0. Setting

In [1]:
```
# import library
import torch
import torch.nn as nn
import matplotlib.pyplot as plt
import math
from pandas import Series, DataFrame
import pandas as pd
import numpy as np

torch.__version__
```

Out[1]: '1.7.0+cu101'

1. Data

In [44]:
```
from torchvision import transforms, datasets

data_path = './MNIST'

data_train  = datasets.MNIST(root = data_path, train= False, download=True)
data_test = datasets.MNIST(root = data_path, train= True, download=True)

data_train_mean = data_train.data.float().mean()/255
data_train_std = data_train.data.float().std()/255

data_test_mean = data_test.data.float().mean()/255
data_test_std = data_test.data.float().std()/255


print("train data mean = {}, std = {}".format(data_train_mean, data_train_std))
print("test data mean = {}, std = {}".format(data_test_mean, data_test_std))

transform = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize((0.1307,),(0.3081,)),  # mean value = 0.1307, standard deviation value = 0.3081
])

'''
train_transform = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize((data_train_mean,),(data_train_std,)),
])

test_transform = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize((data_test_mean,),(data_test_std,)),
])
'''

data_train  = datasets.MNIST(root = data_path, train= False, download=True, transform= transform)
data_test   = datasets.MNIST(root = data_path, train= True, download=True, transform= transform)

print("the number of your training data (must be 10,000) = ", data_train.__len__())
print("hte number of your testing data (must be 60,000) = ", data_test.__len__())
```

```
train data mean = 0.1325146108865738, std = 0.3104802668094635
test data mean = 0.13066047430038452, std = 0.30810779333114624
the number of your training data (must be 10,000) =  10000
hte number of your testing data (must be 60,000) =  60000
```

2.Model

In [59]:
```
def init_weights_xaiver(m):
  if type(m) == nn.Linear:
    nn.init.xavier_normal_(m.weight.data)
    m.bias.data.fill_(0)

def init_weights_he(m):
  if type(m) == nn.Linear:
    nn.init.kaiming_normal_(m.weight.data, a=0, mode='fan_in')
    m.bias.data.fill_(0)

class classification(nn.Module):

    def __init__(self):
        super(classification, self).__init__()

        # construct layers for a neural network
        self.classifier1 = nn.Sequential(
            nn.Linear(in_features=28*28, out_features=20*20),
            nn.ReLU(),
            #nn.Sigmoid(),
            #nn.Tanh()
            #nn.LeakyReLU(),
            nn.Dropout(0.15)
        )
        self.classifier2 = nn.Sequential(
            nn.Linear(in_features=20*20, out_features=10*10),
            nn.ReLU(),
            #nn.Sigmoid()
            #nn.Tanh()
            #nn.LeakyReLU(),
            nn.Dropout(0.15)
        )
        self.classifier3 = nn.Sequential(
            nn.Linear(in_features=10*10, out_features=10),
```

```
            nn.LogSoftmax(dim=1)
        )

        self.classifier1.apply(init_weights_he)
        self.classifier2.apply(init_weights_he)
        self.classifier3.apply(init_weights_he)

    def forward(self, inputs):                # [batchSize, 1, 28, 28]
        x = inputs.view(inputs.size(0), -1)   # [batchSize, 28*28]
        x = self.classifier1(x)               # [batchSize, 20*20]
        x = self.classifier2(x)               # [batchSize, 10*10]
        out = self.classifier3(x)             # [batchSize, 10]

        return out
```

3. Loss Function

In [4]:
```
model = classification()
criterion = nn.CrossEntropyLoss()
train_y_pred = model(data_train.data.float())
train_y = data_train.targets
temp_loss = criterion(train_y_pred, train_y)
print(temp_loss.data.item())
```

2.3054168224334717

4. Optimization

Define Train Function

In [5]:
```
def train(model, criterion, train_loader, optimizer, batch_size):

  model.train()
  loss_sum = 0
  acc_sum = 0
  iteration = 0
  for xs, ts in iter(train_loader):

    iteration = iteration + 1
    optimizer.zero_grad()
    y_pred = model(xs)
    loss = criterion(y_pred, ts)
    loss.backward()
    optimizer.step()

    loss_sum = loss_sum + float(loss)
    zs = y_pred.max(1, keepdim=True)[1] # first column has actual prob
    acc_sum = acc_sum + zs.eq(ts.view_as(zs)).sum().item()/batch_size

  loss_avg = math.trunc(loss_sum/iteration * 100) / 100
  acc_avg = math.trunc(acc_sum/iteration * 100) / 100

  return loss_avg, acc_avg
```

Define Test Function

In [6]:
```
def test(model,criterion, test_loader, batch_size):
  model.eval()
  loss_sum = 0
  acc_sum = 0
  iteration = 0
  with torch.no_grad():
    for xs, ts in iter(test_loader):
      iteration = iteration + 1
      y_pred = model(xs)
      loss_sum = loss_sum + criterion(y_pred, ts).data.item()
      zs = y_pred.max(1, keepdim=True)[1]
      acc_sum = acc_sum + zs.eq(ts.view_as(zs)).sum().item()/batch_size

  loss_avg = math.trunc(loss_sum/iteration * 100) / 100
  acc_avg = math.trunc(acc_sum/iteration * 100) / 100

  return loss_avg, acc_avg
```

Define Gradient Descent Fucntion

In [7]:
```
def gradient_descent(model, optimizer, criterion, batch_size, num_epochs):

  # batching
  train_loader = torch.utils.data.DataLoader(
      data_train,
      batch_size=batch_size,
      num_workers=2,
      shuffle=True,
      drop_last=True)

  test_loader = torch.utils.data.DataLoader(
      data_test,
      batch_size=batch_size,
      num_workers=2,
      shuffle=False,
      drop_last=True)


  # return variables
  train_loss_list, train_acc_list = [], []
  test_loss_list, test_acc_list = [], []


  # run training & testing
  for epoch in range(num_epochs + 1):
```

```
    train_loss_avg, train_acc_avg = train(model, criterion, train_loader, optimizer, batch_size)
    test_loss_avg, test_acc_avg = test(model, criterion, test_loader, batch_size)

    # add loss and accuracy data
    train_loss_list.append(train_loss_avg)
    train_acc_list.append(train_acc_avg)
    test_loss_list.append(test_loss_avg)
    test_acc_list.append(test_acc_avg)

    # print
    if epoch % 10 != 0 :
      continue

    print("epoch : ", epoch, " ---------------------------------- ")
    print("train loss : {}      accuracy = {}".format(train_loss_avg, train_acc_avg))
    print("test loss : {}       accuracy = {}".format(test_loss_avg, test_acc_avg))


  return train_loss_list, train_acc_list, test_loss_list, test_acc_list
```

5. Select Hyperparameter & Modify/Test Model

size of the mini-batch : 64
optimization algorithm : SGD
loss funtion : cross entropy
regularization algorithm : -
learning rate : constant

In [ ]:
```
# model
model = classification()

# mini-batch size
batch_size = 32

# num of epochs
num_epochs = 200

# learning rate
learning_rate = 0.01

# optimizer
optimizer = torch.optim.SGD(model.parameters(), lr = learning_rate)

# loss function
criterion = nn.CrossEntropyLoss()

# run
train_loss_list1, train_acc_list1, test_loss_list1, test_acc_list1 = gradient_descent(model, optimizer, criterion, batch_size, num_epochs)
```

```
epoch :  0  ----------------------------------
train loss : 2.302      accuracy = 0.146
test loss : 2.288       accuracy = 0.136
epoch :  10  ----------------------------------
train loss : 2.023      accuracy = 0.761
test loss : 2.018       accuracy = 0.753
epoch :  20  ----------------------------------
train loss : 1.843      accuracy = 0.821
test loss : 1.846       accuracy = 0.808
epoch :  30  ----------------------------------
train loss : 1.761      accuracy = 0.845
test loss : 1.769       accuracy = 0.828
epoch :  40  ----------------------------------
train loss : 1.713      accuracy = 0.86
test loss : 1.722       accuracy = 0.845
epoch :  50  ----------------------------------
train loss : 1.681      accuracy = 0.872
test loss : 1.691       accuracy = 0.858
epoch :  60  ----------------------------------
train loss : 1.657      accuracy = 0.882
test loss : 1.669       accuracy = 0.866
epoch :  70  ----------------------------------
train loss : 1.639      accuracy = 0.888
test loss : 1.652       accuracy = 0.871
epoch :  80  ----------------------------------
train loss : 1.626      accuracy = 0.893
test loss : 1.64        accuracy = 0.876
epoch :  90  ----------------------------------
train loss : 1.615      accuracy = 0.897
test loss : 1.629       accuracy = 0.879
epoch :  100  ----------------------------------
train loss : 1.606      accuracy = 0.9
test loss : 1.621       accuracy = 0.882
epoch :  110  ----------------------------------
train loss : 1.599      accuracy = 0.905
test loss : 1.614       accuracy = 0.885
epoch :  120  ----------------------------------
train loss : 1.593      accuracy = 0.907
test loss : 1.608       accuracy = 0.887
epoch :  130  ----------------------------------
train loss : 1.587      accuracy = 0.91
test loss : 1.603       accuracy = 0.889
epoch :  140  ----------------------------------
train loss : 1.581      accuracy = 0.913
test loss : 1.598       accuracy = 0.891
epoch :  150  ----------------------------------
train loss : 1.576      accuracy = 0.915
test loss : 1.593       accuracy = 0.894
epoch :  160  ----------------------------------
train loss : 1.571      accuracy = 0.918
test loss : 1.589       accuracy = 0.895
epoch :  170  ----------------------------------
train loss : 1.567      accuracy = 0.919
test loss : 1.585       accuracy = 0.898
epoch :  180  ----------------------------------
train loss : 1.563      accuracy = 0.921
test loss : 1.582       accuracy = 0.899
epoch :  190  ----------------------------------
train loss : 1.56       accuracy = 0.923
```

```
test loss : 1.579 ..... accuracy = 0.9
epoch :  200  ----------------------------------
train loss : 1.557 ..... accuracy = 0.925
test loss : 1.576 ..... accuracy = 0.902
```

In [8]:
```python
def gradient_descent_with_scheduler(scheduler, model, optimizer, criterion, batch_size, num_epochs):

  # batching
  train_loader = torch.utils.data.DataLoader(
      data_train,
      batch_size=batch_size,
      num_workers=2,
      shuffle=True,
      drop_last=True)

  test_loader = torch.utils.data.DataLoader(
      data_test,
      batch_size=batch_size,
      num_workers=2,
      shuffle=False,
      drop_last=True)


  # return variables
  train_loss_list, train_acc_list = [], []
  test_loss_list, test_acc_list = [], []


  # run training & testing
  for epoch in range(num_epochs + 1):

    train_loss_avg, train_acc_avg = train(model, criterion, train_loader, optimizer, batch_size)
    test_loss_avg, test_acc_avg = test(model, criterion, test_loader, batch_size)
    scheduler.step(train_loss_avg)

    # add loss and accuracy data
    train_loss_list.append(train_loss_avg)
    train_acc_list.append(train_acc_avg)
    test_loss_list.append(test_loss_avg)
    test_acc_list.append(test_acc_avg)

    # print
    if epoch % 10 != 0 :
      continue

    print("epoch : ", epoch, " ---------------------------------- ")
    print("train loss : {}      accuracy = {}".format(train_loss_avg, train_acc_avg))
    print("test loss : {}       accuracy = {}".format(test_loss_avg, test_acc_avg))


  return train_loss_list, train_acc_list, test_loss_list, test_acc_list
```

In [61]:
```python
# model
model = classification()

# mini-batch size
batch_size = 32

# num of epochs
num_epochs = 100

# learning rate
learning_rate = 0.01

# optimizer
optimizer = torch.optim.SGD(model.parameters(), lr = learning_rate, weight_decay=0.0001)
scheduler = torch.optim.lr_scheduler.ReduceLROnPlateau(optimizer, 'min', factor=0.3, verbose=True)

# loss function
criterion = nn.CrossEntropyLoss()

# run
train_loss_list8, train_acc_list8, test_loss_list8, test_acc_list8 = gradient_descent_with_scheduler(scheduler, model, optimizer, criterion, batch_size, nu
```

```
epoch :  0  ----------------------------------
train loss : 0.85 ..... accuracy = 0.72
test loss : 0.42 ..... accuracy = 0.88
epoch :  10  ----------------------------------
train loss : 0.13 ..... accuracy = 0.95
test loss : 0.2 ..... accuracy = 0.94
epoch :  20  ----------------------------------
train loss : 0.06 ..... accuracy = 0.97
test loss : 0.18 ..... accuracy = 0.95
epoch :  30  ----------------------------------
train loss : 0.03 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
epoch :  40  ----------------------------------
train loss : 0.03 ..... accuracy = 0.99
test loss : 0.17 ..... accuracy = 0.95
Epoch    51: reducing learning rate of group 0 to 3.0000e-03.
epoch :  50  ----------------------------------
train loss : 0.02 ..... accuracy = 0.99
test loss : 0.17 ..... accuracy = 0.95
epoch :  60  ----------------------------------
train loss : 0.01 ..... accuracy = 0.99
test loss : 0.18 ..... accuracy = 0.95
Epoch    63: reducing learning rate of group 0 to 9.0000e-04.
epoch :  70  ----------------------------------
train loss : 0.01 ..... accuracy = 0.99
test loss : 0.18 ..... accuracy = 0.96
Epoch    74: reducing learning rate of group 0 to 2.7000e-04.
epoch :  80  ----------------------------------
train loss : 0.01 ..... accuracy = 0.99
test loss : 0.18 ..... accuracy = 0.96
Epoch    85: reducing learning rate of group 0 to 8.1000e-05.
epoch :  90  ----------------------------------
train loss : 0.01 ..... accuracy = 0.99
test loss : 0.17 ..... accuracy = 0.96
Epoch    96: reducing learning rate of group 0 to 2.4300e-05.
epoch :  100  ----------------------------------
```

```
train loss : 0.01 ..... accuracy = 0.99
test loss : 0.17 ..... accuracy = 0.96
```

In [27]:
```python
# model
model = classification()

# mini-batch size
batch_size = 64

# num of epochs
num_epochs = 100

# learning rate
learning_rate = 0.01

# optimizer
optimizer = torch.optim.SGD(model.parameters(), lr = learning_rate, weight_decay=0.0001)
scheduler = torch.optim.lr_scheduler.ReduceLROnPlateau(optimizer, 'min', factor=0.5, patience = 5, verbose=True)

# loss function
criterion = nn.CrossEntropyLoss()

# run
train_loss_list7, train_acc_list7, test_loss_list7, test_acc_list7 = gradient_descent_with_scheduler(scheduler, model, optimizer, criterion, batch_size, nu
```

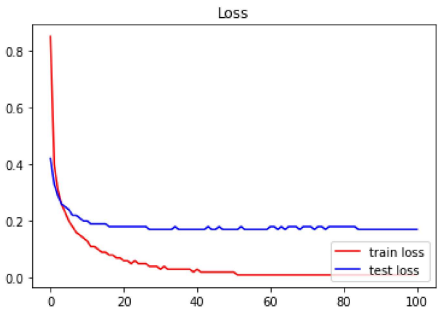
```
epoch : 0 ----------------------------------
train loss : 1.84 ..... accuracy = 0.36
test loss : 1.25 ..... accuracy = 0.62
epoch : 10 ----------------------------------
train loss : 0.24 ..... accuracy = 0.92
test loss : 0.25 ..... accuracy = 0.93
epoch : 20 ----------------------------------
train loss : 0.15 ..... accuracy = 0.95
test loss : 0.2 ..... accuracy = 0.94
epoch : 30 ----------------------------------
train loss : 0.11 ..... accuracy = 0.96
test loss : 0.18 ..... accuracy = 0.95
epoch : 40 ----------------------------------
train loss : 0.08 ..... accuracy = 0.97
test loss : 0.18 ..... accuracy = 0.95
epoch : 50 ----------------------------------
train loss : 0.06 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
epoch : 60 ----------------------------------
train loss : 0.05 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
Epoch    63: reducing learning rate of group 0 to 5.0000e-03.
epoch : 70 ----------------------------------
train loss : 0.04 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
Epoch    72: reducing learning rate of group 0 to 2.5000e-03.
Epoch    78: reducing learning rate of group 0 to 1.2500e-03.
epoch : 80 ----------------------------------
train loss : 0.04 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
Epoch    84: reducing learning rate of group 0 to 6.2500e-04.
Epoch    90: reducing learning rate of group 0 to 3.1250e-04.
epoch : 90 ----------------------------------
train loss : 0.04 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
Epoch    96: reducing learning rate of group 0 to 1.5625e-04.
epoch : 100 ----------------------------------
train loss : 0.04 ..... accuracy = 0.98
test loss : 0.17 ..... accuracy = 0.95
```

In [ ]:

6. Output

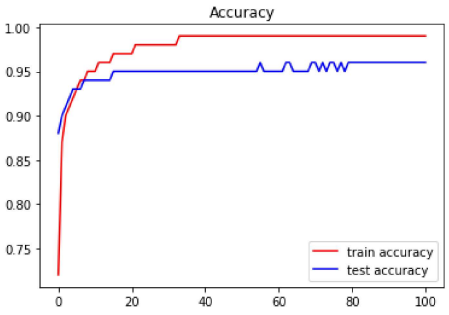
1. Plot the training and testing losses over epochs [2pt]

In [62]:
```python
plt.title("Loss")
plt.plot(train_loss_list8, c = 'red', label = 'train loss')
plt.plot(test_loss_list8, c = 'blue', label = 'test loss')
plt.legend(loc = 'lower right')
plt.show()
```



1. Plot the training and testing accuracies over epochs [2pt]

In [63]:
```python
plt.title("Accuracy")
plt.plot(train_acc_list8, c = 'red', label = 'train accuracy')
plt.plot(test_acc_list8, c = 'blue', label = 'test accuracy')
plt.legend(loc = 'lower right')
plt.show()
```



1. Print the final training and testing losses at convergence [2pt]

In [66]:
```
data1 = {'' : [train_loss_list8[-1], test_loss_list8[-1]]}
index1 = ['training', 'testing']
frame1 = DataFrame(data1, index = index1)
frame1.columns.name = 'loss'
frame1
```

Out[66]:

loss	
training	0.01
testing	0.17

1. Print the final training and testing accuracies at convergence [20pt]

In [73]:
```
data2 = {'' : [train_acc_list8[-1], test_acc_list8[-1]]}
index2 = ['training', 'testing']
frame2 = DataFrame(data2, index = index2)
frame2.columns.name = 'accuracy'
frame2
```

Out[73]:

accuracy	
training	0.99
testing	0.96