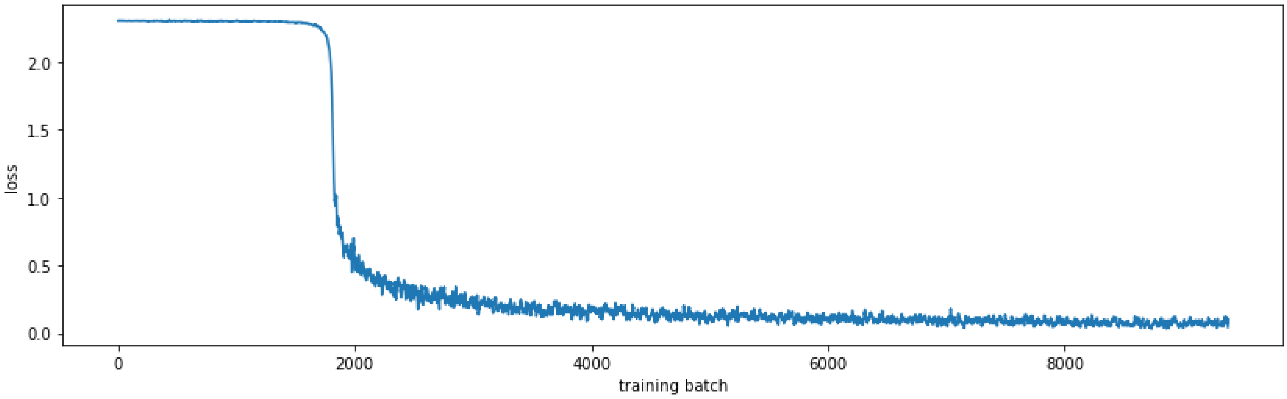
```
from __future__ import print_function
import numpy as np
import argparse
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
from torchvision import datasets, transforms
from sklearn.metrics import *
from matplotlib import pyplot as plt
%matplotlib inline

class CNN(nn.Module):
    def __init__(self):
        super(CNN, self).__init__()
        self.conv1 = nn.Conv2d(1, 20, 5, 1)
········self.conv2·=·nn.Conv2d(20,·20,·5,·1)

········self.conv3·=·nn.Conv2d(20,·50,·1,·1)
········self.conv4·=·nn.Conv2d(50,·50,·1,·1)
········self.conv5·=·nn.Conv2d(50,·50,·1,·1)
········self.conv6·=·nn.Conv2d(50,·50,·1,·1)
········self.conv7·=·nn.Conv2d(50,·50,·1,·1)

········self.fc1·=·nn.Linear(4*4*50,·500)
········self.fc2·=·nn.Linear(500,·10)

····def·forward(self,·x):
········x·=·F.relu(self.conv1(x))
········x·=·F.max_pool2d(x,·2,·2)
········x·=·F.relu(self.conv2(x))
·
········x·=·F.relu(self.conv3(x))
········x·=·F.relu(self.conv4(x))
········x·=·F.relu(self.conv5(x))
········x·=·F.relu(self.conv6(x))
········x·=·F.relu(self.conv7(x))
········
········x·=·F.max_pool2d(x,·2,·2)

········x·=·x.view(-1,·4*4*50)
········x·=·F.relu(self.fc1(x))
········x·=·self.fc2(x)
········return·F.log_softmax(x,·dim=1)

def train(model, device, train_loader, optimizer, epoch):
    losses = []
    model.train()
    for batch_idx, (data, target) in enumerate(train_loader):
        data, target = data.to(device), target.to(device)
        optimizer.zero_grad()
        output = model(data)
        loss = F.nll_loss(output, target)
        loss.backward()
        loss.backward()
        optimizer.step()
        losses.append(loss.item())
        if batch_idx > 0 and batch_idx % 100 == 0:
            print('Train Epoch: {} [{}/{}\t({:.0f}%)]\tLoss: {:.6f}'.format(
                epoch, batch_idx * len(data), len(train_loader.dataset),
                100. * batch_idx / len(train_loader), loss.item()))
    return losses

def test(model, device, test_loader):
    model.eval()
    test_loss = 0
    correct = 0
    with torch.no_grad():
        for data, target in test_loader:
            data, target = data.to(device), target.to(device)
            output = model(data)
            test_loss += F.nll_loss(output, target, reduction='sum').item() # sum up batch
            pred = output.argmax(dim=1, keepdim=True) # get the index of the max log-proba
            correct += pred.eq(target.view_as(pred)).sum().item()
    test_loss /= len(test_loader.dataset)
    print('\nTest set: Average loss: {:.4f}, Accuracy: {}/{} ({:.0f}%)\n'.format(
        test_loss, correct, len(test_loader.dataset),
        100. * correct / len(test_loader.dataset)))
    return (float(correct) / len(test_loader.dataset))

train_loader = torch.utils.data.DataLoader(
    datasets.MNIST(
        '../data',
       train=True,
       download=True,
       transform=transforms.Compose([
           transforms.ToTensor(),
           transforms.Normalize((0.1307,), (0.3081,))
       ])
    ),
    batch_size=64,
    shuffle=True)
test_loader = torch.utils.data.DataLoader(
    datasets.MNIST(
        '../data',
        train=False,
        transform=transforms.Compose([
           transforms.ToTensor(),
           transforms.Normalize((0.1307,), (0.3081,))
        ])
    ),
    batch_size=1000,
    shuffle=True)

model = CNN()
optimizer = optim.SGD(model.parameters(), lr=0.01, momentum=0.5)
device = torch.device("cpu") # or 'gpu'
losses = []
accuracies = []
for epoch in range(0, 10):
```

```
for epoch in range(0, 10):
    losses.extend(train(model, device, train_loader, optimizer, epoch))
    accuracies.append(test(model, device, train_loader))
```

```
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz
```

```
def mean(li): return sum(li)/len(li)
plt.figure(figsize=(14, 4))
plt.xlabel('training batch')
plt.ylabel('loss')
plt.plot([mean(losses[i:i+10]) for i in range(len(losses))])
```

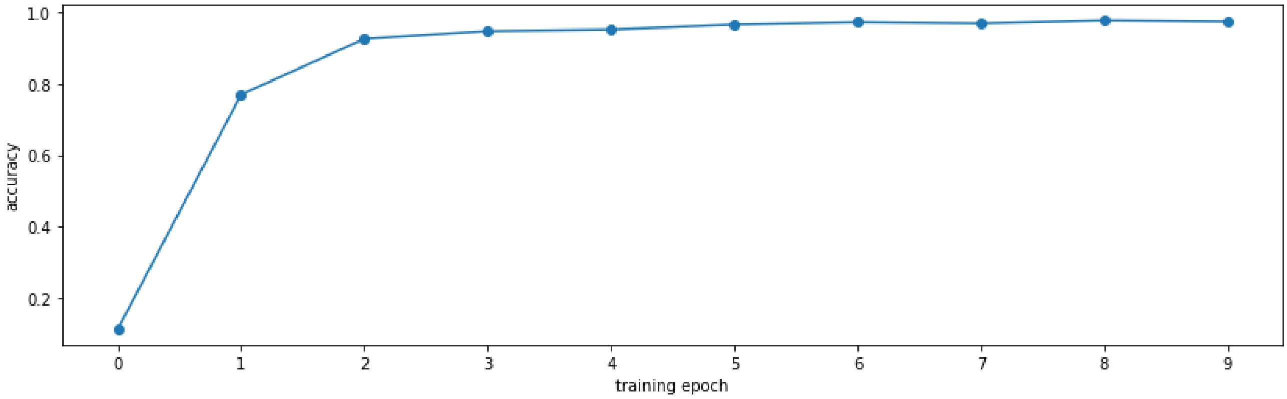
```
[<matplotlib.lines.Line2D at 0x7f00466b8fd0>]
```



```
Train Epoch: 0 [12800/60000     (21%)]  Loss: 2.307724
```

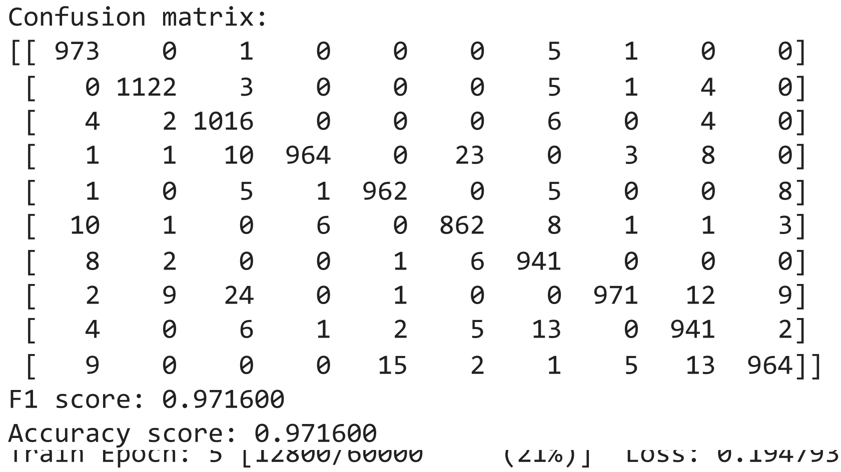
```
plt.figure(figsize=(14, 4))
plt.xticks(range(len(accuracies)))
plt.xlabel('training epoch')
plt.ylabel('accuracy')
plt.plot(accuracies, marker='o')
```

```
[<matplotlib.lines.Line2D at 0x7f0046628ad0>]
```



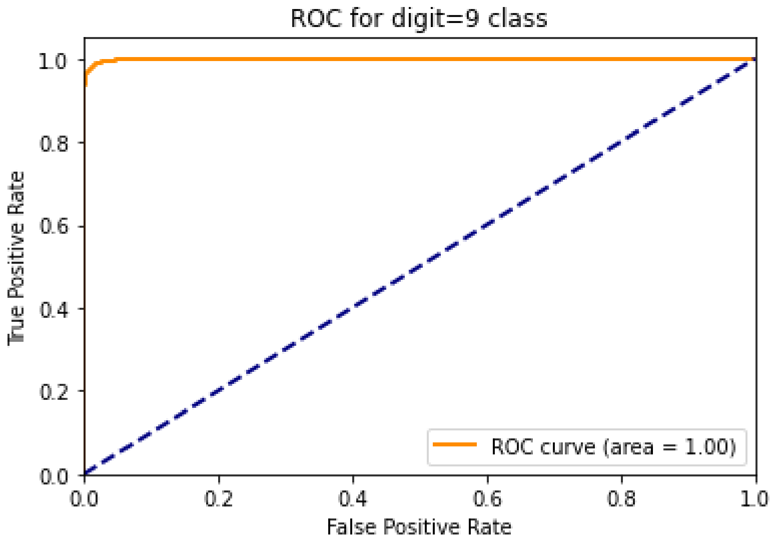
```
Train Epoch: 1 [12800/60000     (21%)]  Loss: [illegible]
Train Epoch: 2 [19200/60000     (32%)]  Loss: 0.302434
```

```
def test_label_predictions(model, device, test_loader):
    model.eval()
    actuals = []
    predictions = []
    with torch.no_grad():
        for data, target in test_loader:
            data, target = data.to(device), target.to(device)
            output = model(data)
            prediction = output.argmax(dim=1, keepdim=True)
            actuals.extend(target.view_as(prediction))
            predictions.extend(prediction)
    return [i.item() for i in actuals], [i.item() for i in predictions]

actuals, predictions = test_label_predictions(model, device, test_loader)
print('Confusion matrix:')
print(confusion_matrix(actuals, predictions))
print('F1 score: %f' % f1_score(actuals, predictions, average='micro'))
print('Accuracy score: %f' % accuracy_score(actuals, predictions))
```



```
Confusion matrix:
[[ 973    0    1    0    0    0    5    1    0    0]
 [   0 1122    3    0    0    0    5    1    4    0]
 [   4    2 1016    0    0    0    6    0    4    0]
 [   1    1   10  964    0   23    0    3    8    0]
 [   1    0    5    1  962    0    5    0    0    8]
 [  10    1    0    6    0  862    8    1    1    3]
 [   8    2    0    0    1    6  941    0    0    0]
 [   2    9   24    0    1    0    0  971   12    9]
 [   4    0    6    1    2    5   13    0  941    2]
 [   9    0    0    0   15    2    1    5   13  964]]
F1 score: 0.971600
Accuracy score: 0.971600
Train Epoch: 5 [12800/60000     (21%)]  Loss: 0.194793
```

```
def test_class_probabilities(model, device, test_loader, which_class):
    model.eval()
    actuals = []
    probabilities = []
    with torch.no_grad():
        for data, target in test_loader:
            data, target = data.to(device), target.to(device)
            output = model(data)
            prediction = output.argmax(dim=1, keepdim=True)
            actuals.extend(target.view_as(prediction) == which_class)
            probabilities.extend(np.exp(output[:, which_class]))
    return [i.item() for i in actuals], [i.item() for i in probabilities]

which_class = 9
actuals, class_probabilities = test_class_probabilities(model, device, test_loader, which_

fpr, tpr, _ = roc_curve(actuals, class_probabilities)
roc_auc = auc(fpr, tpr)
plt.figure()
lw = 2
plt.plot(fpr, tpr, color='darkorange',
         lw=lw, label='ROC curve (area = %0.2f)' % roc_auc)
plt.plot([0, 1], [0, 1], color='navy', lw=lw, linestyle='--')
plt.xlim([0.0, 1.0])
plt.ylim([0.0, 1.05])
plt.xlabel('False Positive Rate')
plt.ylabel('True Positive Rate')
plt.title('ROC for digit=%d class' % which_class)
plt.legend(loc="lower right")
plt.show()
```



```
print('Trainable parameters:')
for name, param in model.named_parameters():
    if param.requires_grad:
        print(name, '\t',param.numel())
```

```
Trainable parameters:
conv1.weight     500
conv1.bias       20
conv2.weight     10000
conv2.bias       20
conv3.weight     1000
conv3.bias       50
conv4.weight     2500
conv4.bias       50
conv5.weight     2500
conv5.bias       50
conv6.weight     2500
conv6.bias       50
conv7.weight     2500
conv7.bias       50
fc1.weight       400000
fc1.bias         500
fc2.weight       5000
fc2.bias         10
```