
Epoch [1/3], Step [200/1875], Loss: 2.7361
Epoch [1/3], Step [300/1875], Loss: 2.5388
Epoch [1/3], Step [400/1875], Loss: 2.5938
Epoch [1/3], Step [500/1875], Loss: 2.3819
Epoch [1/3], Step [600/1875], Loss: 2.2306
Epoch [1/3], Step [700/1875], Loss: 2.1422
Epoch [1/3], Step [800/1875], Loss: 2.2707
Epoch [1/3], Step [900/1875], Loss: 1.9539
Epoch [1/3], Step [1000/1875], Loss: 2.1284
Epoch [1/3], Step [1100/1875], Loss: 2.0494
Epoch [1/3], Step [1200/1875], Loss: 2.0679
Epoch [1/3], Step [1300/1875], Loss: 1.6716
Epoch [1/3], Step [1400/1875], Loss: 1.8248
Epoch [1/3], Step [1500/1875], Loss: 1.6916
Epoch [1/3], Step [1600/1875], Loss: 1.3100
Epoch [1/3], Step [1700/1875], Loss: 1.4979
Epoch [1/3], Step [1800/1875], Loss: 1.6195
Epoch [2/3], Step [100/1875], Loss: 1.6101
Epoch [2/3], Step [200/1875], Loss: 1.4253
Epoch [2/3], Step [300/1875], Loss: 1.3510
Epoch [2/3], Step [400/1875], Loss: 1.6336
Epoch [2/3], Step [500/1875], Loss: 1.5093
Epoch [2/3], Step [600/1875], Loss: 1.4700
Epoch [2/3], Step [700/1875], Loss: 1.1975
Epoch [2/3], Step [800/1875], Loss: 1.5613
Epoch [2/3], Step [900/1875], Loss: 1.4831
```

```
Epoch [2/3], Step [1000/1875], Loss: 1.3831
Epoch [2/3], Step [1100/1875], Loss: 1.4867
Epoch [2/3], Step [1200/1875], Loss: 1.2582
Epoch [2/3], Step [1300/1875], Loss: 1.3508
Epoch [2/3], Step [1400/1875], Loss: 1.2983
Epoch [2/3], Step [1500/1875], Loss: 1.2798
Epoch [2/3], Step [1600/1875], Loss: 1.6067
Epoch [2/3], Step [1700/1875], Loss: 1.5767
Epoch [2/3], Step [1800/1875], Loss: 1.4397
Epoch [3/3], Step [100/1875], Loss: 1.2378
Epoch [3/3], Step [200/1875], Loss: 1.3466
Epoch [3/3], Step [300/1875], Loss: 1.4327
Epoch [3/3], Step [400/1875], Loss: 1.2882
Epoch [3/3], Step [500/1875], Loss: 1.4829
Epoch [3/3], Step [600/1875], Loss: 1.4978
Epoch [3/3], Step [700/1875], Loss: 1.7869
Epoch [3/3], Step [800/1875], Loss: 1.2314
Epoch [3/3], Step [900/1875], Loss: 1.3909
Epoch [3/3], Step [1000/1875], Loss: 1.3966
Epoch [3/3], Step [1100/1875], Loss: 1.6517
Epoch [3/3], Step [1200/1875], Loss: 1.4526
Epoch [3/3], Step [1300/1875], Loss: 1.3311
Epoch [3/3], Step [1400/1875], Loss: 1.3902
Epoch [3/3], Step [1500/1875], Loss: 1.3996
Epoch [3/3], Step [1600/1875], Loss: 1.3542
Epoch [3/3], Step [1700/1875], Loss: 1.5322
Epoch [3/3], Step [1800/1875], Loss: 1.5383
Done!
```

13. Plot your train losses and accuracies

[ ]:
```python
import matplotlib.pyplot as plt
plt.plot(losses)
plt.title("Loss")
plt.show()
plt.plot(accs)
plt.title("Accuracy")
plt.show()
```





14. Evaluate your model

[ ]:

```python
# Test the model
model.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for inputs, targets in loaders['test']:
        inputs = inputs.to(device)
        targets = targets.to(device)
        outputs = model(inputs)
        predicted = torch.argmax(outputs, dim = 1)
        total = total + targets.size(0)
        correct = correct + (predicted == targets).sum().item()
print('Test Accuracy of the model on the 10000 test set: {} %'.format(100 *␣
 ↪correct / total))
```

```
Test Accuracy of the model on the 10000 test set: 74.44 %
```