# dev1num2

February 5, 2019

In [8]:
```
import torch
import torchvision
import torchvision.transforms as transforms #
import torchvision.datasets.mnist as mnist  # to import data

# we use torch.cuda.Event(enable_timing=True) to measure time
# from timeit import default_timer as timer
# import time

import torch.optim as optim
import torch.nn as nn
import torch.nn.functional as F

import collections           # for ordered_dictionnary
import torch.nn.init as init # to initialize model

import copy                  # for copy.deepcopy( ... )

import matplotlib.pyplot as plt
import numpy as np

import collections
import torch.nn.init as init
```

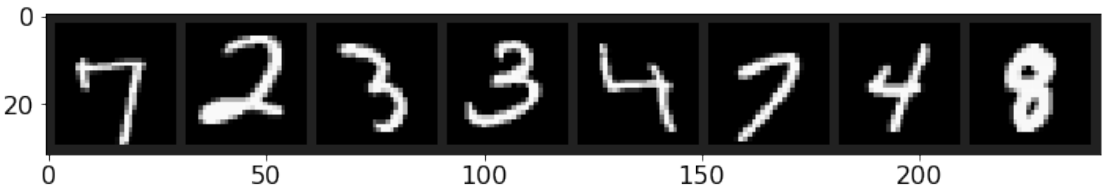
## 1 Assigment 1, part 2

### 1.1 import data

In [3]:
```
transform1 = transforms.Compose( [transforms.ToTensor(), transforms.Normalize((0.5, 0.5
transform2 = transforms.Compose( [transforms.ToTensor(), transforms.Normalize( (0.1307
dl_path  = "./data_mnist"

trainset = mnist.MNIST( root = dl_path, train=True , download=True, transform = transfo
testset  = mnist.MNIST( root = dl_path, train=False, download=True, transform = transfo
```

display some samples

```
In [27]: nb_sample = 8

         trainloader = torch.utils.data.DataLoader(trainset, batch_size = nb_sample, shuffle=Tr
         testloader  = torch.utils.data.DataLoader(testset , batch_size = nb_sample, shuffle=Fa

         # functions to show an image

         def imshow(img):
             img = ( img + 0.43 ) / 3.3     # to be in the interval [0,1]
             npimg = img.numpy()
             npimg = (255*npimg).astype(np.uint8) # to be a int in (0,...,255)
             plt.imshow(np.transpose(npimg, (1, 2, 0)))
             plt.show()

         # get some random training images
         dataiter = iter(trainloader)
         images, labels = dataiter.next()

         # show images
         imshow(torchvision.utils.make_grid(images))
         # print labels
         print(' '.join('%5s' % labels[j].item() for j in range(nb_sample)))
         print( "img size = " , images.size() , "label size = " , labels.size() )
```




```
    7     2     3     3     4     7     4     8
img size =  torch.Size([8, 1, 28, 28]) label size =  torch.Size([8])
```

print size of train-test dataset

```
In [5]: training_dataset_size = trainset.__len__()
        testing_dataset_size  = testset.__len__()

        print( training_dataset_size )
        print( testing_dataset_size )
```

```
60000
10000
```

set the device to cuda if possible

```
In [6]: device = torch.device("cuda:0" if torch.cuda.is_available() else "cpu")
        print(device)
```

```
cuda:0
```

## 1.2 Define some modules

### 1.2.1 the MPL

```
In [9]: class MLP(nn.Module):
            def __init__(self, h1, h2):
                super(MLP, self).__init__()
                self.fc1 = nn.Linear(784, h1)
                self.fc2 = nn.Linear(h1 , h2)
                self.fc3 = nn.Linear(h2 , 10)

            def forward(self, x):
                x = x.view( -1, 28 * 28 )
                x = F.relu(self.fc1(x))
                x = F.relu(self.fc2(x))
                x = F.softmax(self.fc3(x), dim=-1)
                return x
```

```
In [10]: # fan_in, fan_out = _calculate_fan_in_and_fan_out(tensor)
         # print( nn.init._calculate_fan_in_and_fan_out(net.state_dict()["fc1.weight"]) )
         # print( net.state_dict()["fc1.weight"].size() )
```

### 1.2.2 The CNN

architecture taken from : https://github.com/MaximumEntropy/welcome_tutorials/tree/pytorch/pytorch

```
In [11]: class Classifier(nn.Module):
             """Convnet Classifier"""
             def __init__(self, kernel_sz = 3 ):

                 if kernel_sz % 2 == 0 :
                     raise ValueError("kernel size must be odd")
                 pad = kernel_sz // 2

                 super(Classifier, self).__init__()
                 self.conv = nn.Sequential(
                     # Layer 1
                     nn.Conv2d(in_channels=1, out_channels=16, kernel_size=( kernel_sz , kernel
                     # nn.Dropout(p=0.5),
                     nn.ReLU(),
                     nn.MaxPool2d(kernel_size=(2, 2), stride=2),
```

```
            # Layer 2
            nn.Conv2d(in_channels=16, out_channels=32, kernel_size=( kernel_sz , kerne
            # nn.Dropout(p=0.5),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=(2, 2), stride=2),

            # Layer 3
            nn.Conv2d(in_channels=32, out_channels=64, kernel_size=( kernel_sz , kerne
            # nn.Dropout(p=0.5),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=(2, 2), stride=2),

            # Layer 4
            nn.Conv2d(in_channels=64, out_channels=128, kernel_size=(kernel_sz , kerne
            # nn.Dropout(p=0.5),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=(2, 2), stride=2)
        )
        # Logistic Regression
        self.clf = nn.Linear(128, 10)

    def forward(self, x):
        return self.clf(self.conv(x).squeeze())
```

Print the number of parameters in each models and display the computation

```
In [12]: def number_of_params( net ) :
    nb_param  = 0
    param_lst = " "
    for i, (key, value) in enumerate( net.state_dict().items() ) :

        if i == 0 :
            param_lst = param_lst + "\n ({:<20}    ".format( key + ")" )
        else :
            param_lst = param_lst + "\n ({:<20}  + ".format( key + ")" )


        nb_param_tmp = 1

        for j , x in enumerate(value.size()) :
            if j == 0 :
                param_lst = param_lst + "{xx}".format( xx = x )
            else :
                param_lst = param_lst + "*{xx}".format( xx = x )

            nb_param_tmp = nb_param_tmp * x
```

```
                nb_param = nb_param + nb_param_tmp

            print( "number of params = " , nb_param , " = ", param_lst  )

        mytestnet1 = MLP(h1=620,h2=620)
        mytestnet2 = Classifier( kernel_sz=9 )
        number_of_params( mytestnet1 )
        number_of_params( mytestnet2 )
        del mytestnet1
        del mytestnet2

number of params =  877930  =
 (fc1.weight)             620*784
 (fc1.bias)             + 620
 (fc2.weight)           + 620*620
 (fc2.bias)             + 620
 (fc3.weight)           + 10*620
 (fc3.bias)             + 10
number of params =  873738  =
 (conv.0.weight)          16*1*9*9
 (conv.0.bias)          + 16
 (conv.3.weight)        + 32*16*9*9
 (conv.3.bias)          + 32
 (conv.6.weight)        + 64*32*9*9
 (conv.6.bias)          + 64
 (conv.9.weight)        + 128*64*9*9
 (conv.9.bias)          + 128
 (clf.weight)           + 10*128
 (clf.bias)             + 10
```

### 1.2.3 Define some initialization methods

```
In [13]: def glorot_init ( layer ) :
             """
             Weiths are generated from U[-d,d] where d = sqrt(6/(fan_in + fan_out)), biases ar
             """
             if type(layer) == nn.Linear or type(layer) == nn.Conv2d :
                 init.xavier_uniform_( layer.weight , gain=1 )
                 layer.bias.data.fill_(0.0)

         def zero_init ( layer ) :
             """Everything is set to zero"""
             if type(layer) == nn.Linear or type(layer) == nn.Conv2d :
                 layer.weight.data.fill_(0.0)
                 layer.bias.data.fill_(0.0)

         def norm_init ( layer ) :
```

```
            """Weiths are generated from std normal, biases are set to zero"""
            if type(layer) == nn.Linear or type(layer) == nn.Conv2d :
                init.normal_(layer.weight, mean=0, std=1)
                layer.bias.data.fill_(0.0)
```

In [14]:
```
# net = MLP(500,500)
# print( net.state_dict()["fc1.weight"] )
# print( net.state_dict()["fc1.bias"] )
# net.apply( one_step_Glorot_init )
# print( net.state_dict()["fc1.weight"])
# print( net.state_dict()["fc1.bias"] )
```

In [100]:
```
if False :
    del cudanet
```

In [15]:
```
cudanet = Classifier( kernel_sz = 9 )
# cudanet = MLP(h1=620,h2=620)

cudanet.apply( glorot_init )
# cudanet.apply( zero_init )
# cudanet.apply( norm_init )

# cudanet.load_state_dict(torch.load(path), strict=False)
cudanet.to(device)
```

Out[15]:
```
Classifier(
  (conv): Sequential(
    (0): Conv2d(1, 16, kernel_size=(9, 9), stride=(1, 1), padding=(4, 4))
    (1): ReLU()
    (2): MaxPool2d(kernel_size=(2, 2), stride=2, padding=0, dilation=1, ceil_mode=Fals
    (3): Conv2d(16, 32, kernel_size=(9, 9), stride=(1, 1), padding=(4, 4))
    (4): ReLU()
    (5): MaxPool2d(kernel_size=(2, 2), stride=2, padding=0, dilation=1, ceil_mode=Fals
    (6): Conv2d(32, 64, kernel_size=(9, 9), stride=(1, 1), padding=(4, 4))
    (7): ReLU()
    (8): MaxPool2d(kernel_size=(2, 2), stride=2, padding=0, dilation=1, ceil_mode=Fals
    (9): Conv2d(64, 128, kernel_size=(9, 9), stride=(1, 1), padding=(4, 4))
    (10): ReLU()
    (11): MaxPool2d(kernel_size=(2, 2), stride=2, padding=0, dilation=1, ceil_mode=Fal
  )
  (clf): Linear(in_features=128, out_features=10, bias=True)
)
```

In [16]:
```
criterion = nn.CrossEntropyLoss()
optimizer = optim.SGD(cudanet.parameters(), lr=0.055, momentum=0.0, weight_decay=0)
nb_epoch  = 10
```

In [17]:
```
trainloader = torch.utils.data.DataLoader(trainset, batch_size=16*64,shuffle=True, nu
state_dict_list = list()
```

```
        torch.cuda.synchronize()

        start = torch.cuda.Event(enable_timing=True)
        end   = torch.cuda.Event(enable_timing=True)
        start.record()

        for epoch in range( nb_epoch ):  # loop over the dataset multiple times

            # if epoch == 5 :
            #   optimizer = optim.SGD(cudanet.parameters(), lr=0.05, momentum=0.0, weight_dec

            running_loss = 0.0
            for i, data in enumerate(trainloader, 0):
                # get the inputs
                inputs, labels = data
                inputs, labels = inputs.to(device), labels.to(device)

                # zero the parameter gradients
                optimizer.zero_grad()

                # forward + backward + optimize
                outputs = cudanet(inputs)
                # if i == 0 : print( outputs )
                loss = criterion(outputs, labels)
                loss.backward()
                optimizer.step()

                # print statistics
                running_loss += loss.item()
            else : # print every epoch
                print('epoch = %d, loss = %.8f' % (epoch + 1, running_loss / (i*8*64))) # nb
                running_loss = 0.0
                torch.cuda.synchronize()
                tmp_state_dict = {}
                for k, v in cudanet.state_dict().items():
                    tmp_state_dict[k] = v.cpu()
                state_dict_list.append( tmp_state_dict )
                torch.cuda.synchronize()

        else :
            print('Finished Training')

        end.record()
        torch.cuda.synchronize()
        print( "time required = " , start.elapsed_time(end)*0.001 , " s ")

epoch = 1, loss = 0.00347052
```

```
epoch = 2, loss = 0.00084709
epoch = 3, loss = 0.00039708
epoch = 4, loss = 0.00031282
epoch = 5, loss = 0.00021171
epoch = 6, loss = 0.00018068
epoch = 7, loss = 0.00015818
epoch = 8, loss = 0.00014084
epoch = 9, loss = 0.00012693
epoch = 10, loss = 0.00011423
Finished Training
time required =  139.8591875  s
```

test accuracy of net in its current state on the validation set

```
In [75]: testloader = torch.utils.data.DataLoader(testset, batch_size=8*64,shuffle=True, num_w
         correct = torch.tensor([0])
         total = torch.tensor([0])

         correct, total = correct.to(device) , total.to(device)
         with torch.no_grad():
             for data in testloader:
                 images, labels = data
                 images, labels = images.to(device), labels.to(device)
                 outputs = cudanet(images)
                 _, predicted = torch.max(outputs.data, 1)
                 total += labels.size(0)
                 # print(correct)
                 # print(predicted.size())
                 # print(labels.size())
                 # break
                 correct += (predicted == labels).sum()

         print('Accuracy of the network on the' , testing_dataset_size , 'test images: %.2f %%
                   % ( (100 * correct.double()) / total.double()  )
              )
```

```
Accuracy of the network on the 10000 test images: 91.18 %
```

Display the current state of the net

```
In [77]: if False :
             for key, value in cudanet.state_dict().items() :
                 pass
                 print( key , " = \n" , value , end = "\n")
```

training accuracy

```
In [96]: trainloader = torch.utils.data.DataLoader(trainset, batch_size=16*64,shuffle=True, nu

         correct = torch.tensor([0])
         total = torch.tensor([0])

         correct, total = correct.to(device) , total.to(device)
         with torch.no_grad():
             for data in trainloader:
                 images, labels = data
                 images, labels = images.to(device), labels.to(device)
                 outputs = cudanet(images)
                 _, predicted = torch.max(outputs.data, 1)
                 total += labels.size(0)
                 # print(correct)
                 # print(predicted)
                 # print(labels)
                 correct += (predicted == labels).sum()

         print('Accuracy of the network on the' , training_dataset_size  , 'train images: %.2f
                   % ( (100.0 * correct.double() ) / total.double() )
              )
```

```
Accuracy of the network on the 60000 train images: 98.32 %
```

compare accuracy across epoch on training-test dataset

```
In [24]: trainloader = torch.utils.data.DataLoader(trainset, batch_size = 8*64, shuffle=True ,
         testloader  = torch.utils.data.DataLoader(testset , batch_size = 8*64, shuffle=True ,

         accuracy = torch.ones(nb_epoch,2, dtype=torch.float) * 100
         for epoch , tmp_state_dict in enumerate(state_dict_list,0) :
             if epoch % 1 != 0 :
                 continue

             # net_model = cudanet.__class__
             # cudaTOCPUnet = net_model(h1,h2)
             # cudaTOCPUnet = Classifier( kernel_sz = 9 )
             cudaTOCPUnet = copy.deepcopy( cudanet )
             cudaTOCPUnet.load_state_dict( tmp_state_dict )
             cuda_test_net = copy.deepcopy(cudaTOCPUnet).to(device)

             correct = torch.tensor([0,0])
             total   = torch.tensor([0,0])

             correct, total = correct.to(device) , total.to(device)

             loader_list = [ testloader , trainloader ]
```

```
            with torch.no_grad():
                for i, loader in enumerate(loader_list,0) :
                    for data in loader:
                        images, labels = data
                        images, labels = images.to(device), labels.to(device)
                        outputs = cuda_test_net(images)
                        _, predicted = torch.max(outputs.data, 1)
                        total[i] += labels.size(0)
                        correct[i] += (predicted == labels).sum()

            accuracy[epoch,:] = accuracy[epoch,:] * correct.type(torch.FloatTensor) / total.ty

            print('epoch %3d : Accuracy of the network on the test images: %.2f %% , training
                      % ( epoch+1, accuracy[epoch,0] , accuracy[epoch,1] )
                 )
```

```
epoch   1 : Accuracy of the network on the test images: 92.44 % , training images 91.84 %
epoch   2 : Accuracy of the network on the test images: 95.77 % , training images 95.63 %
epoch   3 : Accuracy of the network on the test images: 96.42 % , training images 96.55 %
epoch   4 : Accuracy of the network on the test images: 96.96 % , training images 97.02 %
epoch   5 : Accuracy of the network on the test images: 97.54 % , training images 97.55 %
epoch   6 : Accuracy of the network on the test images: 97.28 % , training images 97.31 %
epoch   7 : Accuracy of the network on the test images: 97.76 % , training images 97.94 %
epoch   8 : Accuracy of the network on the test images: 98.04 % , training images 98.19 %
```

Plot the train and validation errors for each of the model

```
In [25]: from matplotlib.pyplot import figure
         # import warnings
         # warnings.filterwarnings('ignore')

         # data to plot
         n_groups = nb_epoch
         accuracy_toplot = accuracy.numpy()

         tests_accuracy = accuracy_toplot[:,0]
         train_accuracy = accuracy_toplot[:,1]

         #
         plt.rcParams.update({'font.size': 16})
         plt.rcParams["figure.figsize"] = (12 ,8)
         # create plot
         fig, ax = plt.subplots()
         index = np.arange(n_groups)
         bar_width = 0.3
         opacity = 0.8
```

```
rects1 = plt.bar(index, tests_accuracy, bar_width,
                 alpha=opacity,
                 color='g',
                 label='Test set')

rects2 = plt.bar(index + bar_width, train_accuracy, bar_width,
                 alpha=opacity,
                 color='r',
                 label='Training set')

eps = 3
top = min(int( np.ceil(accuracy_toplot.max() + eps)) , 100)
bot = max(int(np.floor(accuracy_toplot.min() - eps)) , 0  )


plt.ylim(bot, top)     # set the ylim to bottom, top
plt.axhline(y=97,color="black")

plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.title('Comparison between training set and test set accuracy \nduring the trainin
plt.xticks(index + bar_width, range(1,11,1) )
plt.yticks( range(bot,top+1,1) )
plt.legend()

# plt.tight_layout()
plt.show()
```


## 1.3 Some additionnal stuff

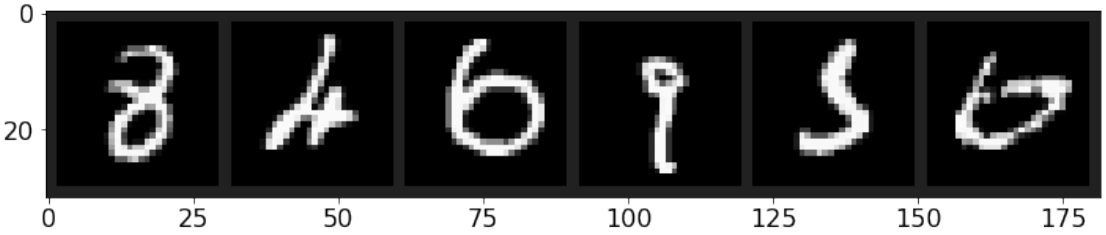
**3-best accuracy : having the right label in the net's top 3 answers count as a good answer**

```
In [58]: correct = torch.tensor([0])
         total = torch.tensor([0])

         correct, total = correct.to(device) , total.to(device)
         with torch.no_grad():
             for data in testloader:
                 images, labels = data
                 images, labels = images.to(device), labels.to(device)
                 outputs = cudanet(images)
                 predicted = torch.topk(outputs.data, 3)[1]
                 total += labels.size(0)
                 correct += (predicted[:,0] == labels).sum()
                 correct += (predicted[:,1] == labels).sum()
                 correct += (predicted[:,2] == labels).sum()

         print('3-best Accuracy of the network on the ' , testing_dataset_size , ' test images
                   % ( 100 * correct.double() / total.double())
              )
```

```
3-best Accuracy of the network on the  10000  test images: 99.920 %
```

**print some test sample that the net misclassifies**

```
In [90]: nb_of_error = torch.tensor([6])
         j = torch.tensor([0])
         errorimages  = torch.empty(6,1,28,28)
         errorlabels  = torch.empty(6)
         erroroutputs = torch.empty(6, 10)
         for images, labels in testloader :
             images, labels = images.to(device), labels.to(device)
             outputs = cudanet(images)
             _, predicted = torch.max(outputs.data, 1)
             if not (predicted == labels).sum() == labels.size()[0] :
                 comparison = (predicted == labels)
                 for i,b in enumerate( comparison ) :
                     if b == 0 :
                         errorimages[j,:,:,:] = copy.deepcopy(images[i,:,:,:]).cpu()
                         errorlabels[j] = labels[i].clone().detach().requires_grad_(False).cpu
                         erroroutputs[j,:] = outputs[i,:].clone().detach().requires_grad_(Fals
                         j = j + 1
                         if j.item() >= nb_of_error.item() :
                             break
                 else :
                     continue
                 break

         if j.item() == 0 :
             print( "no error found")
         else :
             imshow( torchvision.utils.make_grid(errorimages) )

             print( "this should be : " , ",".join( "%2d" % nb.item() for nb in errorlabels ) )
             for i in range(3) :
                 print( "net choice #" , i+1 , ": " , ",".join( "%2d" % nb.item() for nb in lis
```



```
this should be :   8, 4, 6, 9, 5, 6
net choice # 1 :   3, 2, 0, 7, 3, 0
net choice # 2 :   8, 4, 6, 9, 5, 6
net choice # 3 :   2, 6, 5, 8, 8, 5
```

### 1.3.1 Save and load models

**Save the state_dict of the model for each epoch on a local directory**

```
In [21]: local_path = "./save"
         for epoch , tmp_state_dict in enumerate(state_dict_list,1) :
             saving_path = local_path + "/dev1num2model_for_epoch{Epoch}.pth".format( Epoch = e
             torch.save( tmp_state_dict , saving_path)
```

```
./save/dev1num2model_for_epoch1.pth
./save/dev1num2model_for_epoch2.pth
./save/dev1num2model_for_epoch3.pth
./save/dev1num2model_for_epoch4.pth
./save/dev1num2model_for_epoch5.pth
./save/dev1num2model_for_epoch6.pth
./save/dev1num2model_for_epoch7.pth
./save/dev1num2model_for_epoch8.pth
./save/dev1num2model_for_epoch9.pth
./save/dev1num2model_for_epoch10.pth
```

**load from file and set the load the state_dict of the last epoch on a object** the files have to be located in "./save" and named "dev1num2model_for_epoch{j}.pth" for j from ... to ...

```
In [23]: local_path = "./save"
         state_dict_list = list()

         from_idx = 1
         to_idx = 10

         for epoch in range( from_idx + 1 , to_idx , 1 ):
             path = local_path + "/dev1num2model_for_epoch{Epoch}.pth".format( Epoch = epoch )
             tmp_dict = torch.load(path)
             state_dict_list.append(tmp_dict)
         else :
             cudanet = Classifier( kernel_sz = 9 )
             cudanet.load_state_dict(tmp_dict)
             cudanet.eval()
```