PA3_EE21S055Final

October 14, 2022

[1]:
```
import numpy as np
import torch
import matplotlib.pyplot as plt
from torchvision.datasets import MNIST
import torch.nn as nn
from tqdm import tqdm
from torchvision import transforms
from torch.utils.data import DataLoader
from torch.optim import Adam #Adam for GD
import time
```

[2]:
```
```

[3]:
```
hidden_dim = 128
input_dim = 28
output_dim = 10
num_layers = 1
```

[4]:
```
class Vanilla_RNN(nn.Module):

    def __init__(self ,input_dim, hidden_dim, num_layers, output_dim):
        super(Vanilla_RNN,self).__init__()
        self.hidden_dim = hidden_dim
        self.num_layers = num_layers
        self.rnn = nn.RNN(input_dim,hidden_dim,batch_first =True)

        self.Hidden_layer = nn.Linear(hidden_dim,output_dim)
        self.log_softmax = nn.LogSoftmax(dim=1)

    def forward(self,x):
        #x = x.permute(1, 0, 2)
        hiddenlayer=torch.zeros(1,x.size(0),hidden_dim)
        out, hn = self.rnn(x, hiddenlayer.detach())
        out = self.Hidden_layer(out[:, -1, :]) #hidden states of last time step
        pred=self.log_softmax(out)
        return pred
```

[5]:
```
class Vanilla_LSTM(nn.Module):
    def __init__(self,input_dim,hidden_dim,num_layers,output_dim):
        super(Vanilla_LSTM,self).__init__()
        self.hidden_dim = hidden_dim

        self.lstm = nn.LSTM(input_dim,hidden_dim,num_layers,batch_first = True)

        self.Hidden_layer = nn.Linear(hidden_dim, output_dim)
        self.log_softmax = nn.LogSoftmax(dim=1)

    def forward(self,x):

        hidden_state = torch.zeros(num_layers,x.size(0),hidden_dim ).
 ↪requires_grad_()
        self_state = torch.zeros(num_layers,x.size(0),hidden_dim).
 ↪requires_grad_()
        #x = x.permute(1, 0, 2)
        out , (h_s,c_s) = self.lstm(x,(hidden_state.detach(),self_state.
 ↪detach()))

        out = self.Hidden_layer(out[:,-1,:])
        pred = self.log_softmax(out)
        return pred
```

[6]:
```
class Vanilla_GRU(nn.Module):
    def __init__(self, input_dim, hidden_dim, num_layers, output_dim):
        super(Vanilla_GRU, self).__init__()
        self.hidden_dim = hidden_dim
        self.num_layers = num_layers
        self.gru = nn.GRU(input_dim, hidden_dim, num_layers,␣
 ↪batch_first=True,bidirectional=False)
        self.fc = nn.Linear(hidden_dim, output_dim)
        self.logsoftmax=nn.LogSoftmax(dim=1)

    def forward(self, x):
        h0 = torch.zeros(self.num_layers, x.size(0), self.hidden_dim).
 ↪requires_grad_()
        out, hn = self.gru(x, h0.detach())
        out = self.fc(out[:, -1, :])
        pred=self.logsoftmax(out)
        return pred
```

[13]:
```
class Vanilla_BIRNN(nn.Module):

    def __init__(self):
        super(Vanilla_BIRNN,self).__init__()
```

```
        self.rnn = nn.RNN(28,100,1,bidirectional =True)

        self.Hidden_layer = nn.Linear(200, 10)

        self.log_softmax = nn.LogSoftmax(dim=1)

    def forward(self,x):
        x = x.permute(1, 0, 2)
        hiddenlayer=torch.zeros(2,x.size(1),100)
        _,hiddenlayer = self.rnn(x,hiddenlayer)
        fin , bin = hiddenlayer[0],hiddenlayer[1]
        inp=torch.cat((fin,bin),dim=-1)
        out = self.Hidden_layer(inp)
        return out.reshape(500,10)
```

[ ]:

[8]:
```
learning_rate = 0.002
num_epochs = 5
lamb=0.01
criterion1 = nn.CrossEntropyLoss()
optimizer1 = torch.optim.
 ↪Adam(Vanilla_RNN(input_dim,hidden_dim,num_layers,output_dim).parameters(),␣
 ↪lr=learning_rate)
```

[9]:
```
transform = transforms.ToTensor()
trainset = MNIST('', download=True, train=True, transform=transform)
testset = MNIST('',download=True, train=False, transform=transform)
trainset,valset=torch.utils.data.random_split(trainset,(50000,10000))
trainloader = torch.utils.data.DataLoader(trainset,batch_size=500)
valloader = torch.utils.data.DataLoader(valset,batch_size=500)
testloader = torch.utils.data.DataLoader(testset,batch_size=500)
```

```
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
MNIST/raw/train-images-idx3-ubyte.gz

  0%|          | 0/9912422 [00:00<?, ?it/s]

Extracting MNIST/raw/train-images-idx3-ubyte.gz to 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
MNIST/raw/train-labels-idx1-ubyte.gz

  0%|          | 0/28881 [00:00<?, ?it/s]

Extracting MNIST/raw/train-labels-idx1-ubyte.gz to 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
MNIST/raw/t10k-images-idx3-ubyte.gz

  0%|          | 0/1648877 [00:00<?, ?it/s]

Extracting MNIST/raw/t10k-images-idx3-ubyte.gz to 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
MNIST/raw/t10k-labels-idx1-ubyte.gz

  0%|          | 0/4542 [00:00<?, ?it/s]

Extracting MNIST/raw/t10k-labels-idx1-ubyte.gz to MNIST/raw
```

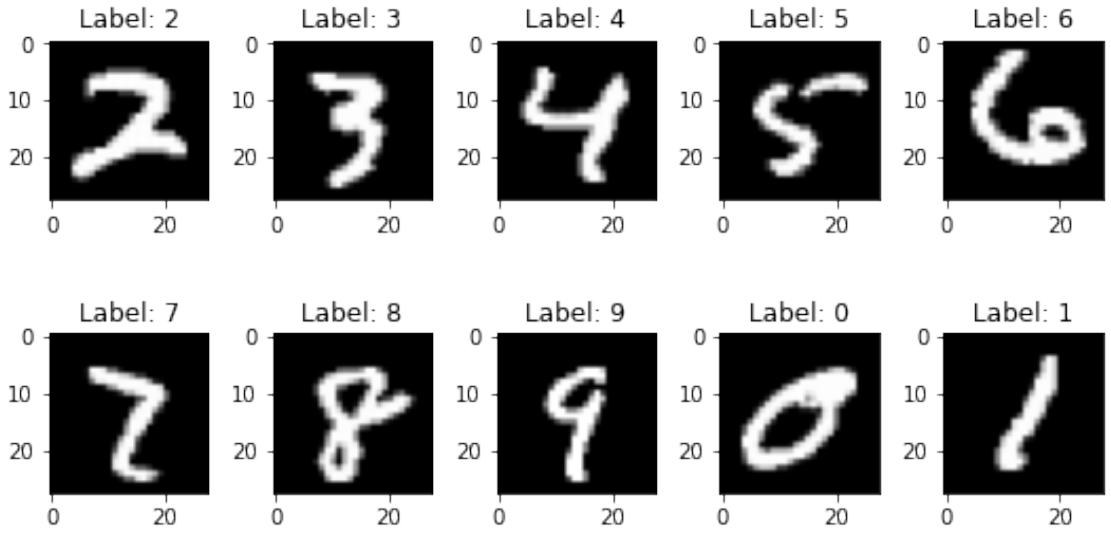
[10]:
```python
from math import e
def Training_Testing(model,optimzer,loss,regularizer = False):
    # trainingloss_list = []
    validationloss_list = []
    validationaccuracy_list = []

    if regularizer:
        trainingloss_listr = []
    else :
        trainingloss_list = []

    optimizer1 = torch.optim.Adam(model.parameters(), lr=learning_rate)

    for epoch in range(num_epochs):
        for i, (images, labels) in enumerate(trainloader):
            images = images.reshape(-1, 28, 28)
            outputs = model(images)

            if regularizer:
                loss = criterion1(outputs, labels) + lamb*torch.norm(model.
 ↪Hidden_layer.weight)
                trainingloss_listr.append(loss.item())
            else:
                loss = criterion1(outputs, labels)
                trainingloss_list.append(loss.item())


            optimizer1.zero_grad()
            loss.backward()
            optimizer1.step()
```

```
        iteration=0
        tempvalloss=0
        correctval=0
        for images, labels in valloader:
            images = images.reshape(-1, 28, 28)
            outputs = model(images)
            loss = criterion1(outputs, labels)
            _, predicted = torch.max(outputs.data, 1)
            correctval += (predicted == labels).sum().item()
            iteration+=1
            tempvalloss+=loss.item()

        validationloss_list.append(tempvalloss/iteration)
        validationaccuracy_list.append(correctval/100)
        print('Epoch',epoch+1,'out of',num_epochs,'epochs are over')

    with torch.no_grad():
        correct = 0
        total = 0
        for images, labels in testloader:
            images = images.reshape(-1, 28, 28)
            outputs = model(images)

            _, predicted = torch.max(outputs.data, 1)

            total += labels.size(0)
            correct += (predicted == labels).sum().item()
        print("Predicted",predicted[1:10])
        print("real-Label",labels[1:10])
        num_row = 2
        num_col = 5# plot images
        fig, axes = plt.subplots(num_row, num_col, figsize=(1.
↪5*num_col,2*num_row))
        for i in range(10):
            ax = axes[i//num_col, i%num_col]
            ax.imshow(images[i], cmap='gray')
            ax.set_title('Label: {}'.format(labels[i]))
        plt.tight_layout()
        plt.show()

        if regularizer:
            print('Test Accuracy of the L2 model on the 10000 test images: {}␣
↪%'.format((correct / total) * 100))
        else:
            print('Test Accuracy of the unregularized model on the 10000 test␣
↪images: {} %'.format((correct / total) * 100))
```

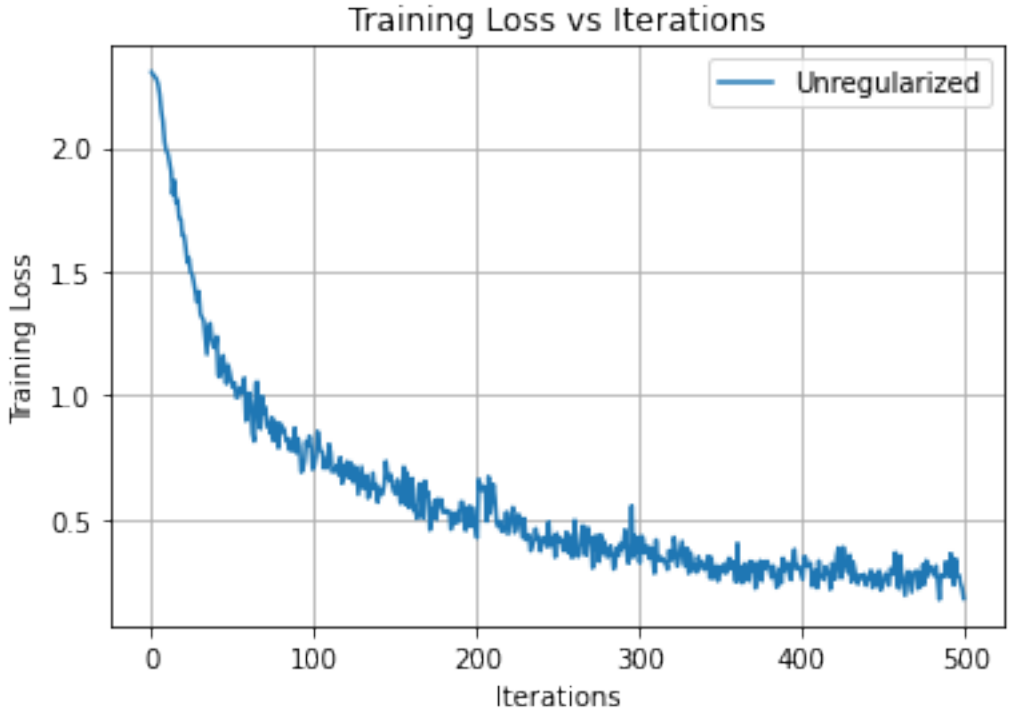
```
    plt.figure(1)
    if regularizer:
        xtrainloss=np.arange(len(trainingloss_listr))
    else:
        xtrainloss=np.arange(len(trainingloss_list))

    if regularizer:
        plt.plot(xtrainloss,trainingloss_listr,label="L2 Regularized")
    else:
        plt.plot(xtrainloss,trainingloss_list,label="Unregularized")
    plt.legend()
    plt.grid(True)
    plt.xlabel('Iterations')
    plt.ylabel('Training Loss')
    plt.title('Training Loss vs Iterations')

    plt.figure(2)
    xvalloss=np.arange(len(validationloss_list))
    plt.plot(xvalloss,validationloss_list,label="Unregularized")
    plt.grid(True)
    plt.xlabel('Epochs')
    plt.ylabel('Validation Loss')
    plt.title('Validation Loss vs Epochs')

    plt.figure(3)
    plt.plot(xvalloss,validationaccuracy_list,label='Unregularized')
    plt.grid(True)
    plt.xlabel('Epochs')
    plt.ylabel('Validation Accuracy')
    plt.title('Validation Accuracy vs Epochs')

    plt.show()
```

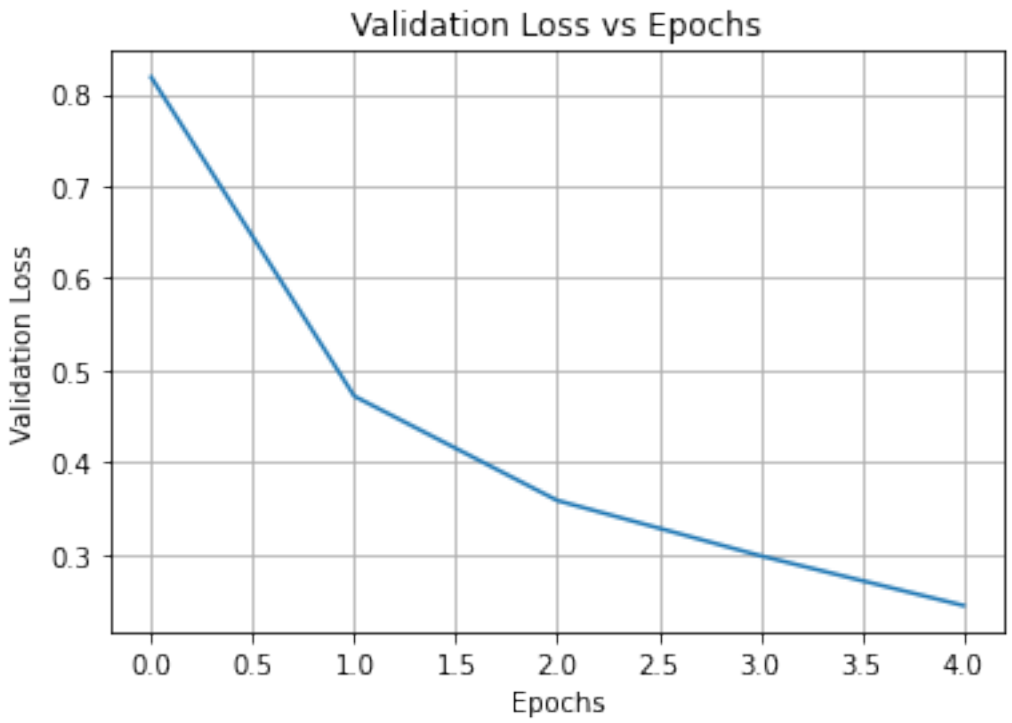
[ ]:
```
Training_Testing(Vanilla_RNN(input_dim,hidden_dim,num_layers,output_dim),optimizer1,criterion1
 ↪False)
```

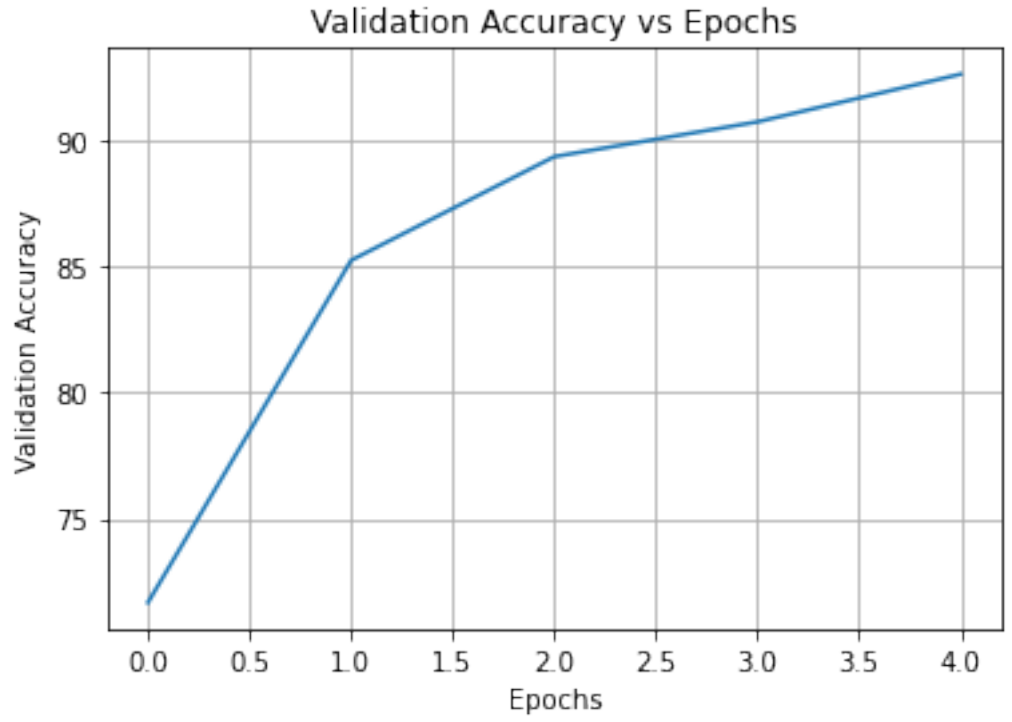
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
Predicted tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
real-Label tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
```




```
Test Accuracy of the unregularized model on the 10000 test images:
93.08999999999999 %
```

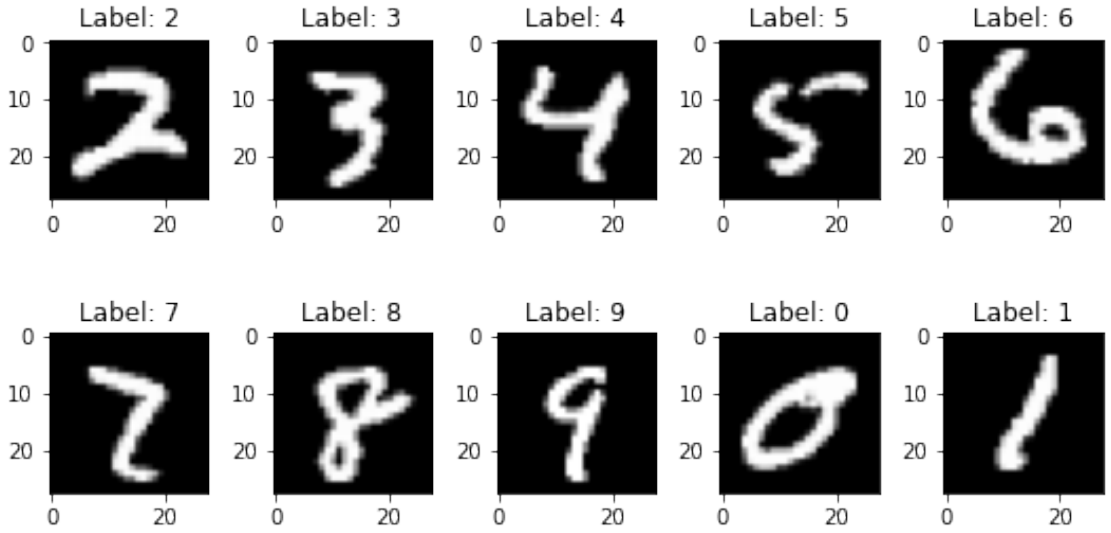



Validation Loss vs Epochs
Validation Loss
0.8
0.7
0.6
0.5
0.4
0.3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs

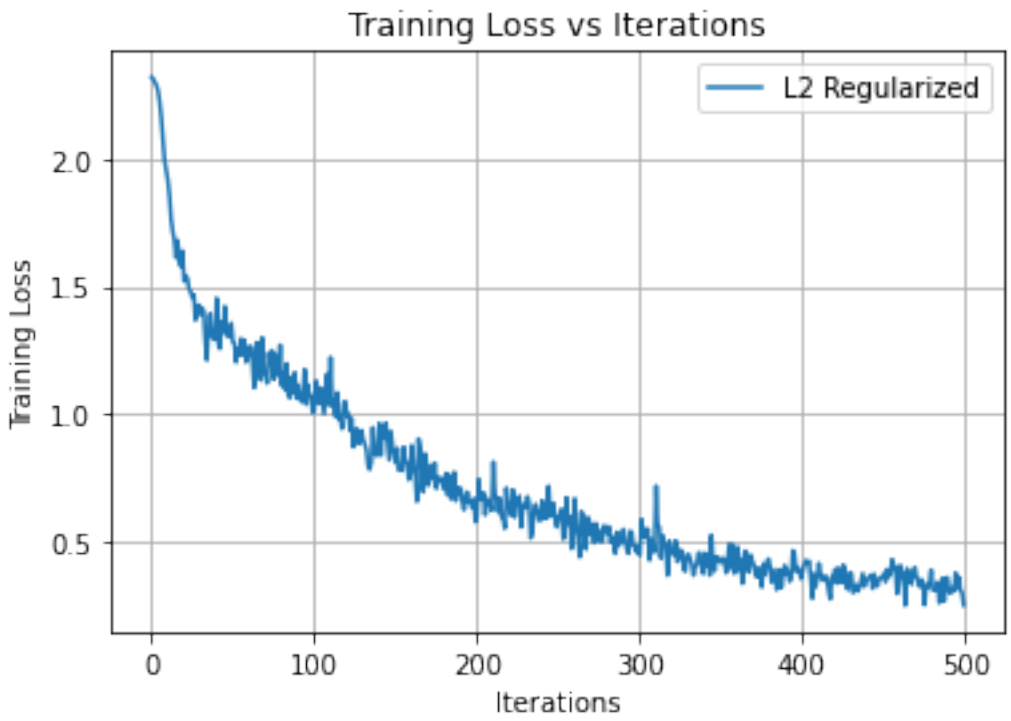

Validation Accuracy vs Epochs
Validation Accuracy
90
85
80
75
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs

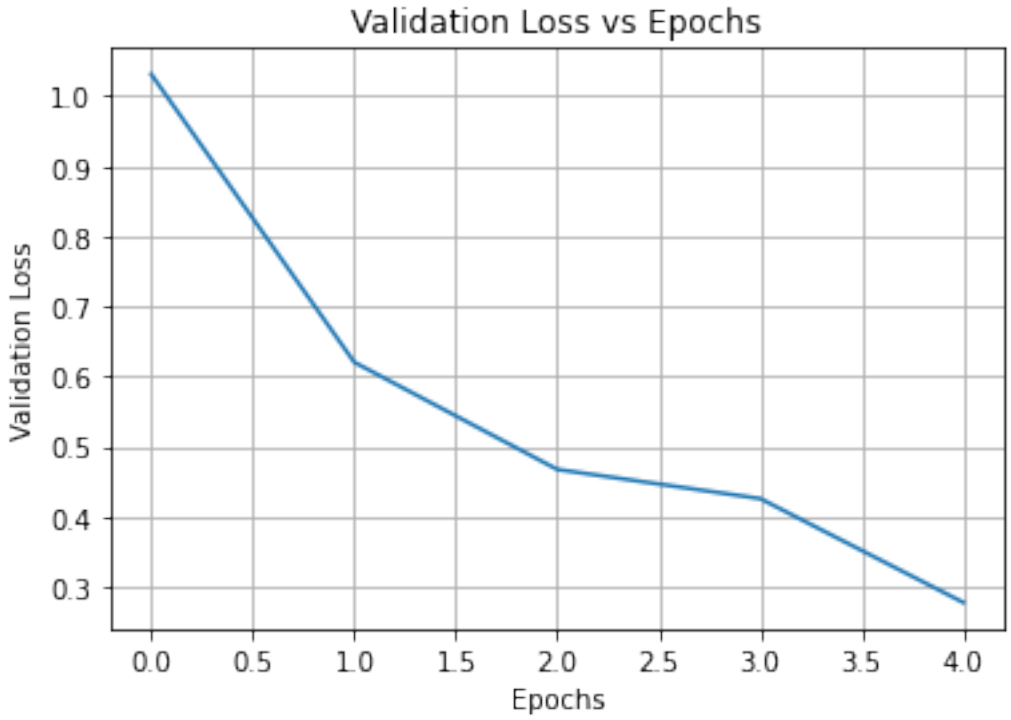
```
[ ]: Training_Testing(Vanilla_RNN(input_dim,hidden_dim,num_layers,output_dim),optimizer1,criterion1
     ↪True)
```

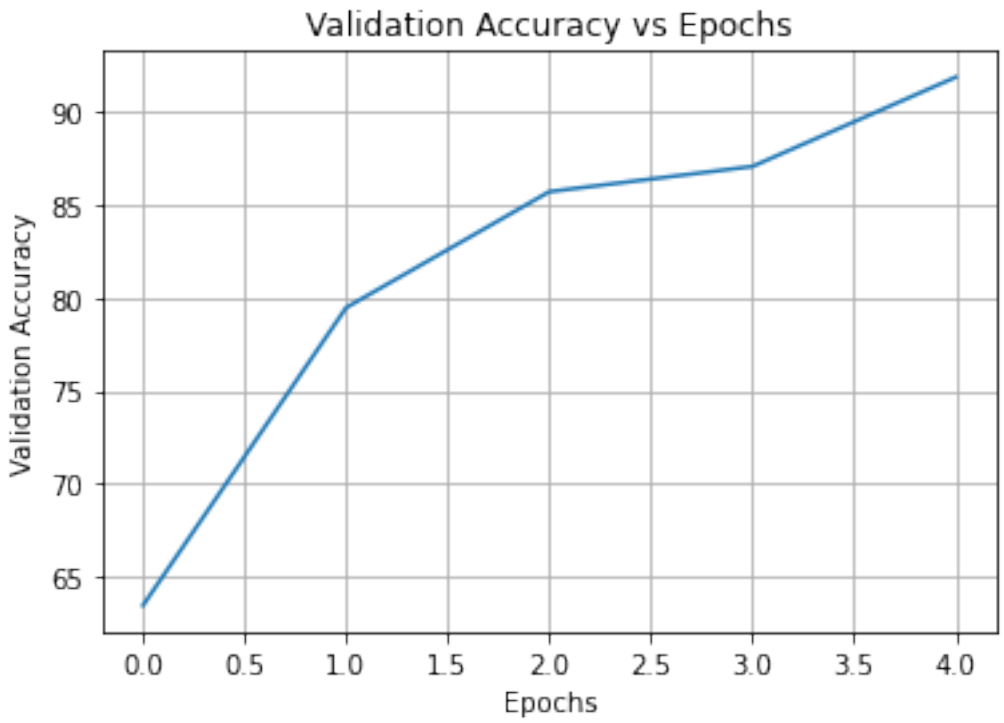
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
Predicted tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
real-Label tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
```




```
Test Accuracy of the L2 model on the 10000 test images: 91.9 %
```


Training Loss vs Iterations
L2 Regularized
Training Loss
2.0
1.5
1.0
0.5
0
100
200
300
400
500
Iterations

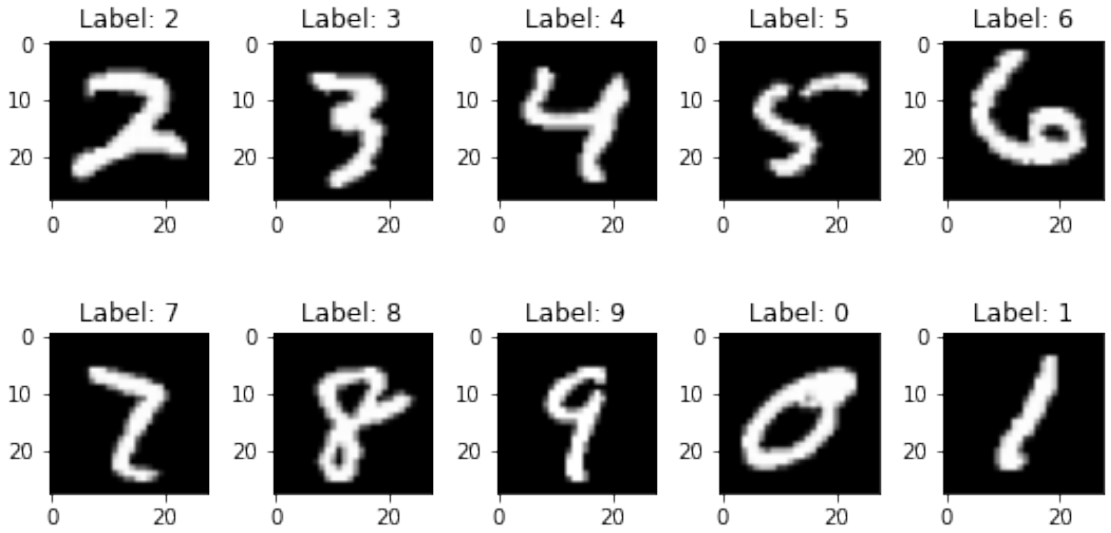

Validation Loss vs Epochs
Validation Loss
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs



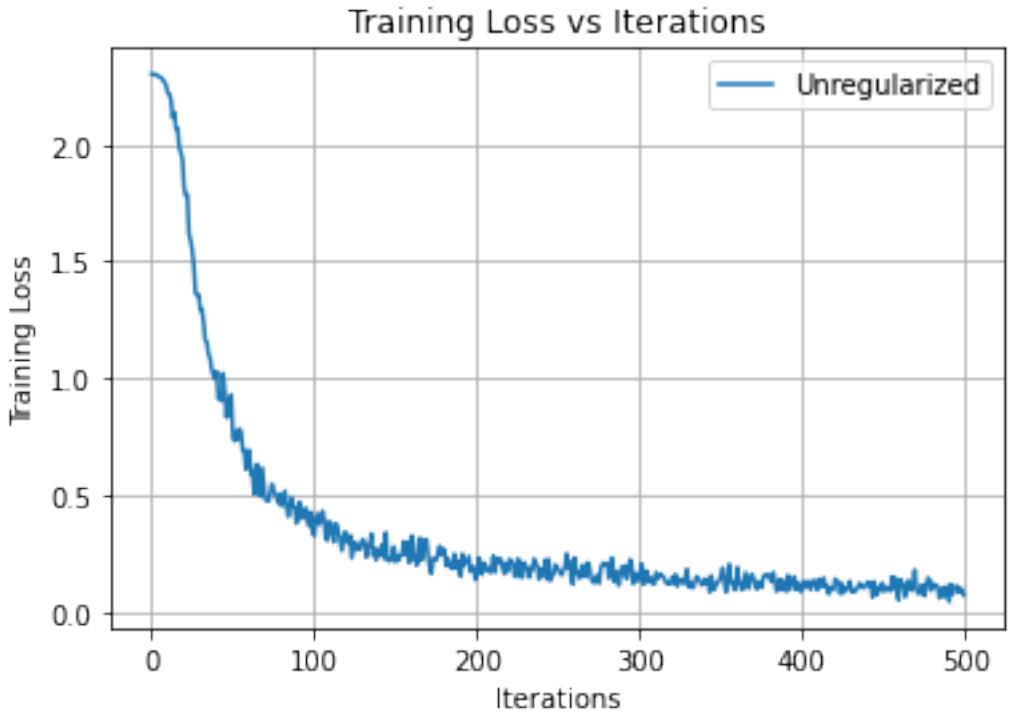
[ ]:
```
learning_rate = 0.002
epochs = 3
regul=0.005
criterion2 = nn.CrossEntropyLoss()
```

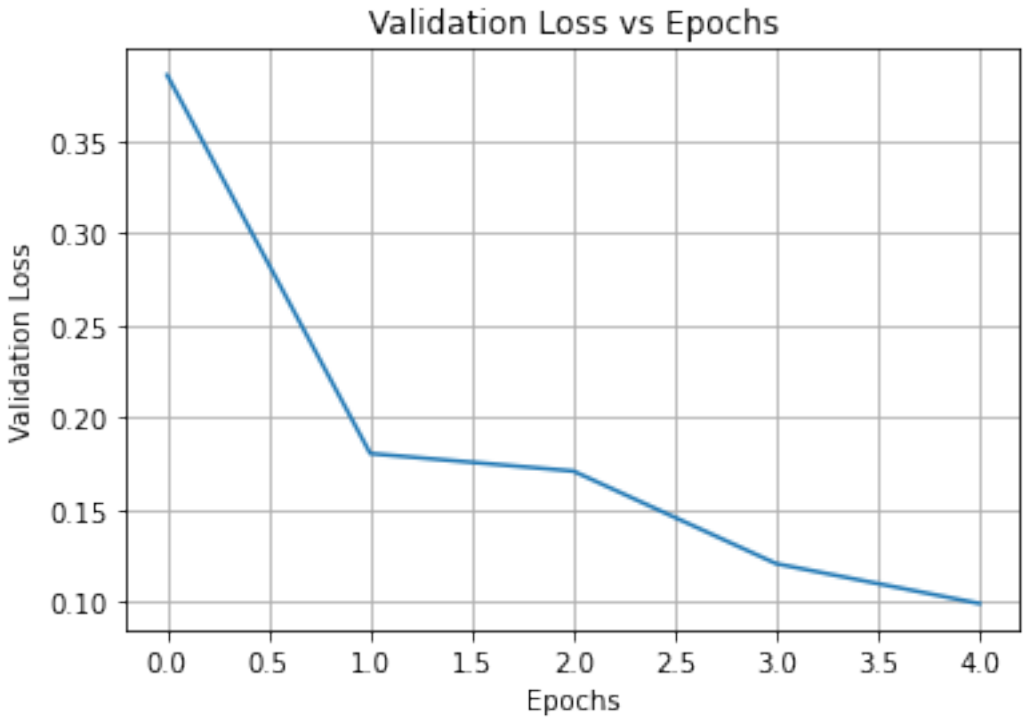
[ ]:
```
Training_Testing(Vanilla_LSTM(input_dim,hidden_dim,num_layers,output_dim),optimizer1,criterion
  ↪False)
```

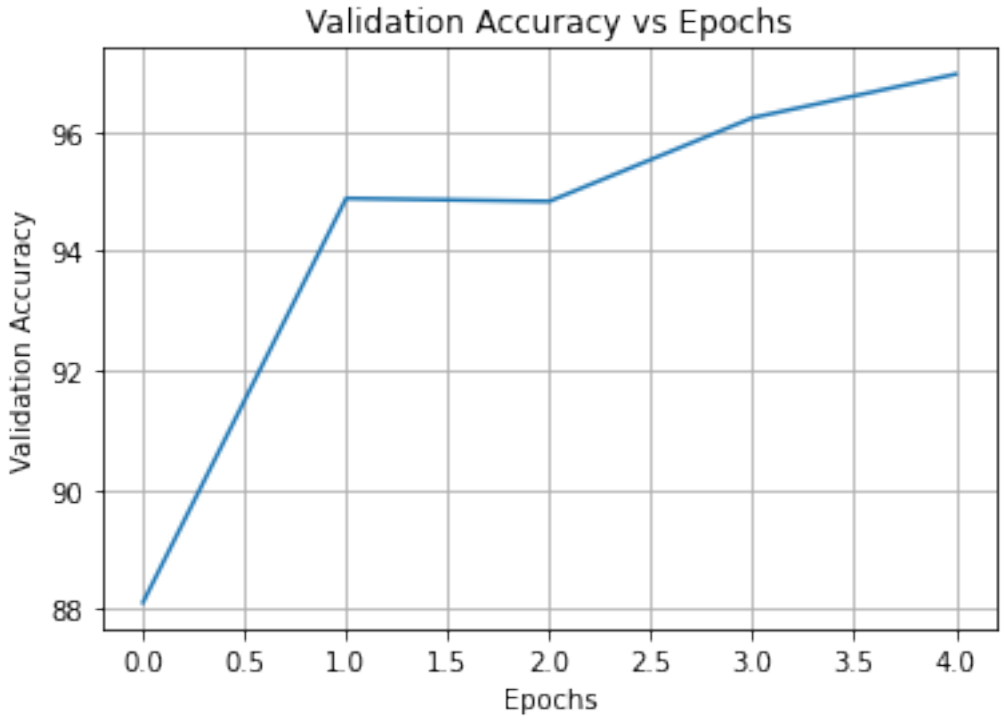
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
Predicted tensor([7, 4, 5, 6, 7, 8, 9, 0, 1])
real-Label tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
```




```
Test Accuracy of the unregularized model on the 10000 test images: 96.98 %
```



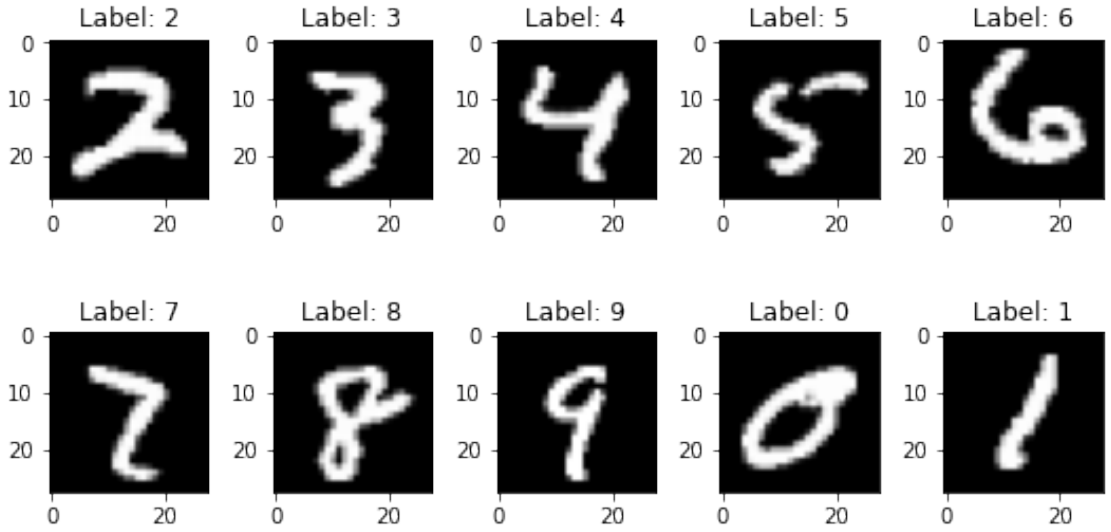

Validation Loss vs Epochs
Validation Loss
0.35
0.30
0.25
0.20
0.15
0.10
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs


Validation Accuracy vs Epochs
Validation Accuracy
96
94
92
90
88
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs

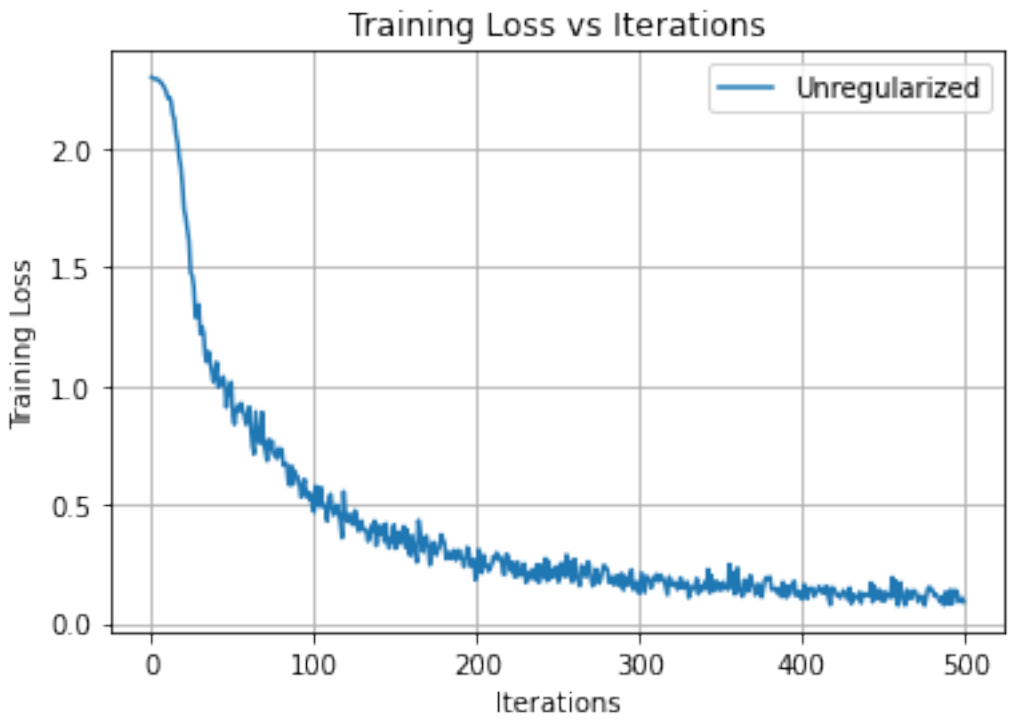
[ ]:
```
optimizer1 = torch.optim.
  ↪Adam(Vanilla_GRU(input_dim,hidden_dim,num_layers,output_dim).parameters(),␣
  ↪lr=learning_rate)
```

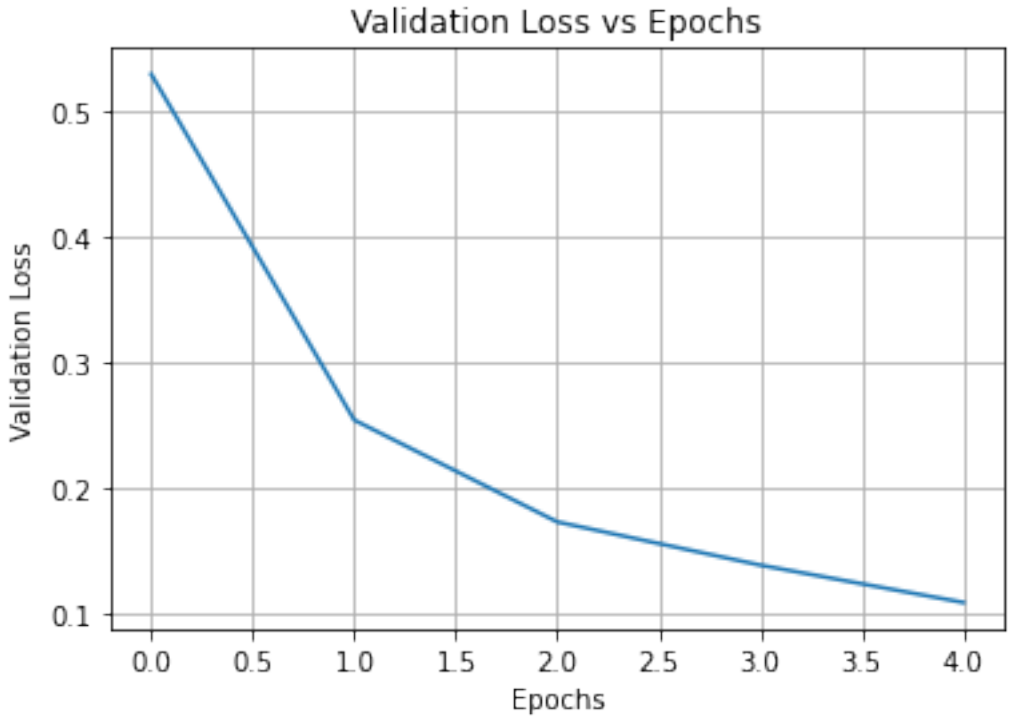
[ ]:
```
Training_Testing(Vanilla_GRU(input_dim,hidden_dim,num_layers,output_dim),optimizer1,criterion2
  ↪False)
```

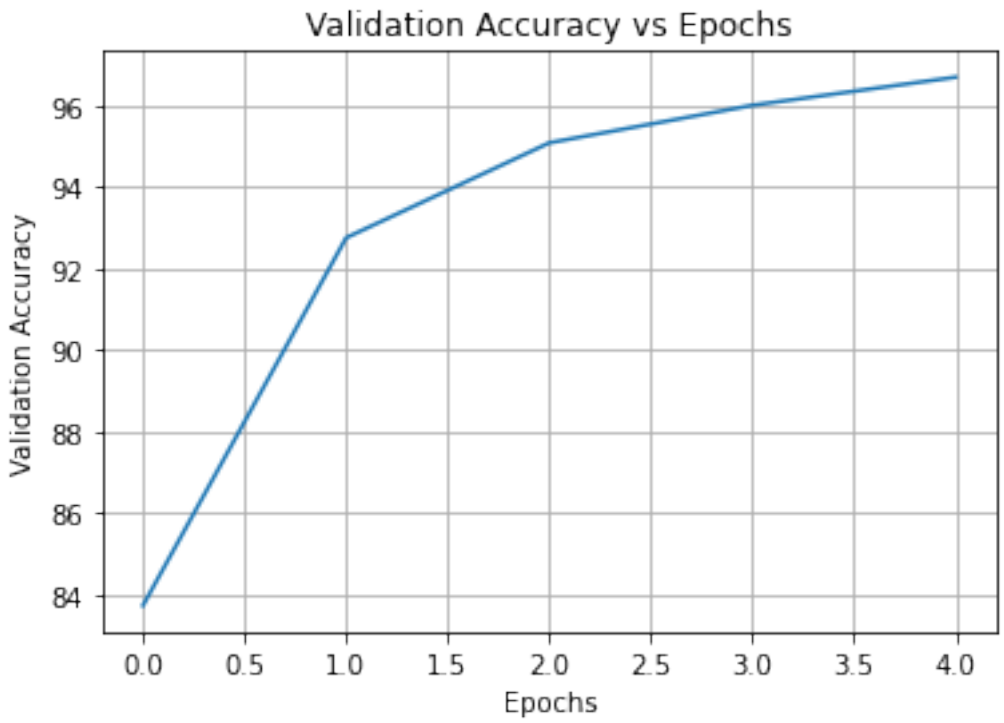
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
Predicted tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
real-Label tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
```




```
Test Accuracy of the unregularized model on the 10000 test images: 96.8 %
```

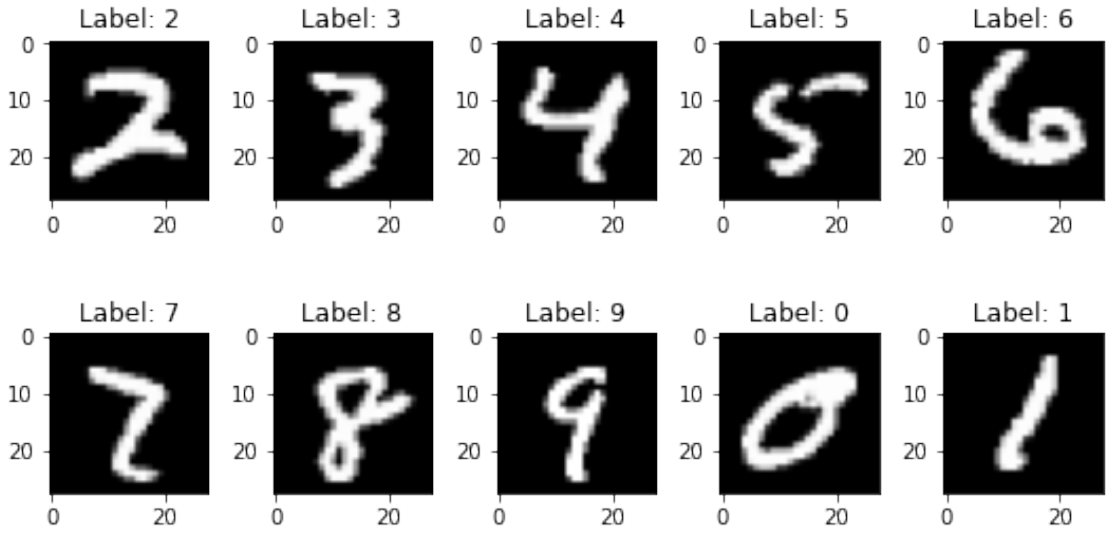

Training Loss vs Iterations
Unregularized
Training Loss
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
Iterations


Validation Loss vs Epochs
Validation Loss
0.5
0.4
0.3
0.2
0.1
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs

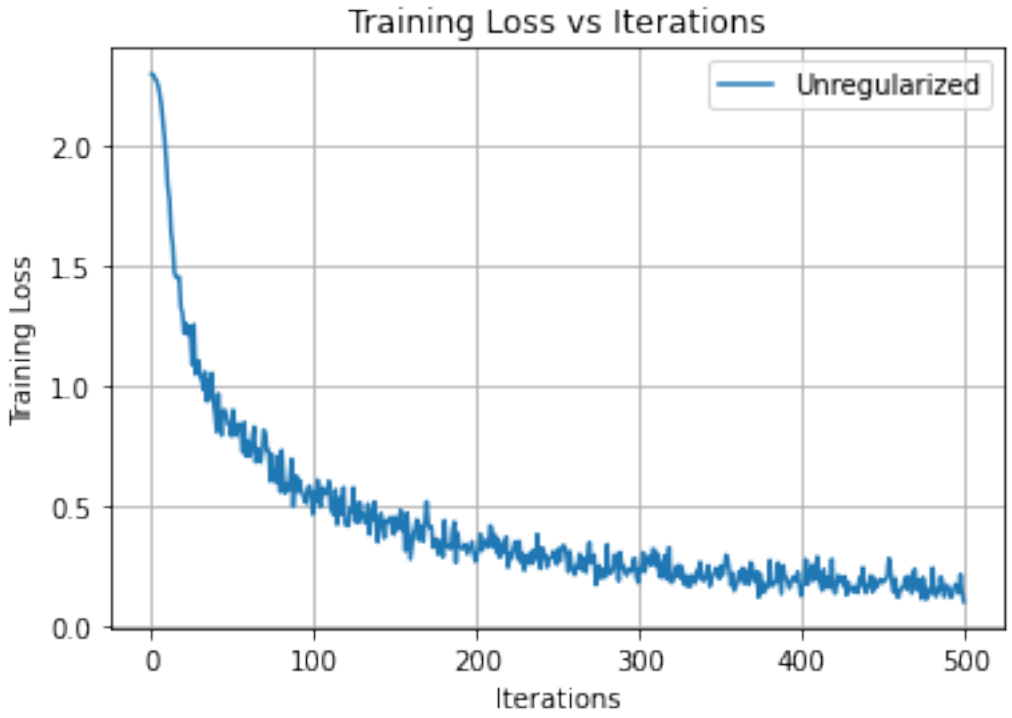


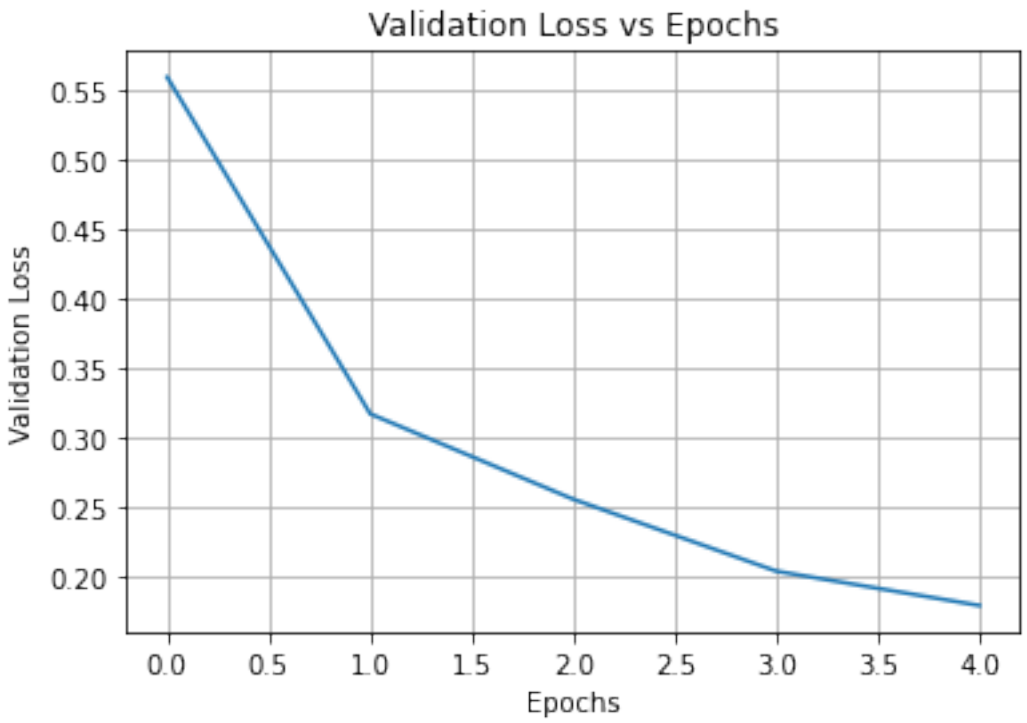
[14]:
```
Training_Testing(Vanilla_BIRNN(),optimizer1,criterion1,regularizer= False)
```

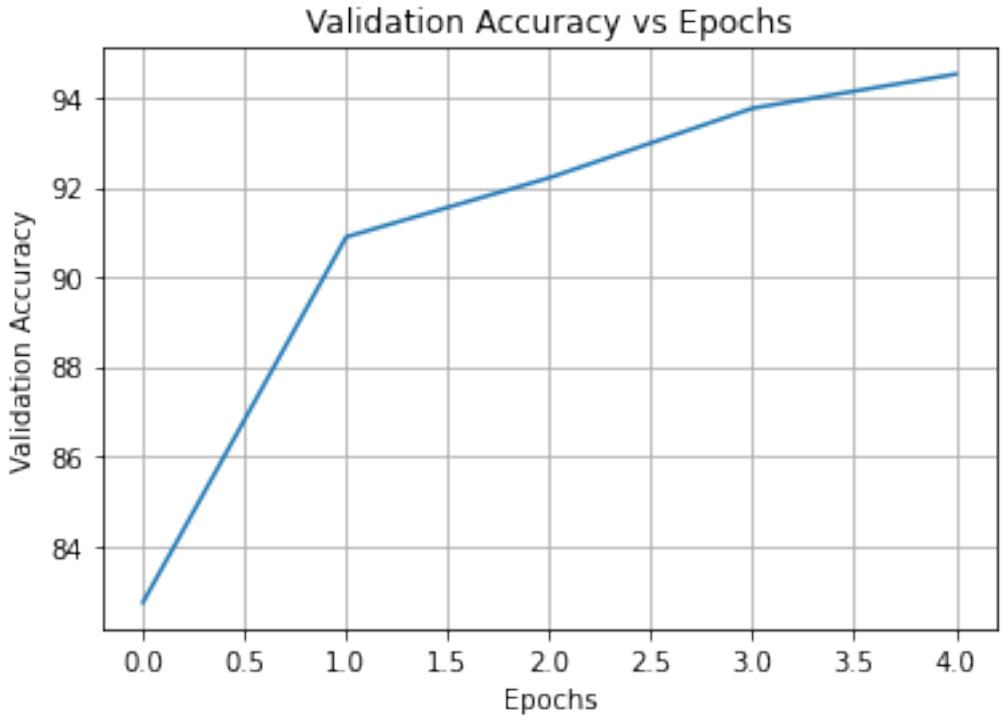
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
Predicted tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
real-Label tensor([3, 4, 5, 6, 7, 8, 9, 0, 1])
```




```
Test Accuracy of the unregularized model on the 10000 test images: 94.75 %
```




Validation Loss vs Epochs
Validation Loss
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs


Validation Accuracy vs Epochs
Validation Accuracy
94
92
90
88
86
84
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Epochs

2

[15]:
```
epochs = 10
```

[16]:
```
def Random_creator(L):
  #takes input of length L
  return np.random.randint(0,10,L)
```

[17]:
```
def one_hot_encoded(x):
  x_new = np.zeros((len(x),10))
  x_new[np.arange(len(x)), x] = 1
  return x_new
```

[18]:
```
class LSTM_2(nn.Module):
  def __init__(self,hidden_size):
    super(LSTM_2,self).__init__()

    self.hidden_size = hidden_size
    self.lstm = nn.LSTM(10,hidden_size)
    self.Hidden_layer = nn.Linear(hidden_size , 10)


  def forward(self,x):
    hiddenstate=torch.zeros(1,x.size(0),self.hidden_size)
    cellstate=torch.zeros(1,x.size(0),self.hidden_size)
    x=x.permute(1,0,2)
    out,(hs,cs) = self.lstm(x,(hiddenstate,cellstate))
    out = self.Hidden_layer(out[-1])
    return out.reshape(1,10)
```

[19]:
```
trainranlist=[]
valranlist=[]
testranlist=[]
for i in range(100):
  for j in range(3,11):
    trainranlist.append(Random_creator(j))
  L=np.random.randint(3,11)
  valranlist.append(Random_creator(L))
  L=np.random.randint(3,11)
  testranlist.append(Random_creator(L))
# testranlist
```

[ ]:
```

```

[20]:
```
K=1
hidstatesize=[2,5,10]
trainingglosslist2=[]
```

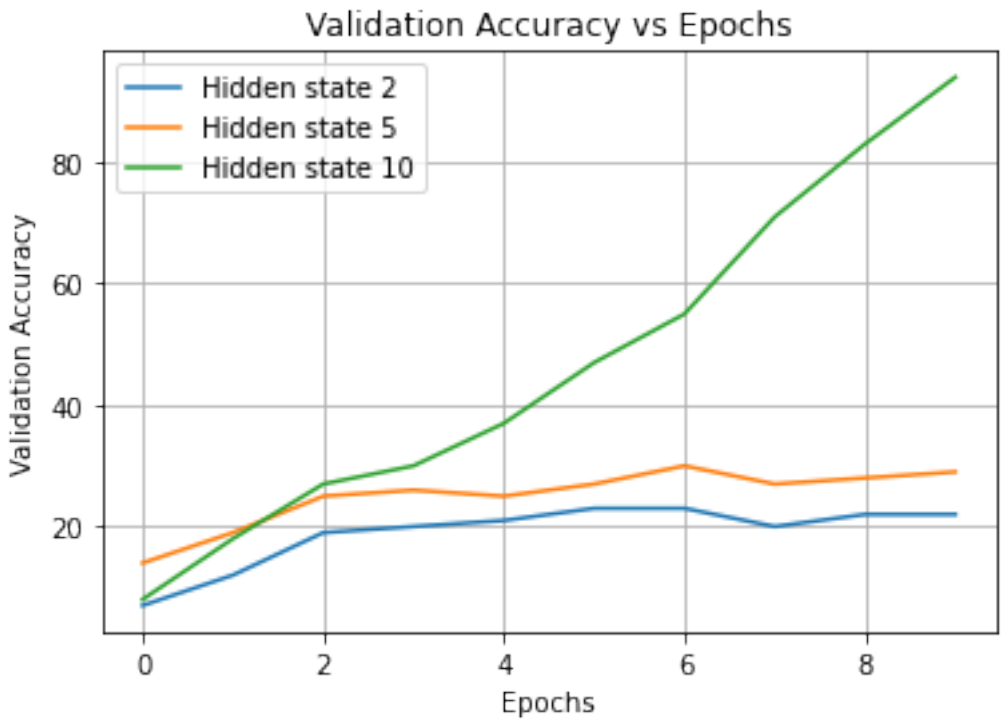
```
validationaccuracy_list2=[]
traininglosslist5=[]
validationaccuracy_list5=[]
traininglosslist10=[]
validationaccuracy_list10=[]

iteration=0
tempvalloss=0
correctval=0

model41=LSTM_2(hidstatesize[0])
optimizer41 = torch.optim.Adam(model41.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(trainranlist)):
    hotranlist=torch.zeros((1,len(trainranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(trainranlist[i]))

    output=model41(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([trainranlist[i][K]],dtype=torch.long)
    loss = criterion1(output, label.long())
    traininglosslist2.append(loss.item())

    optimizer41.zero_grad()
    loss.backward()
    optimizer41.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(valranlist)):
    hotranlist=torch.zeros((1,len(valranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(valranlist[i]))

    output=model41(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([valranlist[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  validationaccuracy_list2.append(correctval/len(valranlist)*100)
```

```
model42=LSTM_2(hidstatesize[1])
optimizer42 = torch.optim.Adam(model42.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(trainranlist)):
    hotranlist=torch.zeros((1,len(trainranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(trainranlist[i]))

    output=model42(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([trainranlist[i][K]],dtype=torch.long)
    loss = criterion1(output, label.long())
    traininglosslist5.append(loss.item())

    optimizer42.zero_grad()
    loss.backward()
    optimizer42.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(valranlist)):
    hotranlist=torch.zeros((1,len(valranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(valranlist[i]))

    output=model42(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([valranlist[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  validationaccuracy_list5.append(correctval/len(valranlist)*100)


model43=LSTM_2(hidstatesize[2])
optimizer43 = torch.optim.Adam(model43.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(trainranlist)):
    hotranlist=torch.zeros((1,len(trainranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(trainranlist[i]))
```

```
    output=model43(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([trainranlist[i][K]],dtype=torch.long)
    loss = criterion1(output, label.long())
    traininglosslist10.append(loss.item())

    optimizer43.zero_grad()
    loss.backward()
    optimizer43.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(valranlist)):
    hotranlist=torch.zeros((1,len(valranlist[i]),10))
    hotranlist[0]=torch.from_numpy(one_hot_encoded(valranlist[i]))

    output=model43(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([valranlist[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  validationaccuracy_list10.append(correctval/len(valranlist)*100)
```

[21]:
```
plt.figure(1)
xtrainloss=np.arange(len(traininglosslist2))
plt.plot(xtrainloss,traininglosslist2,label="Hidden state 2")
plt.plot(xtrainloss,traininglosslist5,label="Hidden state 5")
plt.plot(xtrainloss,traininglosslist10,label="Hidden state 10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt.figure(2)
xvalloss=np.arange(len(validationaccuracy_list2))
plt.plot(xvalloss,validationaccuracy_list2,label="Hidden state 2")
plt.plot(xvalloss,validationaccuracy_list5,label="Hidden state 5")
plt.plot(xvalloss,validationaccuracy_list10,label="Hidden state 10")
```

```
plt.grid(True)
plt.xlabel('Epochs')
plt.ylabel('Validation Accuracy')
plt.title('Validation Accuracy vs Epochs')
plt.legend()
plt.show()
```



[22]:
```
model41.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(testranlist)):
      hotranlist=torch.zeros((1,len(testranlist[i]),10))
      hotranlist[0]=torch.from_numpy(one_hot_encoded(testranlist[i]))
      output=model41(hotranlist.float())
      label=torch.tensor([testranlist[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 2 hidden states on the 100 test␣
 ↪samples: {} %'.format((correct / len(testranlist)) * 100))

model42.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(testranlist)):
      hotranlist=torch.zeros((1,len(testranlist[i]),10))
      hotranlist[0]=torch.from_numpy(one_hot_encoded(testranlist[i]))
      output=model42(hotranlist.float())
```

```
      label=torch.tensor([testranlist[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 5 hidden states on the 100 test␣
 ↪samples: {} %'.format((correct / len(testranlist)) * 100))

model43.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(testranlist)):
      hotranlist=torch.zeros((1,len(testranlist[i]),10))
      hotranlist[0]=torch.from_numpy(one_hot_encoded(testranlist[i]))
      output=model43(hotranlist.float())
      label=torch.tensor([testranlist[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 10 hidden states on the 100 test␣
 ↪samples: {} %'.format((correct / len(testranlist)) * 100))
```

```
Test Accuracy of the model with 2 hidden states on the 100 test samples: 16.0 %
Test Accuracy of the model with 5 hidden states on the 100 test samples: 30.0 %
Test Accuracy of the model with 10 hidden states on the 100 test samples: 96.0 %
```

[24]:
```
for i in range(3,11):
  print("For Length",i)
  for j in range(3):
      a=Random_creator(i)
      hotranlist=torch.zeros((1,len(a),10))
      hotranlist[0]=torch.from_numpy(one_hot_encoded(a))
      output=model43(hotranlist.float())
      label=torch.tensor([a[K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      print("Array:",a,"Prediction at position 2:",predicted.item())
```

```
For Length 3
Array: [5 5 6] Prediction at position 2: 5
Array: [5 7 2] Prediction at position 2: 7
Array: [8 2 0] Prediction at position 2: 2
For Length 4
Array: [3 3 2 5] Prediction at position 2: 3
Array: [6 2 3 5] Prediction at position 2: 2
Array: [5 0 2 6] Prediction at position 2: 0
For Length 5
Array: [2 6 6 3 2] Prediction at position 2: 6
```

```
Array: [2 9 4 5 7] Prediction at position 2: 9
Array: [7 2 1 4 4] Prediction at position 2: 2
For Length 6
Array: [4 6 8 3 9 3] Prediction at position 2: 3
Array: [2 9 9 7 2 7] Prediction at position 2: 9
Array: [9 6 5 1 3 9] Prediction at position 2: 6
For Length 7
Array: [0 3 0 2 1 5 6] Prediction at position 2: 3
Array: [9 5 4 5 2 5 0] Prediction at position 2: 5
Array: [8 4 6 7 0 0 1] Prediction at position 2: 4
For Length 8
Array: [1 9 8 0 9 5 9 6] Prediction at position 2: 9
Array: [3 2 5 4 9 2 0 1] Prediction at position 2: 2
Array: [0 0 4 8 7 9 7 6] Prediction at position 2: 0
For Length 9
Array: [7 8 0 6 7 9 5 2 4] Prediction at position 2: 8
Array: [3 2 2 3 0 2 0 7 6] Prediction at position 2: 2
Array: [1 6 9 2 9 0 4 5 4] Prediction at position 2: 3
For Length 10
Array: [9 7 1 3 1 6 9 4 2 2] Prediction at position 2: 7
Array: [0 0 4 7 2 0 7 3 9 2] Prediction at position 2: 0
Array: [7 9 5 1 0 4 2 3 7 3] Prediction at position 2: 9
```

[25]:
```
def binsgenerator(L):
  N1=np.random.randint(0,2**(L-1))
  N2=np.random.randint(0,2**(L-1))
  S=N1+N2
  binlen=L
  B1=np.zeros((1,binlen))
  B2=np.zeros((1,binlen))
  B3=np.zeros((binlen))
  b=np.flip(np.array(list(np.binary_repr(N1)), dtype=int))
  B1[0][0:len(b)]=b[0:]
  b=np.flip(np.array(list(np.binary_repr(N2)), dtype=int))
  B2[0][0:len(b)]=b[0:]
  b=np.flip(np.array(list(np.binary_repr(S)), dtype=int))
  B3[0:len(b)]=b[0:]
  return(np.concatenate((np.transpose(B1),np.transpose(B2)),axis=1),B3)
```

[26]:
```
traininput=[]
trainoutput=[]
for i in range(250):
  L=np.random.randint(1,21)
  a,b=binsgenerator(L)
  traininput.append(a)
  trainoutput.append(b)
```

```
testinput=[]
testoutput=[]
for i in range(100):
  L=np.random.randint(1,21)
  a,b=binsgenerator(L)
  testinput.append(a)
  testoutput.append(b)

fintestinput=[]
fintestoutput=[]
for j in range(1,21):
  for i in range(100):
    a,b=binsgenerator(j)
    fintestinput.append(a)
    fintestoutput.append(b)
```

[27]:
```
class LSTMQ3(nn.Module):
  def __init__(self,hidsize):
    super(LSTMQ3, self).__init__()
    self.hidsize=hidsize
    self.lstm = nn.LSTM(2,hidsize)
    self.layer2 = nn.Sequential(
        nn.Linear(hidsize,1),
        nn.Sigmoid())

  def forward(self, X):
    X=X.permute(1,0,2)
    hiddenstate=torch.zeros(1,X.size(1),self.hidsize)
    cellstate=torch.zeros(1,X.size(1),self.hidsize)
    out,(hs,cs) = self.lstm(X,(hiddenstate,cellstate))
    out = self.layer2(out)
    return out.reshape(X.size(0))
```

[39]:
```
learning_rate = 0.01
epochs = 10
criterion5 = nn.MSELoss()
model51=LSTMQ3(3)
optimizer51 = torch.optim.Adam(model51.parameters(), lr=learning_rate)
model52=LSTMQ3(10)
optimizer52 = torch.optim.Adam(model52.parameters(), lr=learning_rate)
```

[40]:
```
traininglosslist=[]
testlosslist=[]
correcttestlist=[]
for epoch in range(epochs):
  for i in range(int(len(traininput))):
    a=torch.zeros((1,traininput[i].shape[0],traininput[i].shape[1]))
```

```
    a[0]=torch.from_numpy(traininput[i])
    output=model51(a.float())
    label=torch.tensor(np.transpose(trainoutput[i]))
    loss = criterion5(output,label.float())
    traininglosslist.append(loss.item())

    optimizer51.zero_grad()
    loss.backward()
    optimizer51.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(testinput)):
    correct=0
    a=torch.zeros((1,testinput[i].shape[0],testinput[i].shape[1]))
    a[0]=torch.from_numpy(testinput[i])
    output=model51(a.float())
    label=torch.tensor(np.transpose(testoutput[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  correcttestlist.append(100*correct/iteration)
  testlosslist.append(tempvalloss/iteration)
  print('Epoch',epoch+1,'out of',epochs,'epochs are over')
```

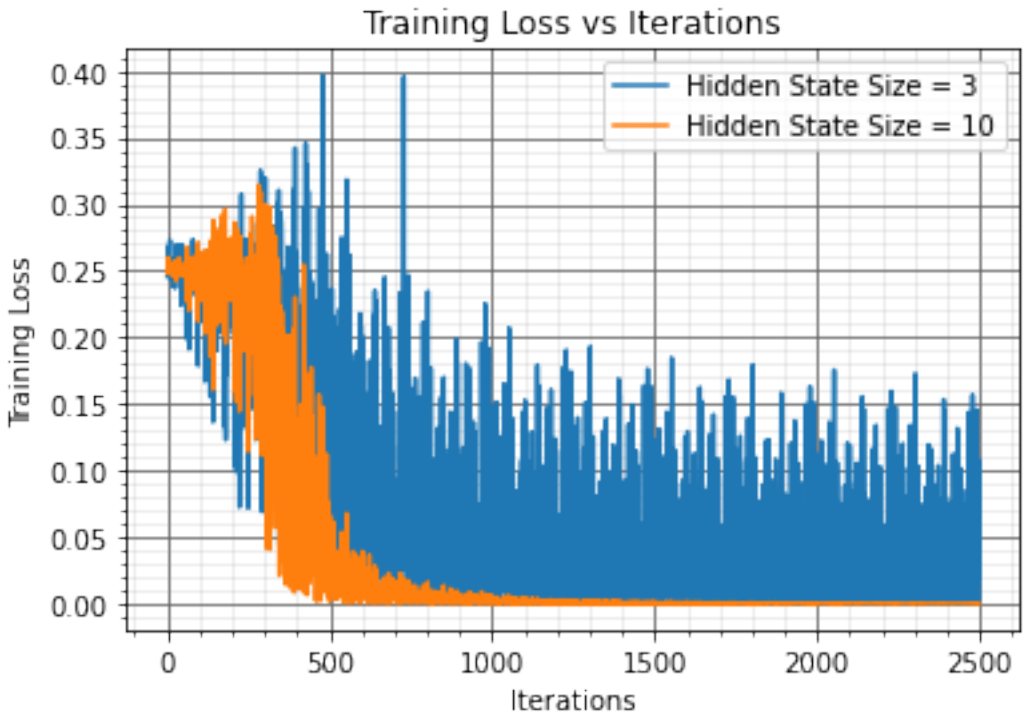
```
Epoch 1 out of 10 epochs are over
Epoch 2 out of 10 epochs are over
Epoch 3 out of 10 epochs are over
Epoch 4 out of 10 epochs are over
Epoch 5 out of 10 epochs are over
Epoch 6 out of 10 epochs are over
Epoch 7 out of 10 epochs are over
Epoch 8 out of 10 epochs are over
Epoch 9 out of 10 epochs are over
Epoch 10 out of 10 epochs are over
```

[41]:
```
trainingglosslist2=[]
testlosslist2=[]
correcttestlist2=[]
```

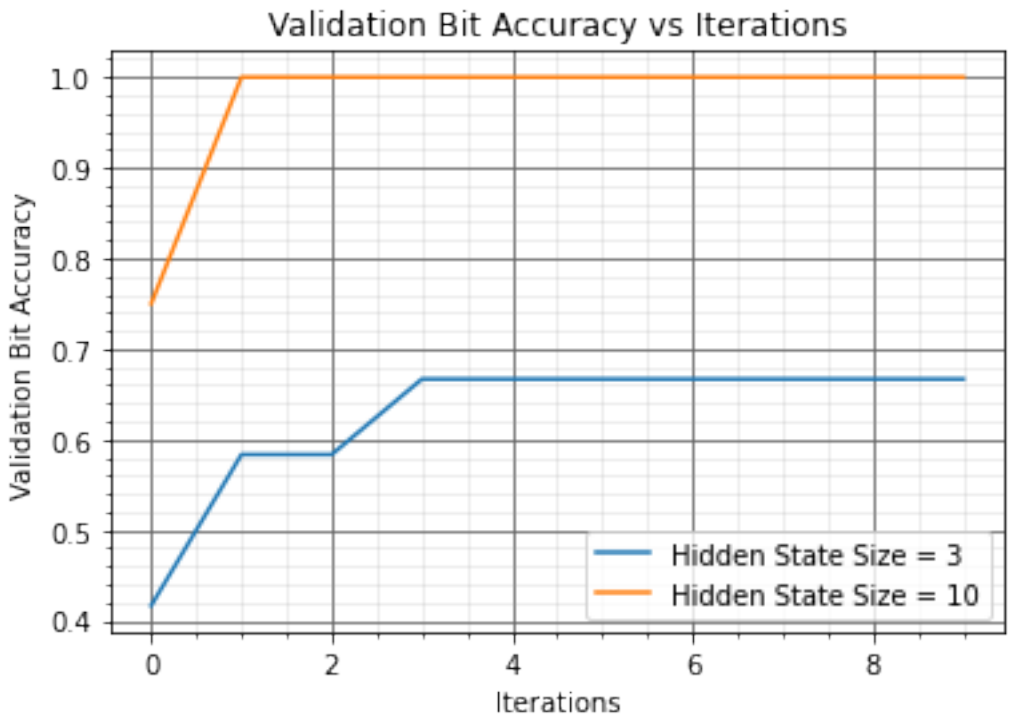
```
for epoch in range(epochs):
  for i in range(len(traininput)):
    a=torch.zeros((1,traininput[i].shape[0],traininput[i].shape[1]))
    a[0]=torch.from_numpy(traininput[i])
    output=model52(a.float())
    label=torch.tensor(np.transpose(trainoutput[i]))
    loss = criterion5(output,label.float())
    traininglosslist2.append(loss.item())

    optimizer52.zero_grad()
    loss.backward()
    optimizer52.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(testinput)):
    correct=0
    a=torch.zeros((1,testinput[i].shape[0],testinput[i].shape[1]))
    a[0]=torch.from_numpy(testinput[i])
    output=model52(a.float())
    label=torch.tensor(np.transpose(testoutput[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  correcttestlist2.append(100*correct/iteration)
  testlosslist2.append(tempvalloss/iteration)
  print('Epoch',epoch+1,'out of',epochs,'epochs are over')
```

```
Epoch 1 out of 10 epochs are over
Epoch 2 out of 10 epochs are over
Epoch 3 out of 10 epochs are over
Epoch 4 out of 10 epochs are over
Epoch 5 out of 10 epochs are over
Epoch 6 out of 10 epochs are over
Epoch 7 out of 10 epochs are over
Epoch 8 out of 10 epochs are over
Epoch 9 out of 10 epochs are over
Epoch 10 out of 10 epochs are over
```

[42]:
```
plt.figure(1)
xtrainloss=np.arange(len(traininglosslist))
plt.plot(xtrainloss,traininglosslist,label="Hidden State Size = 3")
plt.plot(xtrainloss,traininglosslist2,label="Hidden State Size = 10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt.figure(2)
xtestloss=np.arange(len(testlosslist))
plt.plot(xtestloss,testlosslist,label="Hidden State Size = 3")
plt.plot(xtestloss,testlosslist2,label="Hidden State Size = 10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Val Loss')
plt.title('Validation Loss vs Iterations')
plt.legend()

plt.figure(3)
xbittrain=np.arange(len(correcttestlist))
plt.plot(xbittrain,correcttestlist,label="Hidden State Size = 3")
plt.plot(xbittrain,correcttestlist2,label="Hidden State Size = 10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Bit Accuracy')
plt.title('Validation Bit Accuracy vs Iterations')
plt.legend()


plt.show()
```


Training Loss vs Iterations
Hidden State Size = 3
Hidden State Size = 10
Training Loss
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
500
1000
1500
2000
2500
Iterations


Validation Loss vs Iterations
Hidden State Size = 3
Hidden State Size = 10
Val Loss
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
Iterations

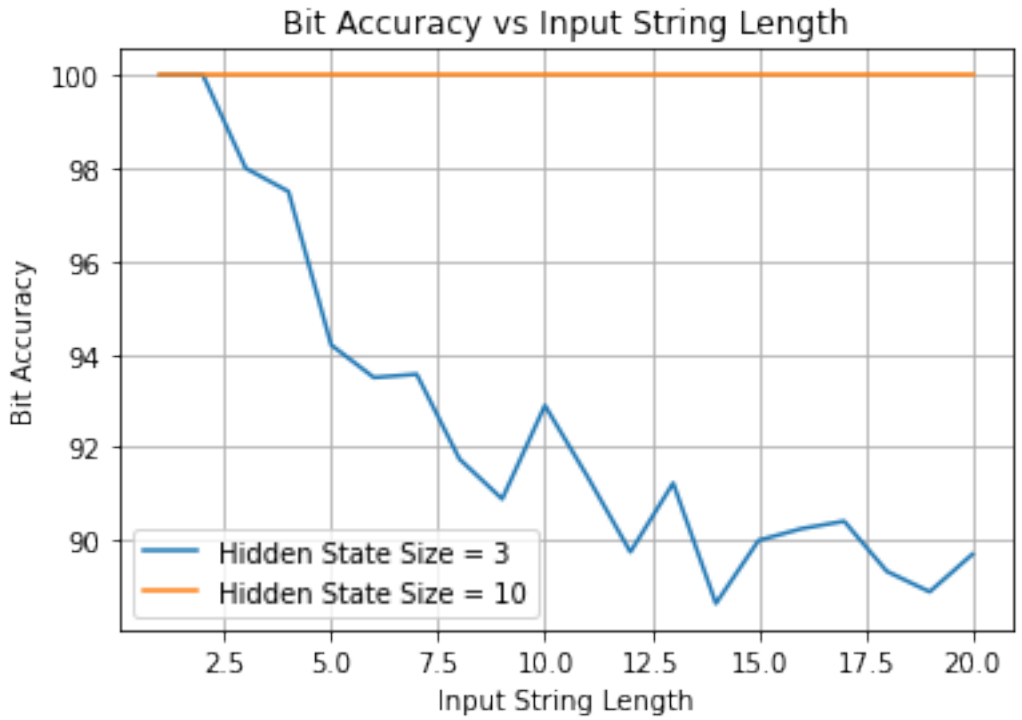


[43]:
```
model51.eval()
correctarr1 = np.zeros(20)
correctarr2 = np.zeros(20)
with torch.no_grad():
    for i in range(len(fintestinput)):
      a=torch.zeros((1,fintestinput[i].shape[0],fintestinput[i].shape[1]))
      a[0]=torch.from_numpy(fintestinput[i])
      output=model51(a.float())
      label=torch.tensor(np.transpose(fintestoutput[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>=0.5]=1
      predicted[output<0.5]=0
      correctarr1[len(label)-1] += (predicted == label.float()).sum().item()/
 ↪(len(label))


    print('Bit accuracy when hidden states = 3:',(np.sum(correctarr1)/20))

model52.eval()
with torch.no_grad():
    for i in range(len(fintestinput)):
      a=torch.zeros((1,fintestinput[i].shape[0],fintestinput[i].shape[1]))
      a[0]=torch.from_numpy(fintestinput[i])
```

```
      output=model52(a.float())
      label=torch.tensor(np.transpose(fintestoutput[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>0.5]=1
      predicted[output<=0.5]=0
      correctarr2[len(label)-1] += (predicted == label.float()).sum().item()/
 ↪(len(label))
    print('Bit accuracy when hidden states = 10:',(np.sum(correctarr2)/20))
```

```
Bit accuracy when hidden states = 3: 92.59437075394503
Bit accuracy when hidden states = 10: 100.0
```

[44]:
```
x=np.arange(1,21)
plt.figure(1)
plt.plot(x,correctarr1,label="Hidden State Size = 3")
plt.plot(x,correctarr2,label="Hidden State Size = 10")
plt.xlabel('Input String Length')
plt.ylabel('Bit Accuracy')
plt.title('Bit Accuracy vs Input String Length')
plt.legend()
plt.grid(True)
plt.show()
```



[45]:
```
learning_rate = 0.01
epochs = 5
criterion5 = nn.MSELoss()
model53=LSTMQ3(5)
optimizer53 = torch.optim.Adam(model53.parameters(), lr=learning_rate)
model54=LSTMQ3(5)
optimizer54 = torch.optim.Adam(model54.parameters(), lr=learning_rate)
```

[46]:
```
traininglosslist=[]
testlosslist=[]
correcttestlist=[]
for epoch in range(epochs):
  for i in range(int(len(traininput))):
    a=torch.zeros((1,traininput[i].shape[0],traininput[i].shape[1]))
    a[0]=torch.from_numpy(traininput[i])
    output=model53(a.float())
    label=torch.tensor(np.transpose(trainoutput[i]))
    loss = criterion5(output,label.float())
    traininglosslist.append(loss.item())

    optimizer53.zero_grad()
    loss.backward()
    optimizer53.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(testinput)):
    correct=0
    a=torch.zeros((1,testinput[i].shape[0],testinput[i].shape[1]))
    a[0]=torch.from_numpy(testinput[i])
    output=model53(a.float())
    label=torch.tensor(np.transpose(testoutput[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  correcttestlist.append(100*correct/iteration)
  testlosslist.append(tempvalloss/iteration)
  print('Epoch',epoch+1,'out of',epochs,'epochs are over')
```

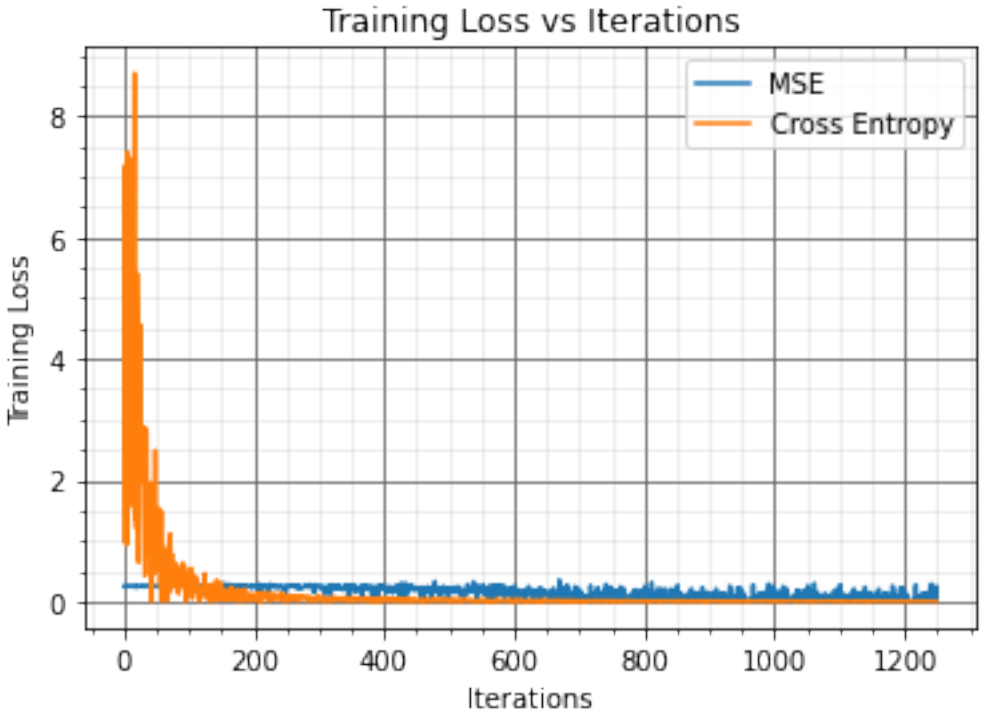
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
```

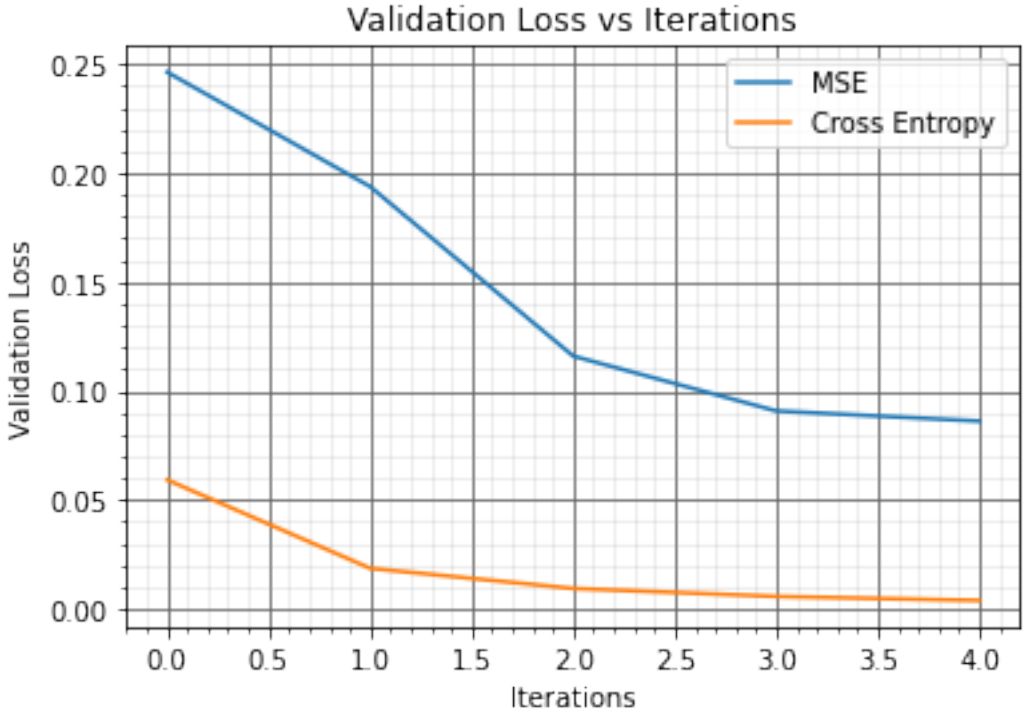
[47]:
```
traininglosslist2=[]
testlosslist2=[]
correcttestlist2=[]
for epoch in range(epochs):
  for i in range(int(len(traininput))):
    a=torch.zeros((1,traininput[i].shape[0],traininput[i].shape[1]))
    a[0]=torch.from_numpy(traininput[i])
    output=model54(a.float())
    label=torch.tensor(np.transpose(trainoutput[i]))
    loss = torch.sum(-1*torch.log(output.clamp(1e-10))*label.float())
    traininglosslist2.append(loss.item())

    optimizer54.zero_grad()
    loss.backward()
    optimizer54.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(testinput)):
    correct=0
    a=torch.zeros((1,testinput[i].shape[0],testinput[i].shape[1]))
    a[0]=torch.from_numpy(testinput[i])
    output=model54(a.float())
    label=torch.tensor(np.transpose(testoutput[i]))
    loss = torch.sum(-1*torch.log(output.clamp(1e-10))*label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  correcttestlist2.append(100*correct/iteration)
  testlosslist2.append(tempvalloss/iteration)
  print('Epoch',epoch+1,'out of',epochs,'epochs are over')
```

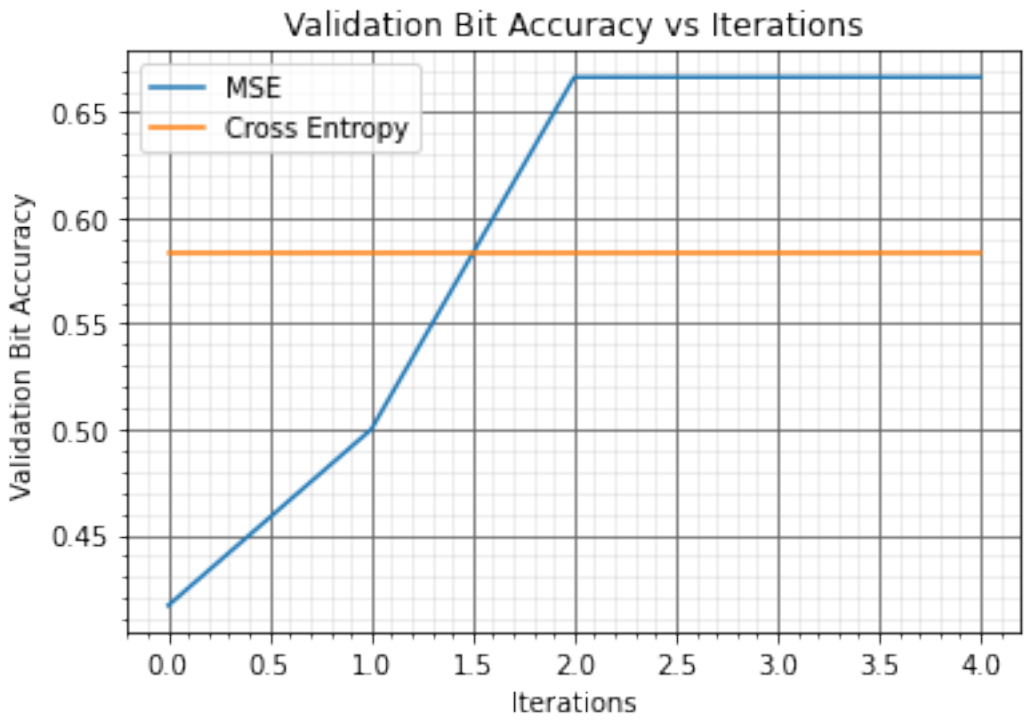
```
Epoch 1 out of 5 epochs are over
Epoch 2 out of 5 epochs are over
Epoch 3 out of 5 epochs are over
```

```
Epoch 4 out of 5 epochs are over
Epoch 5 out of 5 epochs are over
```

[48]:
```
plt.figure(1)
xtrainloss=np.arange(len(trainingloss list))
plt.plot(xtrainloss,trainingloss list,label="MSE")
plt.plot(xtrainloss,trainingloss list2,label="Cross Entropy")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt.figure(2)
xtestloss=np.arange(len(testlosslist))
plt.plot(xtestloss,testlosslist,label="MSE")
plt.plot(xtestloss,testlosslist2,label="Cross Entropy")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Loss')
plt.title('Validation Loss vs Iterations')
plt.legend()

plt.figure(3)
xbittrain=np.arange(len(correcttestlist))
plt.plot(xbittrain,correcttestlist,label="MSE")
plt.plot(xbittrain,correcttestlist2,label="Cross Entropy")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Bit Accuracy')
plt.title('Validation Bit Accuracy vs Iterations')
plt.legend()


plt.show()
```


Training Loss vs Iterations
MSE
Cross Entropy
Training Loss
Iterations
0
2
4
6
8
0
200
400
600
800
1000
1200


Validation Loss vs Iterations
MSE
Cross Entropy
Validation Loss
Iterations
0.00
0.05
0.10
0.15
0.20
0.25
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Validation Bit Accuracy vs Iterations
MSE
Cross Entropy
Validation Bit Accuracy
0.65
0.60
0.55
0.50
0.45
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Iterations

[48]:

[48]:

[48]:

[48]: