Target:

```
-- Our previous model has 6.3M parameters. I want to reduce these parameters here. I want to make them < 10K
```

Results:

```
-- Parameters: 9,916
-- Best Training Accuracy: 99.53
-- Best Test Accuracy: 99.36
```

Analysis:

```
-- The accuracy has dropped a little (from 99.56 to 99.36) after reducing the number of parameters
-- training and test accuracy are increasing with epochs. So we are in the right path. We might improve results by training it for fe
```

Import libraries

```
from __future__ import print_function
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
from torchvision import datasets, transforms
```

Data Transformations (without normalization)

```
# Train Phase transformations
train_transforms = transforms.Compose([
                                      transforms.ToTensor()
                                       ])

# Test Phase transformations
test_transforms = transforms.Compose([
                                      transforms.ToTensor()
                                       ])
```

Dataset and Creating Train/Test Split (without normalization)

```
train = datasets.MNIST('./data', train=True, download=True, transform=train_transforms)
test = datasets.MNIST('./data', train=False, download=True, transform=test_transforms)
```

```
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz to ./data/MNIST/raw/train-images-idx3-ubyte.g
100%                                        9912422/9912422 [00:00<00:00, 38906206.50it/s]
Extracting ./data/MNIST/raw/train-images-idx3-ubyte.gz to ./data/MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz to ./data/MNIST/raw/train-labels-idx1-ubyte.g
100%                                        28881/28881 [00:00<00:00, 1597379.72it/s]
Extracting ./data/MNIST/raw/train-labels-idx1-ubyte.gz to ./data/MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz to ./data/MNIST/raw/t10k-images-idx3-ubyte.gz
100%                                        1648877/1648877 [00:00<00:00, 36732339.39it/s]
Extracting ./data/MNIST/raw/t10k-images-idx3-ubyte.gz to ./data/MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz to ./data/MNIST/raw/t10k-labels-idx1-ubyte.gz
100%                                        4542/4542 [00:00<00:00, 229190.32it/s]
Extracting ./data/MNIST/raw/t10k-labels-idx1-ubyte.gz to ./data/MNIST/raw
```

Dataloader Arguments & Test/Train Dataloaders (without normalization)

```
SEED = 1

# CUDA?
cuda = torch.cuda.is_available()
print("CUDA Available?", cuda)

# For reproducibility
torch.manual_seed(SEED)

if cuda:
    torch.cuda.manual_seed(SEED)

# dataloader arguments - something you'll fetch these from cmdprmt
dataloader_args = dict(shuffle=True, batch_size=128, num_workers=4, pin_memory=True) if cuda else dict(shuffle=True, batch

# train dataloader
train_loader = torch.utils.data.DataLoader(train, **dataloader_args)

# test dataloader
test_loader = torch.utils.data.DataLoader(test, **dataloader_args)
```

```
CUDA Available? True
/usr/local/lib/python3.8/dist-packages/torch/utils/data/dataloader.py:554: UserWarning: This DataLoader will create 4
  warnings.warn(_create_warning_msg(
```

Getting data statistics (without normalization)

We will use the mean and standard deviation that we get from code below to normalize the data

```
import numpy as np

train_data = train.train_data
train_data = train.transform(train_data.numpy())

print('[Train]')
print(' - Numpy Shape:', train.train_data.cpu().numpy().shape)
print(' - Tensor Shape:', train.train_data.size())
print(' - min:', torch.min(train_data))
print(' - max:', torch.max(train_data))
print(' - mean:', torch.mean(train_data))
print(' - std:', torch.std(train_data))
print(' - var:', torch.var(train_data))

dataiter = iter(train_loader)
images, labels = next(dataiter)

print(images.shape)
print(labels.shape)

# Let's visualize some of the images
%matplotlib inline
import matplotlib.pyplot as plt

plt.imshow(images[0].numpy().squeeze(), cmap='gray_r')
```

```
/usr/local/lib/python3.8/dist-packages/torchvision/datasets/mnist.py:75: UserWarning: train_data has been renamed dat
  warnings.warn("train_data has been renamed data")
[Train]
 - Numpy Shape: (60000, 28, 28)
 - Tensor Shape: torch.Size([60000, 28, 28])
 - min: tensor(0.)
 - max: tensor(1.)
 - mean: tensor(0.1307)
 - std: tensor(0.3081)
```

Data Transformations (with normalization)

```
# Train Phase transformations
train_transforms = transforms.Compose([
                                       transforms.ToTensor(),
                                       transforms.Normalize((0.1307,), (0.3081,))
                                        ])

# Test Phase transformations
test_transforms = transforms.Compose([
                                       transforms.ToTensor(),
                                       transforms.Normalize((0.1307,), (0.3081,))
                                        ])
```

Dataset and Creating Train/Test Split (with normalization)

```
train = datasets.MNIST('./data', train=True, download=True, transform=train_transforms)
test = datasets.MNIST('./data', train=False, download=True, transform=test_transforms)
```

Dataloader Arguments & Test/Train Dataloaders (with normalization)

```
SEED = 1

# CUDA?
cuda = torch.cuda.is_available()
print("CUDA Available?", cuda)

# For reproducibility
torch.manual_seed(SEED)

if cuda:
    torch.cuda.manual_seed(SEED)

# dataloader arguments - something you'll fetch these from cmdprmt
dataloader_args = dict(shuffle=True, batch_size=128, num_workers=4, pin_memory=True) if cuda else dict(shuffle=True, batch

# train dataloader
train_loader = torch.utils.data.DataLoader(train, **dataloader_args)

# test dataloader
test_loader = torch.utils.data.DataLoader(test, **dataloader_args)
```

```
CUDA Available? True
```

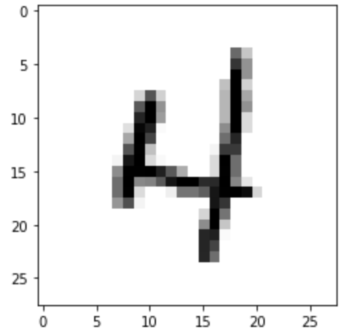
Getting data statistics (with normalization)

We will use the mean and standard deviation that we get from code below to normalize the data

```
import numpy as np

train_data = train.train_data
train_data = train.transform(train_data.numpy())

print('[Train]')
print(' - Numpy Shape:', train.train_data.cpu().numpy().shape)
print(' - Tensor Shape:', train.train_data.size())
print(' - min:', torch.min(train_data))
print(' - max:', torch.max(train_data))
```

```
print(' - mean:', torch.mean(train_data))
print(' - std:', torch.std(train_data))
print(' - var:', torch.var(train_data))

dataiter = iter(train_loader)
images, labels = next(dataiter)

print(images.shape)
print(labels.shape)

# Let's visualize some of the images
%matplotlib inline
import matplotlib.pyplot as plt

plt.imshow(images[0].numpy().squeeze(), cmap='gray_r')
```

```
[Train]
 - Numpy Shape: (60000, 28, 28)
 - Tensor Shape: torch.Size([60000, 28, 28])
 - min: tensor(-0.4242)
 - max: tensor(2.8215)
 - mean: tensor(-0.0001)
 - std: tensor(1.0000)
 - var: tensor(1.0001)
torch.Size([128, 1, 28, 28])
torch.Size([128])
<matplotlib.image.AxesImage at 0x7f252a010040>
```



Model

```
dropout_rate = 0.05
class Net(nn.Module):
  def __init__(self):
    super(Net, self).__init__()

    #input block
    self.convblock1 = nn.Sequential(nn.Conv2d(in_channels = 1, out_channels = 10, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(10),
                                    nn.ReLU()) #R_in = 1, C_in = 28, K = 3, P = 1, S = 1, J_in = 1, J_out = 1, R_out = R_i

    #conv block 1
    self.convblock2 = nn.Sequential(nn.Conv2d(in_channels = 10, out_channels = 14, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(14),
                                    nn.ReLU()) #R_in = 3, C_in = 28, K = 3, P = 1, S = 1, J_in = 1, J_out = 1, R_out = R_i

    #conv block 2
    self.convblock3 = nn.Sequential(nn.Conv2d(in_channels = 14, out_channels = 16, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(16),
                                    nn.ReLU()) #R_in = 5, C_in = 28, K = 3, P = 1, S = 1, J_in = 1, J_out = 1, R_out = R_i

    #transition block1
    self.convblock4 = nn.Sequential(nn.Conv2d(in_channels = 16, out_channels = 14, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(14),
                                    nn.ReLU()) #R_in = 7, C_in = 28, K = 3, P = 1, S = 1, J_in = 1, J_out = 1, R_out = R_i

    self.pool1 = nn.MaxPool2d(2, 2) #R_in = 9, C_in = 28, K = 2, P = 0, S = 2, J_in = 1, J_out = 2, R_out = R_in + (K-1)*J

    #conv block 3
    self.convblock5 = nn.Sequential(nn.Conv2d(in_channels = 14, out_channels = 12, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(12),
                                    nn.ReLU()) #R_in = 10, C_in = 14, K = 3, P = 1, S = 1, J_in = 2, J_out = 2, R_out = R_

    #conv block 4
    self.convblock6 = nn.Sequential(nn.Conv2d(in_channels = 12, out_channels = 14, kernel_size = 3, padding = 1),
                                    nn.BatchNorm2d(14),
                                    nn.ReLU()) #R_in = 14, C_in = 14, K = 3, P = 1, S = 1, J_in = 2, J_out = 2, R_out = R_
    #gap layer
```

```
    self.gap = nn.Sequential(
            nn.AvgPool2d(kernel_size=4))  #R_in = 18, C_in = 14, K = 4, P = 1, S = 1, J_in = 2, J_out = 2, R_out = R_in +

    #output block
    self.convblock7 = nn.Sequential(nn.Conv2d(in_channels = 14, out_channels = 10, kernel_size = 3, padding = 0)) #R_in =

  def forward(self, x):
    x = self.convblock1(x)
    x = self.convblock2(x)
    x = self.convblock3(x)
    x = self.convblock4(x)
    x = self.pool1(x)
    x = self.convblock5(x)
    x = self.convblock6(x)
    x = self.gap(x)
    x = self.convblock7(x)
    x = x.view(-1, 10)
    return F.log_softmax(x, dim=-1)
```

Model parameters

```
!pip install torchsummary
from torchsummary import summary

use_cuda = torch.cuda.is_available()
device = torch.device("cuda" if use_cuda else "cpu")

model = Net().to(device)
summary(model, input_size = (1, 28, 28))
```

```
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: torchsummary in /usr/local/lib/python3.8/dist-packages (1.5.1)
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1           [-1, 10, 28, 28]             100
       BatchNorm2d-2           [-1, 10, 28, 28]              20
              ReLU-3           [-1, 10, 28, 28]               0
            Conv2d-4           [-1, 14, 28, 28]           1,274
       BatchNorm2d-5           [-1, 14, 28, 28]              28
              ReLU-6           [-1, 14, 28, 28]               0
            Conv2d-7           [-1, 16, 28, 28]           2,032
       BatchNorm2d-8           [-1, 16, 28, 28]              32
              ReLU-9           [-1, 16, 28, 28]               0
           Conv2d-10           [-1, 14, 28, 28]           2,030
      BatchNorm2d-11           [-1, 14, 28, 28]              28
             ReLU-12           [-1, 14, 28, 28]               0
        MaxPool2d-13           [-1, 14, 14, 14]               0
           Conv2d-14           [-1, 12, 14, 14]           1,524
      BatchNorm2d-15           [-1, 12, 14, 14]              24
             ReLU-16           [-1, 12, 14, 14]               0
           Conv2d-17           [-1, 14, 14, 14]           1,526
      BatchNorm2d-18           [-1, 14, 14, 14]              28
             ReLU-19           [-1, 14, 14, 14]               0
        AvgPool2d-20             [-1, 14, 3, 3]               0
           Conv2d-21             [-1, 10, 1, 1]           1,270
================================================================
Total params: 9,916
Trainable params: 9,916
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.00
Forward/backward pass size (MB): 1.11
Params size (MB): 0.04
Estimated Total Size (MB): 1.15
----------------------------------------------------------------
```

Training and Testing

```
from tqdm import tqdm

train_losses = []
test_losses = []
train_acc = []
test_acc = []

def train(model, device, train_loader, optimizer, epoch):
  model.train()
  pbar = tqdm(train_loader)
  correct = 0
```

```
  processed = 0
  for batch_idx, (data, target) in enumerate(pbar):
    # get samples
    data, target = data.to(device), target.to(device)

    # Init
    optimizer.zero_grad()
    # In PyTorch, we need to set the gradients to zero before starting to do backpropragation because PyTorch accumulates
    # Because of this, when you start your training loop, ideally you should zero out the gradients so that you do the par

    # Predict
    y_pred = model(data)

    # Calculate loss
    loss = F.nll_loss(y_pred, target)
    train_losses.append(loss)

    # Backpropagation
    loss.backward()
    optimizer.step()

    # Update pbar-tqdm

    pred = y_pred.argmax(dim=1, keepdim=True)  # get the index of the max log-probability
    correct += pred.eq(target.view_as(pred)).sum().item()
    processed += len(data)

    pbar.set_description(desc= f'Loss={loss.item()} Batch_id={batch_idx} Accuracy={100*correct/processed:0.2f}')
    train_acc.append(100*correct/processed)

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 loss
            pred = output.argmax(dim=1, keepdim=True)  # get the index of the max log-probability
            correct += pred.eq(target.view_as(pred)).sum().item()

    test_loss /= len(test_loader.dataset)
    test_losses.append(test_loss)

    print('\nTest set: Average loss: {:.4f}, Accuracy: {}/{} ({:.2f}%)\n'.format(
        test_loss, correct, len(test_loader.dataset),
        100. * correct / len(test_loader.dataset)))

    test_acc.append(100. * correct / len(test_loader.dataset))
```

```
from torch.optim.lr_scheduler import StepLR

model =  Net().to(device)
optimizer = optim.SGD(model.parameters(), lr=0.01, momentum=0.9)
# scheduler = StepLR(optimizer, step_size=6, gamma=0.1)


EPOCHS = 15
for epoch in range(EPOCHS):
    print("EPOCH:", epoch)
    train(model, device, train_loader, optimizer, epoch)
    # scheduler.step()
    test(model, device, test_loader)
```

```
EPOCH: 0
Loss=0.059505537152290344 Batch_id=468 Accuracy=92.30: 100%|██████████| 469/469 [00:20<00:00, 23.30it/s]

Test set: Average loss: 0.0690, Accuracy: 9786/10000 (97.86%)

EPOCH: 1
Loss=0.11603377014398575 Batch_id=468 Accuracy=98.17: 100%|██████████| 469/469 [00:15<00:00, 30.74it/s]

Test set: Average loss: 0.1156, Accuracy: 9654/10000 (96.54%)

EPOCH: 2
Loss=0.05809774994850159 Batch_id=468 Accuracy=98.56: 100%|██████████| 469/469 [00:14<00:00, 31.56it/s]

Test set: Average loss: 0.0431, Accuracy: 9871/10000 (98.71%)

EPOCH: 3
```

```
Loss=0.08395007252693176 Batch_id=468 Accuracy=98.78: 100%|██████████| 469/469 [00:14<00:00, 31.61it/s]

Test set: Average loss: 0.0347, Accuracy: 9888/10000 (98.88%)

EPOCH: 4
Loss=0.029559889808297157 Batch_id=468 Accuracy=98.92: 100%|██████████| 469/469 [00:14<00:00, 31.76it/s]

Test set: Average loss: 0.0333, Accuracy: 9891/10000 (98.91%)

EPOCH: 5
Loss=0.01610000990331173 Batch_id=468 Accuracy=99.08: 100%|██████████| 469/469 [00:15<00:00, 30.93it/s]

Test set: Average loss: 0.0320, Accuracy: 9889/10000 (98.89%)

EPOCH: 6
Loss=0.027190232649445534 Batch_id=468 Accuracy=99.14: 100%|██████████| 469/469 [00:15<00:00, 29.83it/s]

Test set: Average loss: 0.0582, Accuracy: 9811/10000 (98.11%)

EPOCH: 7
Loss=0.02244214527308941 Batch_id=468 Accuracy=99.24: 100%|██████████| 469/469 [00:15<00:00, 31.27it/s]

Test set: Average loss: 0.0271, Accuracy: 9908/10000 (99.08%)

EPOCH: 8
Loss=0.013607493601739407 Batch_id=468 Accuracy=99.25: 100%|██████████| 469/469 [00:14<00:00, 31.43it/s]

Test set: Average loss: 0.0229, Accuracy: 9927/10000 (99.27%)

EPOCH: 9
Loss=0.005332443863153458 Batch_id=468 Accuracy=99.32: 100%|██████████| 469/469 [00:16<00:00, 28.95it/s]

Test set: Average loss: 0.0290, Accuracy: 9904/10000 (99.04%)

EPOCH: 10
Loss=0.02520093135535717 Batch_id=468 Accuracy=99.34: 100%|██████████| 469/469 [00:15<00:00, 31.08it/s]

Test set: Average loss: 0.0257, Accuracy: 9921/10000 (99.21%)

EPOCH: 11
Loss=0.01890501007437706 Batch_id=468 Accuracy=99.43: 100%|██████████| 469/469 [00:14<00:00, 31.28it/s]
```

```
train_losses = [i.item() for i in train_losses]
%matplotlib inline
import matplotlib.pyplot as plt
fig, axs = plt.subplots(2,2,figsize=(15,10))
axs[0, 0].plot(train_losses)
axs[0, 0].set_title("Training Loss")
axs[1, 0].plot(train_acc[4000:])
axs[1, 0].set_title("Training Accuracy")
axs[0, 1].plot(test_losses)
axs[0, 1].set_title("Test Loss")
axs[1, 1].plot(test_acc)
axs[1, 1].set_title("Test Accuracy")
```

```
Text(0.5, 1.0, 'Test Accuracy')
```