MLP_PYTORCH2

September 9, 2023

Necessary Imports

[2]:
```
import torch
import numpy as np
from torchvision import datasets
import torchvision.transforms as transforms
from torch.utils.data.sampler import SubsetRandomSampler
import torch.nn as nn
import torch.optim as optim
import torch.nn.functional as F
from sklearn.metrics import confusion_matrix
import matplotlib.pyplot as plt
import seaborn as sns

!pip install -Uqq ipdb
import ipdb
```

```
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7.8 MB/s eta 0:00:00
```

Selecting the device

[3]:
```
if torch.cuda.is_available():
    device = torch.device('cuda')
else:
    device = torch.device('cpu')
device = torch.device('cpu')
```

The Neural Network

[4]:
```
# define NN architecture
class Net(nn.Module):
    def __init__(self, input_dim, output_dim, hidden_layer_dimensions, dropout):

        super(Net,self).__init__()

        # number of hidden nodes in each layer (512)
```

```
        self.dropout = nn.Dropout(dropout)
        self.input_dim = input_dim
        self.output_dim = output_dim

        self.d_layer = [input_dim] + hidden_layer_dimensions + [output_dim]
        layer_list = [nn.Linear(self.d_layer[l], self.d_layer[l+1]) for l in␣
↪range(len(self.d_layer) - 1)]
        self.linears = nn.ModuleList(layer_list)



    def forward(self,X):

        X = X.view(-1, self.input_dim)
        # relu(Wl x) for all hidden layer
        for layer in self.linears[:-1]:
            X = F.relu(layer(X))
            X = self.dropout(X)
        # softmax(Wl x) for output layer
        out = self.linears[-1](X)
        return F.log_softmax(out, dim=1)
```

Class to perform opertaions on the neural network

[5]:
```
%pdb on
class Classifier:

  #def __init__(self):
    #model = Net()


  def load_data(self, batch_size = 64):
    # prepare data loaders

    # how many samples per batch to load
    self.batch_size = batch_size
    # percentage of training set to use as validation
    valid_size = 0.2
    # convert data to torch.FloatTensor
    transform = transforms.ToTensor()


    # choose the training and testing datasets
    train_validation_data = datasets.MNIST(root = 'data', train = True,␣
↪download = True, transform = transform)
    self.test_data = datasets.MNIST(root = 'data', train = False, download =␣
↪True, transform = transform)
```

```
    # obtain training indices that will be used for validation
    num_train_validation = len(train_validation_data)
    self.num_test = len(self.test_data)


    indices = list(range(num_train_validation))
    np.random.shuffle(indices)
    split = int(np.floor(valid_size * num_train_validation))

    train_index, valid_index = indices[split:], indices[:split]

    # define samplers for obtaining training and validation batches
    train_sampler = SubsetRandomSampler(train_index)
    valid_sampler = SubsetRandomSampler(valid_index)

    # prepare data loaders
    self.train_loader = torch.utils.data.DataLoader(train_validation_data,␣
↪batch_size = batch_size,
                                              sampler = train_sampler,␣
↪num_workers = 0)
    self.valid_loader = torch.utils.data.DataLoader(train_validation_data,␣
↪batch_size = batch_size,
                                              sampler = valid_sampler,␣
↪num_workers = 0)
    self.test_loader = torch.utils.data.DataLoader(self.test_data, batch_size =␣
↪batch_size,
                                            num_workers = 0)



    self.image_height = self.test_data[0][0].shape[1]
    self.image_width = self.test_data[0][0].shape[2]

    self.input_dim = self.image_height * self.image_width

    self.output_dim = np.unique(self.test_data.targets).shape[0]

    print("data loaded")



  def create_model(self, opt = "adam", weight_decay = 0.001, learning_rate = 0.
↪01, beta1 = 0.9, beta2 = 0.999, epsilon = 1e-8,hidden_layer_dimensions =␣
↪[500, 250, 100], dropout = 0.2):
```

```
        self.model = Net(self.input_dim, self.output_dim, hidden_layer_dimensions,␣
↪dropout).to(device)
        self.optimizers = {"sgd" : optim.SGD(self.model.parameters(), lr =␣
↪learning_rate, momentum = 0.5, weight_decay = weight_decay),
                           "adam" : optim.Adam(self.model.parameters(), lr =␣
↪learning_rate, betas = [beta1, beta2], eps = epsilon)}
        self.optimizer = self.optimizers[opt]

        print(self.model)

    def train_model(self, criterion = nn.NLLLoss() ,epochs = 15, log_interval =␣
↪200):

        losses, accuracies = dict(train = [], val = []), dict(train=[], val = [])

        for epoch in range(epochs):

            #train phase
            self.model.train() #set the model in training mode
            train_loss = 0.0
            train_corrects = 0
            total = 0

            for batchTrain, (images, labels) in enumerate(self.train_loader):
                train_loss = 0.0
                train_corrects = 0


                images = images.to(device)
                labels = labels.to(device)
                total = len(labels)
                # print(images.shape)

                self.optimizer.zero_grad()

                with torch.set_grad_enabled(True):
                    outputs = self.model(images)
                    _, preds = torch.max(outputs, 1)
                    # print(outputs.device)
                    # print(labels.device)
                    # print(outputs)
                    loss = criterion(outputs, labels)

                    # backward + optimize only if in training phase
                    loss.backward()
                    self.optimizer.step()
```

```
        train_loss += loss.item() * images.size(0)
        train_corrects += torch.sum(preds == labels.data)

      if(batchTrain % log_interval == 0):
        losses["train"].append(train_loss/total)
        accuracies["train"].append(train_corrects/total)


      validation_loss = 0
      validation_corrects = 0
      total = 0

      for batchValidation, (images, labels) in enumerate(self.valid_loader):

        images = images.to(device)
        labels = labels.to(device)

        total += len(images)
        self.model.eval()


        with torch.set_grad_enabled(False):
          outputs = self.model(images)
          _, preds = torch.max(outputs, 1)
          loss = criterion(outputs, labels)

          validation_loss += loss.item() * images.size(0)
          validation_corrects += torch.sum(preds == labels.data)

      if(batchTrain % log_interval == 0):
        losses["val"].append(validation_loss/total)
        accuracies["val"].append(validation_corrects/total)

  return losses, accuracies

def plotConfusionMatrix(self, yTrue, yPred):
  # Create a heatmap of the confusion matrix
  confusion_mat = confusion_matrix(yTrue, yPred)
  plt.figure(figsize=(8, 6))
  sns.heatmap(confusion_mat, annot=True, fmt="d", cmap="Blues")
  plt.xlabel("Predicted")
  plt.ylabel("True")
  plt.title("Confusion Matrix")
  plt.show()

def test_model(self, criterion = nn.NLLLoss(), log_interval = 200):
```

```
    self.model.eval()
    test_loss = 0
    test_corrects = 0
    yPred = []
    yTrue = []
    total = 0

    for batchTest, (images, labels) in enumerate(self.test_loader):

      images = images.to(device)
      labels = labels.to(device)
      yTrue += labels

      total += len(images)

      with torch.set_grad_enabled(False):
        outputs = self.model(images)
        _, preds = torch.max(outputs, 1)
        yPred += preds
        loss = criterion(outputs, labels)

        test_loss += loss.item() * images.size(0)
        test_corrects += torch.sum(preds == labels.data)


    self.plotConfusionMatrix(yTrue, yPred)
    return (test_loss/total, test_corrects/total)
```

```
Automatic pdb calling has been turned ON
```

[6]:
```
def experiment(exp_id, batch_size = 64,opt = "sgd", weight_decay = 0.0,␣
 ↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.0, epochs = 15,␣
 ↪log_interval = 200):

  print("experiment ", exp_id, "started")
  c = Classifier()
  c.load_data(batch_size = batch_size)
  c.create_model(opt = opt, weight_decay = weight_decay,␣
 ↪hidden_layer_dimensions = hidden_layer_dimensions, dropout = dropout)
  (trainLosses, accuracies) = c.train_model(epochs = epochs, log_interval =␣
 ↪log_interval)

  (test_loss, test_accuracy) = c.test_model()

  plt.title("Train & validation losses vs epochs")
  plt.plot(np.linspace(0, len(trainLosses["train"])-1,␣
 ↪len(trainLosses["train"])), trainLosses["train"], label = "train losses")
```

```
plt.plot(np.linspace(0, len(trainLosses["val"])-1, len(trainLosses["val"])),
↪trainLosses["val"], label = "validation losses")
plt.show()
plt.title("Train & validation accuracies vs epochs")
plt.plot(np.linspace(0, len(accuracies["train"])-1,
↪len(accuracies["train"])), accuracies["train"], label = "train accuracies")
plt.plot(np.linspace(0, len(accuracies["val"])-1, len(accuracies["val"])),
↪accuracies["val"],label = "validation accuracies")
plt.legend()
plt.show()

print("test loss is: ", test_loss)
print("test accuracy is: ", test_accuracy)
print("experiment: ", exp_id, " completed")
```

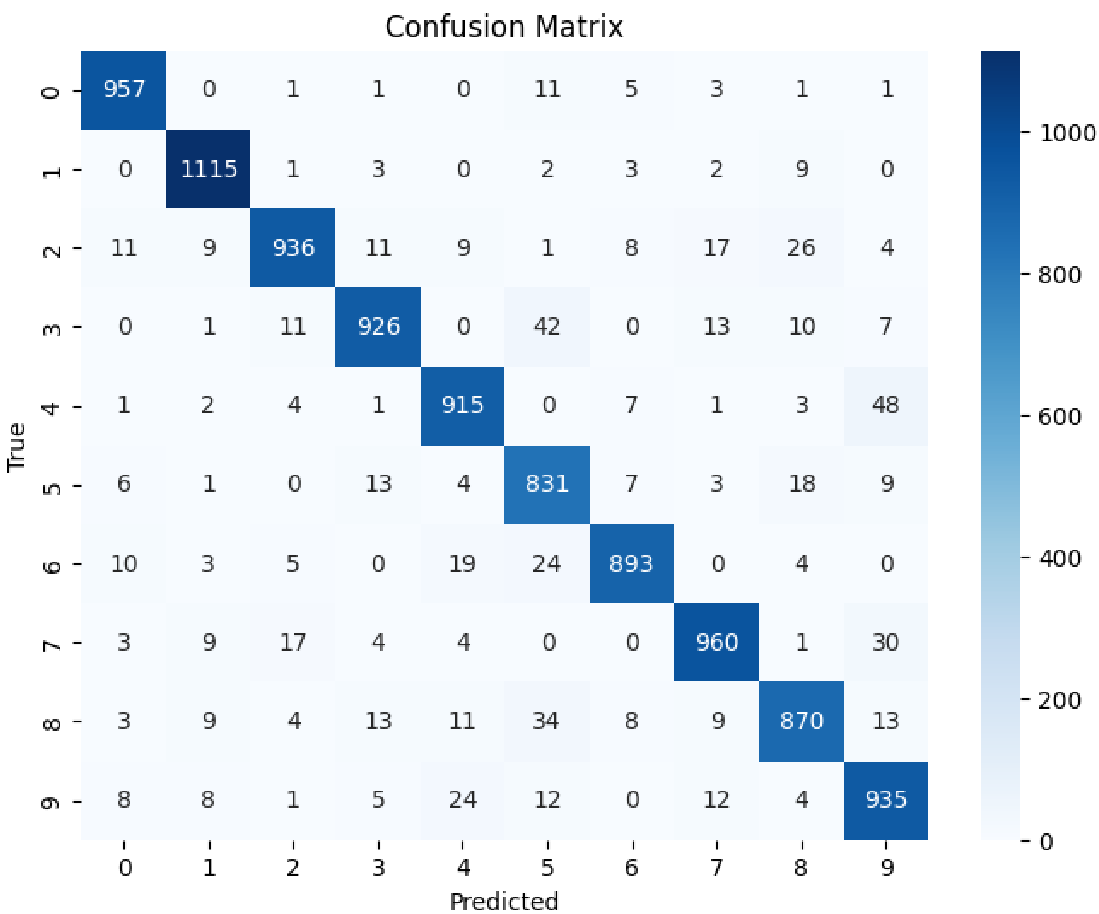
Experimenting the performance with different parameters.

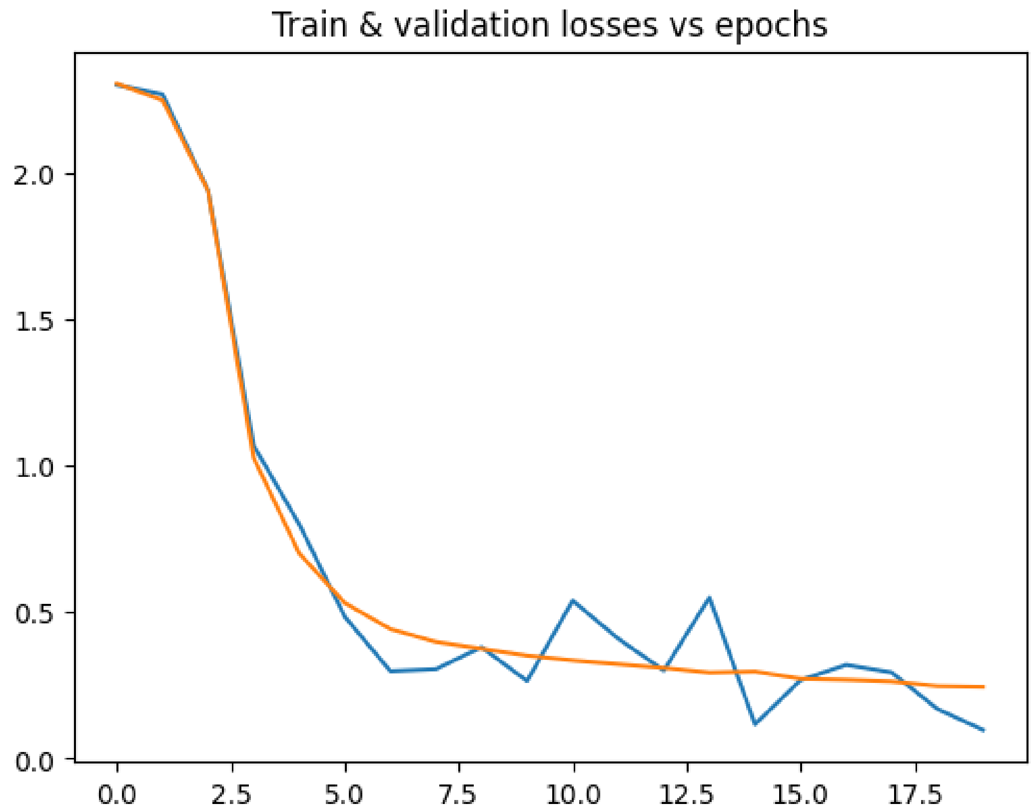
Experiment: With best performing configuration in The Neural Network written from scratch, Obtaining an accuracy of 93% in 5 epochs

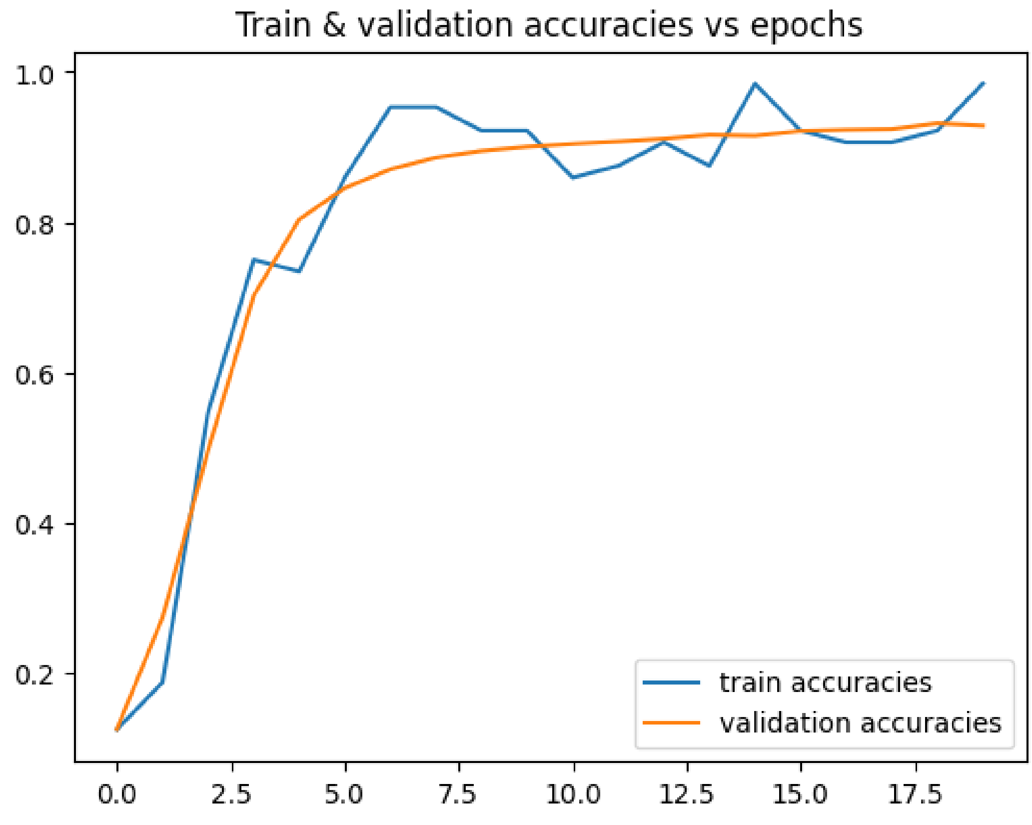
[7]:
```
#experiment : best performance from the Neural Network written from scratch
↪mimicked
experiment(exp_id = 1, batch_size = 64,opt = "sgd", weight_decay = 0.0,
↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.0, epochs = 5,
↪log_interval = 200)
```

```
experiment  1 started
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.gz

100%|      | 9912422/9912422 [00:00<00:00, 72603701.89it/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.gz

100%|      | 28881/28881 [00:00<00:00, 26588168.09it/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, 23077818.44it/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, 13322048.09it/s]

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

data loaded
Net(
  (dropout): Dropout(p=0.0, inplace=False)
  (linears): ModuleList(
    (0): Linear(in_features=784, out_features=500, bias=True)
    (1): Linear(in_features=500, out_features=250, bias=True)
    (2): Linear(in_features=250, out_features=100, bias=True)
    (3): Linear(in_features=100, out_features=10, bias=True)
  )
)
```




Train & validation losses vs epochs
2.0
1.5
1.0
0.5
0.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5



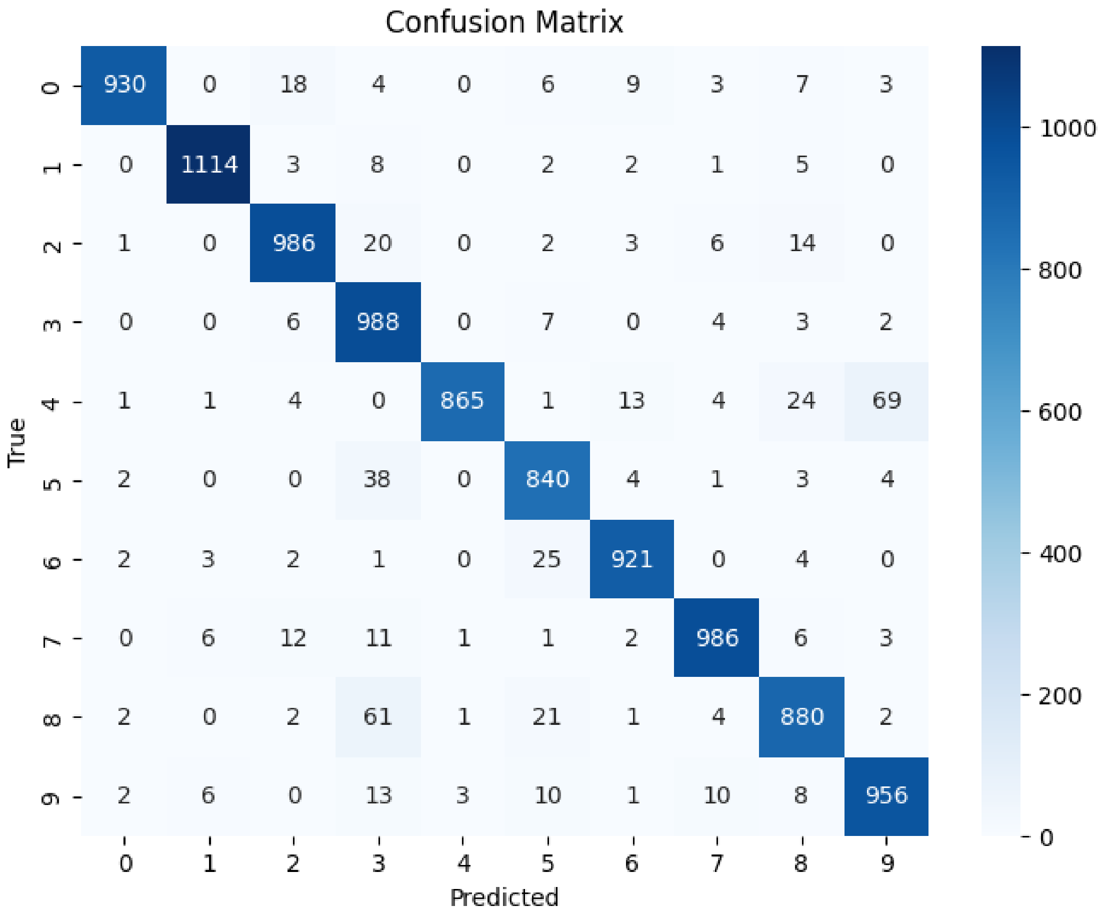

```
test loss is:  0.22002335015535354
test accuracy is:  tensor(0.9338)
experiment:  1  completed
```

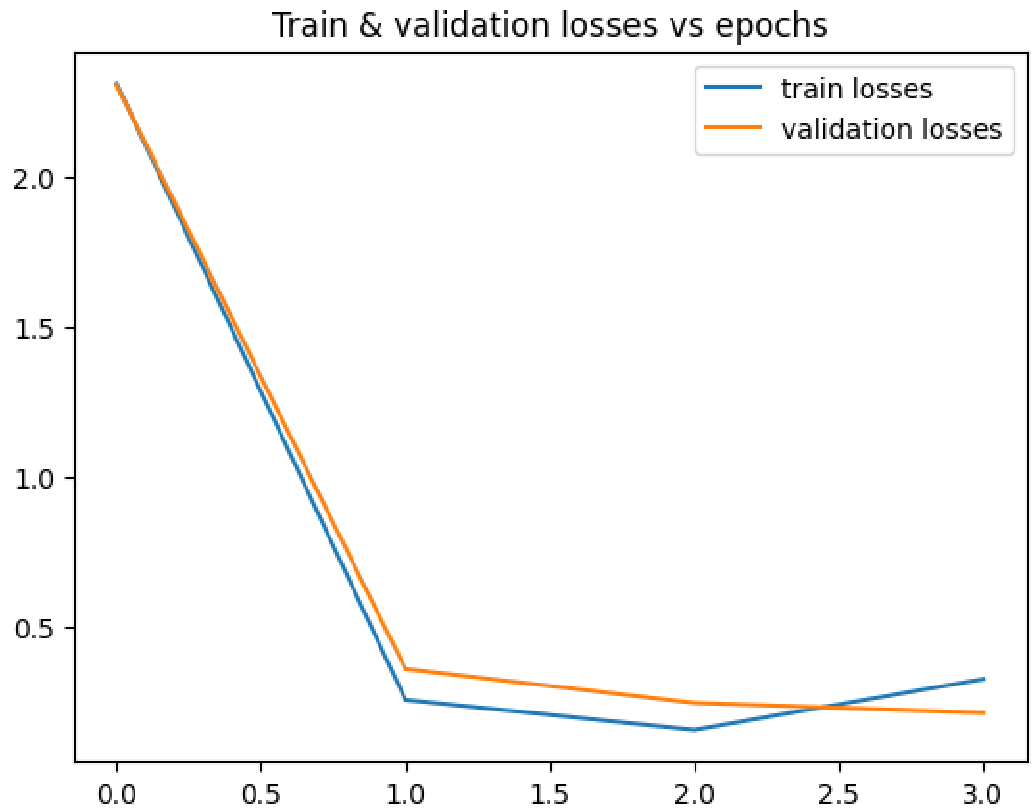
Using Adam optimizer: the obtained accuracy is 94.6% on test data

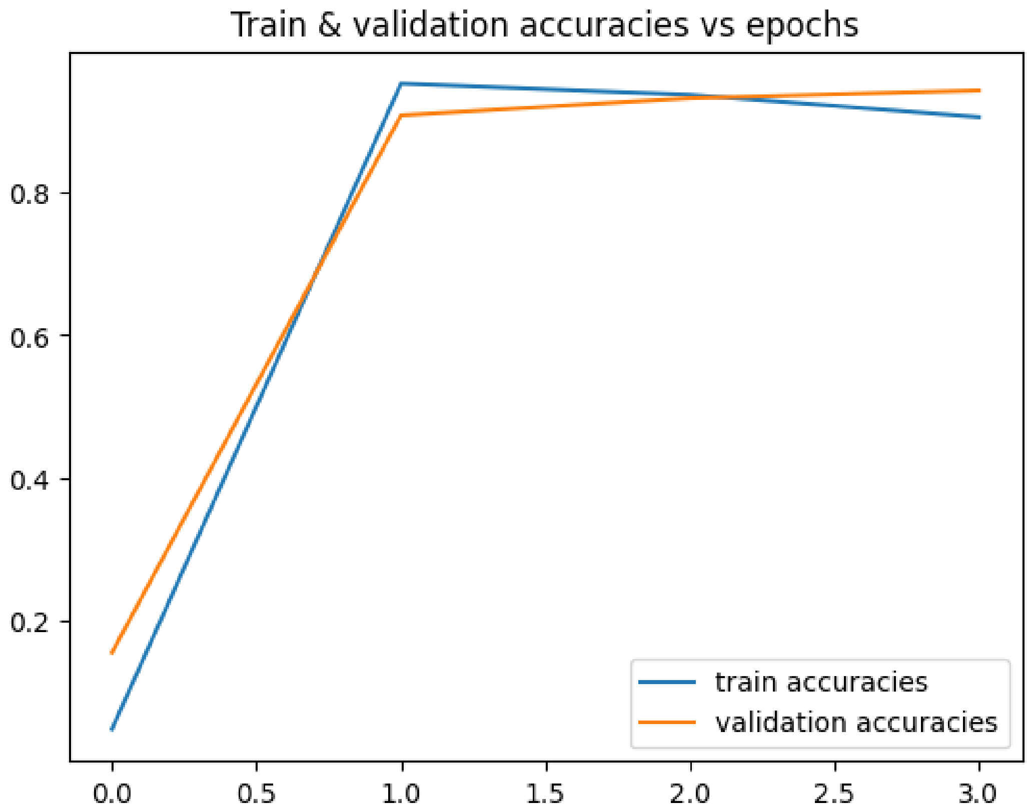
```
[ ]: #experiment : using adam optimizer
experiment(exp_id = 2, batch_size = 64, opt = "adam", weight_decay = 0.0,␣
 ↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.0, epochs = 15,␣
 ↪log_interval = 200)
```

```
experiment  2 started
data loaded
Net(
  (dropout): Dropout(p=0.0, inplace=False)
  (linears): ModuleList(
    (0): Linear(in_features=784, out_features=500, bias=True)
    (1): Linear(in_features=500, out_features=250, bias=True)
    (2): Linear(in_features=250, out_features=100, bias=True)
    (3): Linear(in_features=100, out_features=10, bias=True)
  )
)
```

1
0


Confusion Matrix
True
Predicted
0 1 2 3 4 5 6 7 8 9
930 0 18 4 0 6 9 3 7 3
0 1114 3 8 0 2 2 1 5 0
1 0 986 20 0 2 3 6 14 0
0 0 6 988 0 7 0 4 3 2
1 1 4 0 865 1 13 4 24 69
2 0 0 38 0 840 4 1 3 4
2 3 2 1 0 25 921 0 4 0
0 6 12 11 1 1 2 986 6 3
2 0 2 61 1 21 1 4 880 2
2 6 0 13 3 10 1 10 8 956
1000
800
600
400
200
0


Train & validation losses vs epochs
train losses
validation losses
2.0
1.5
1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0



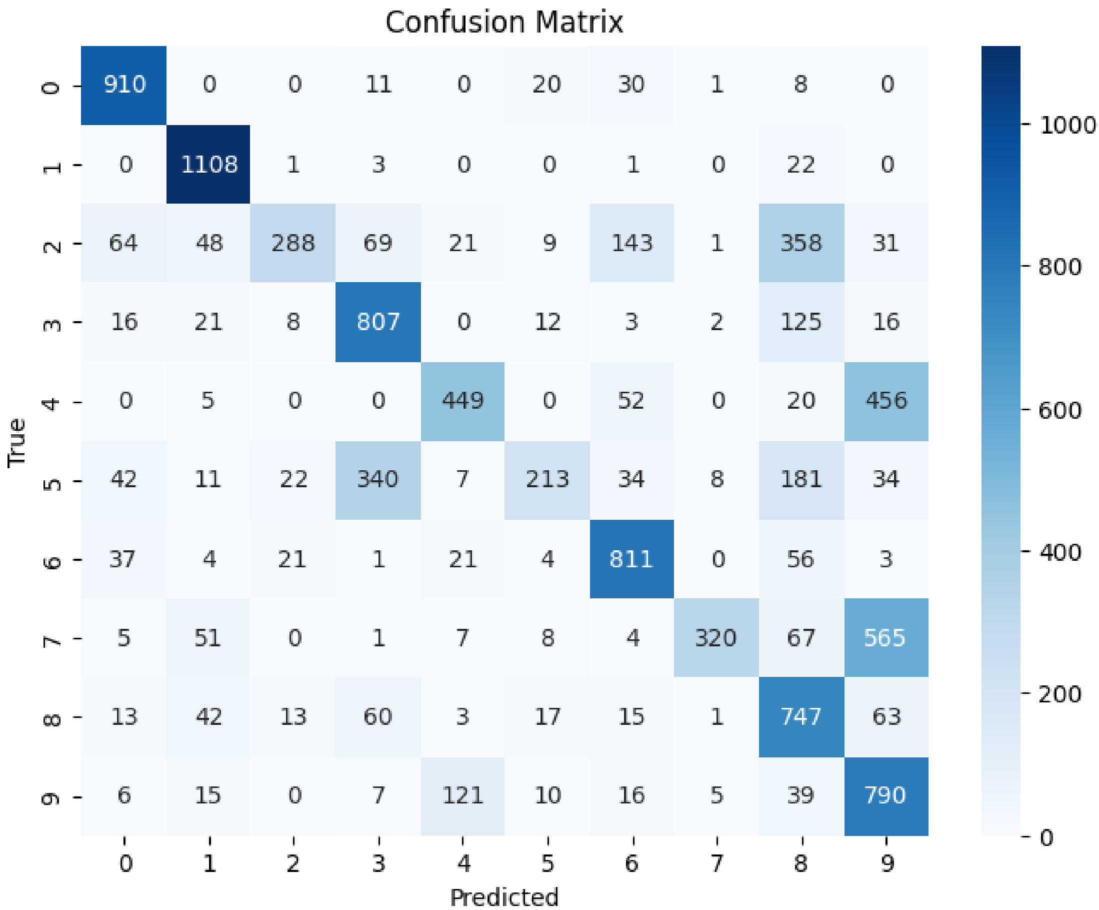

```
test loss is:  0.19614677001610398
test accuracy is:  tensor(0.9466)
experiment:  2  completed
```

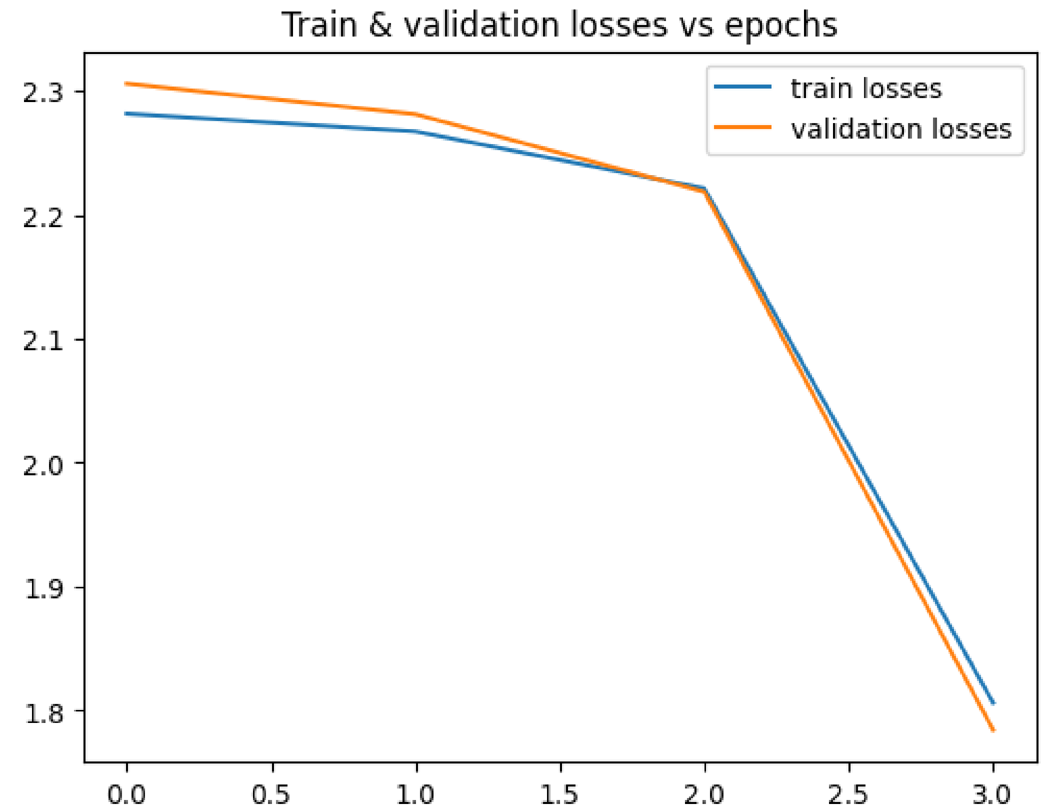
Experiment: Using sgd as optimizer, and l2 regularizer Obtained Accuracy: 64%

[ ]:
```
#experiment : using l2 regularizer
experiment(exp_id = 3, batch_size = 64, opt = "sgd", weight_decay = 0.01,␣
 ↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.0, epochs = 15,␣
 ↪log_interval = 200)
```

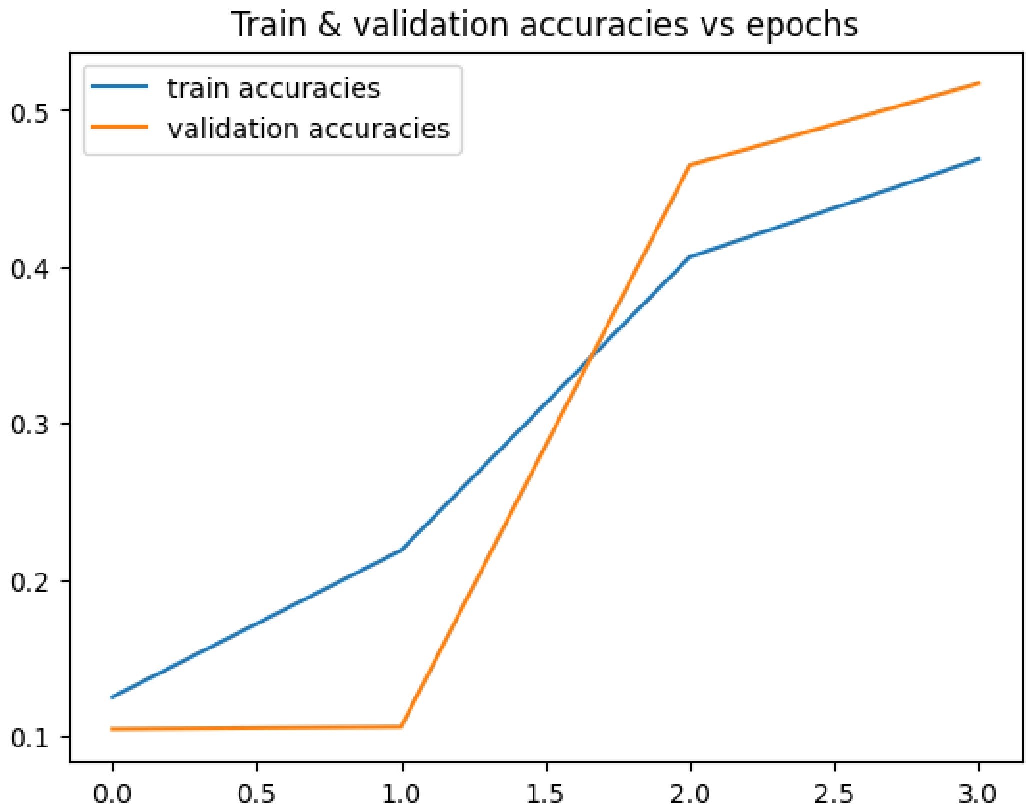
```
experiment  3 started
data loaded
Net(
  (dropout): Dropout(p=0.0, inplace=False)
  (linears): ModuleList(
    (0): Linear(in_features=784, out_features=500, bias=True)
    (1): Linear(in_features=500, out_features=250, bias=True)
    (2): Linear(in_features=250, out_features=100, bias=True)
    (3): Linear(in_features=100, out_features=10, bias=True)
  )
)
```

1
0





Train & validation losses vs epochs
train losses
validation losses
2.3
2.2
2.1
2.0
1.9
1.8
0.0
0.5
1.0
1.5
2.0
2.5
3.0



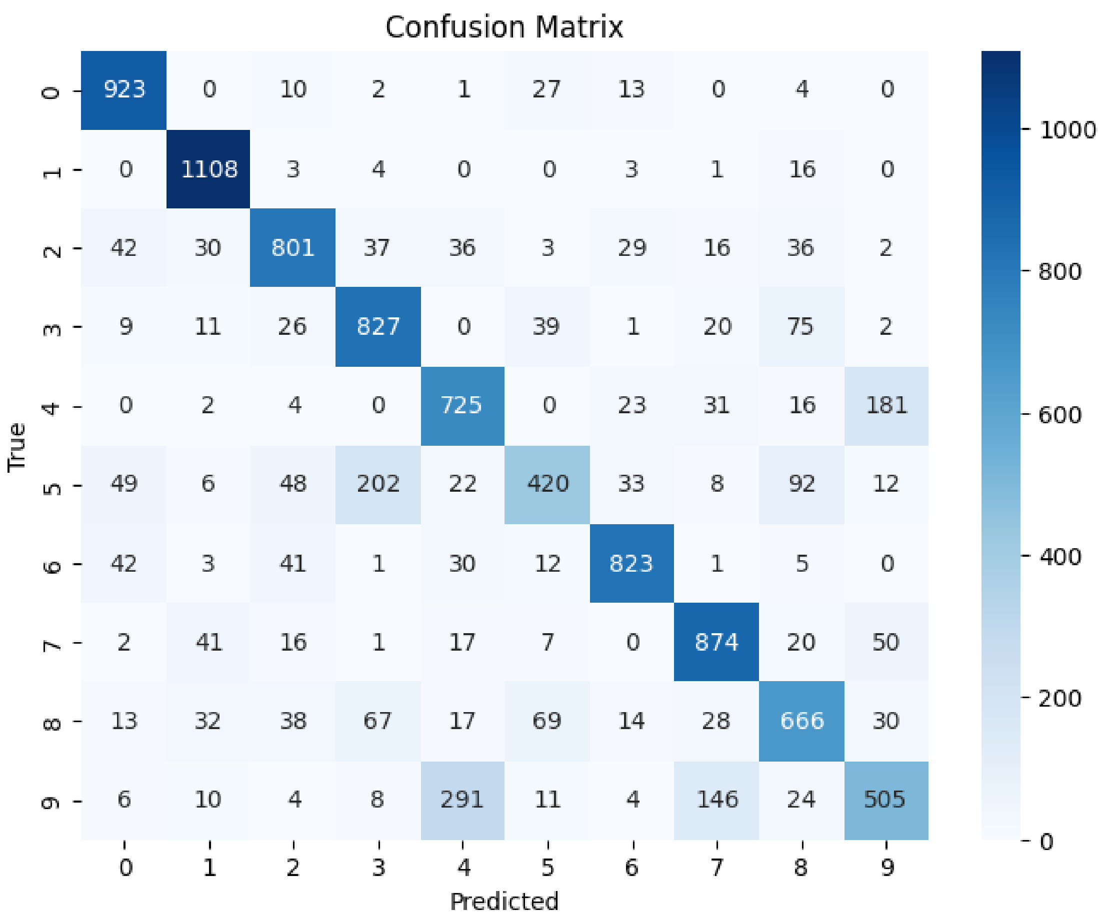

```
test loss is:  1.1016543467521667
test accuracy is:  tensor(0.6443)
experiment:  3  completed
```

Experiment: Using sgd as optimizer and dropout regularizer, Obtained Accuracy: 76%

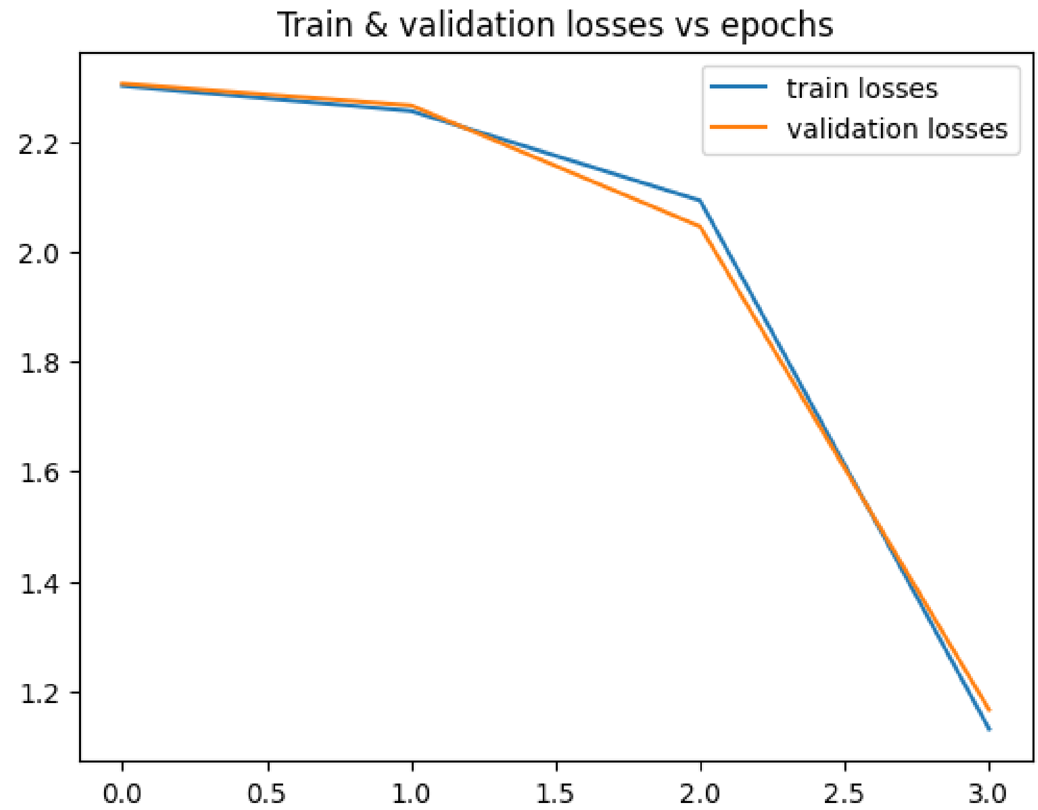
[ ]:
```
#experiment : using dropout
experiment(exp_id = 4, batch_size = 64, opt = "sgd", weight_decay = 0.00,␣
↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.02, epochs = 15,␣
↪log_interval = 200)
```

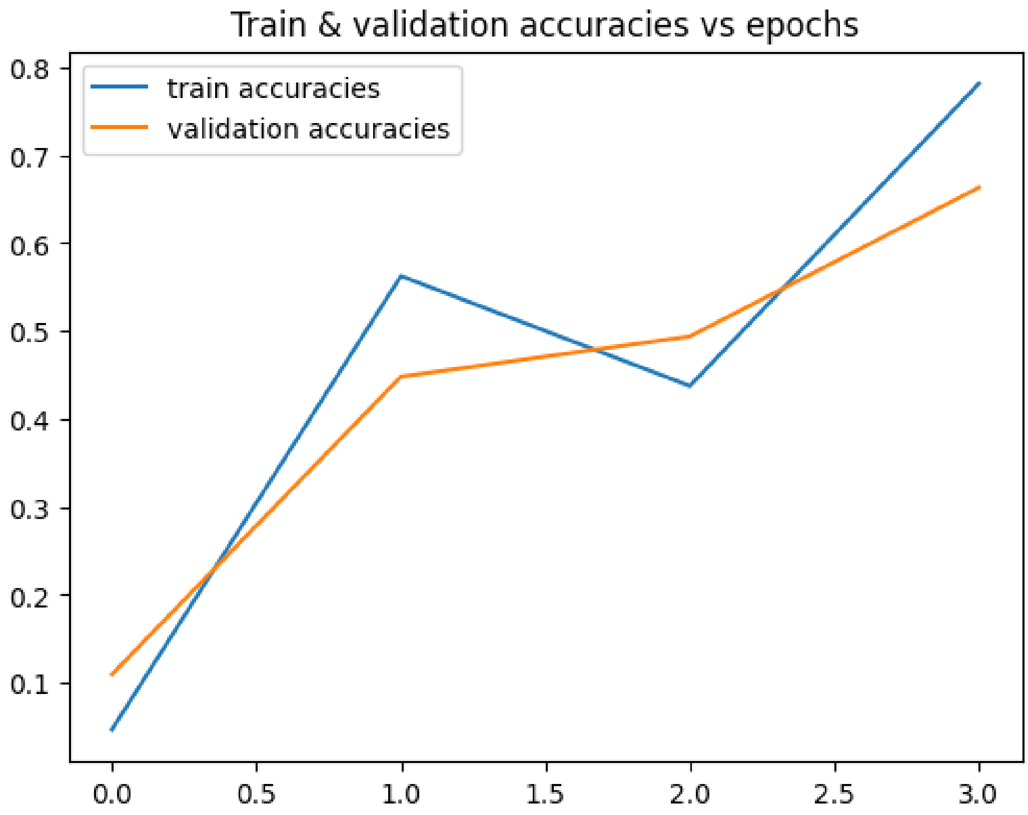
```
experiment  4 started
data loaded
Net(
  (dropout): Dropout(p=0.02, inplace=False)
  (linears): ModuleList(
    (0): Linear(in_features=784, out_features=500, bias=True)
    (1): Linear(in_features=500, out_features=250, bias=True)
    (2): Linear(in_features=250, out_features=100, bias=True)
    (3): Linear(in_features=100, out_features=10, bias=True)
  )
)
```

1
0



Confusion Matrix
True
Predicted
0
1
2
3
4
5
6
7
8
9
923 0 10 2 1 27 13 0 4 0
0 1108 3 4 0 0 3 1 16 0
42 30 801 37 36 3 29 16 36 2
9 11 26 827 0 39 1 20 75 2
0 2 4 0 725 0 23 31 16 181
49 6 48 202 22 420 33 8 92 12
42 3 41 1 30 12 823 1 5 0
2 41 16 1 17 7 0 874 20 50
13 32 38 67 17 69 14 28 666 30
6 10 4 8 291 11 4 146 24 505
1000
800
600
400
200
0


Train & validation losses vs epochs
train losses
validation losses
2.2
2.0
1.8
1.6
1.4
1.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0



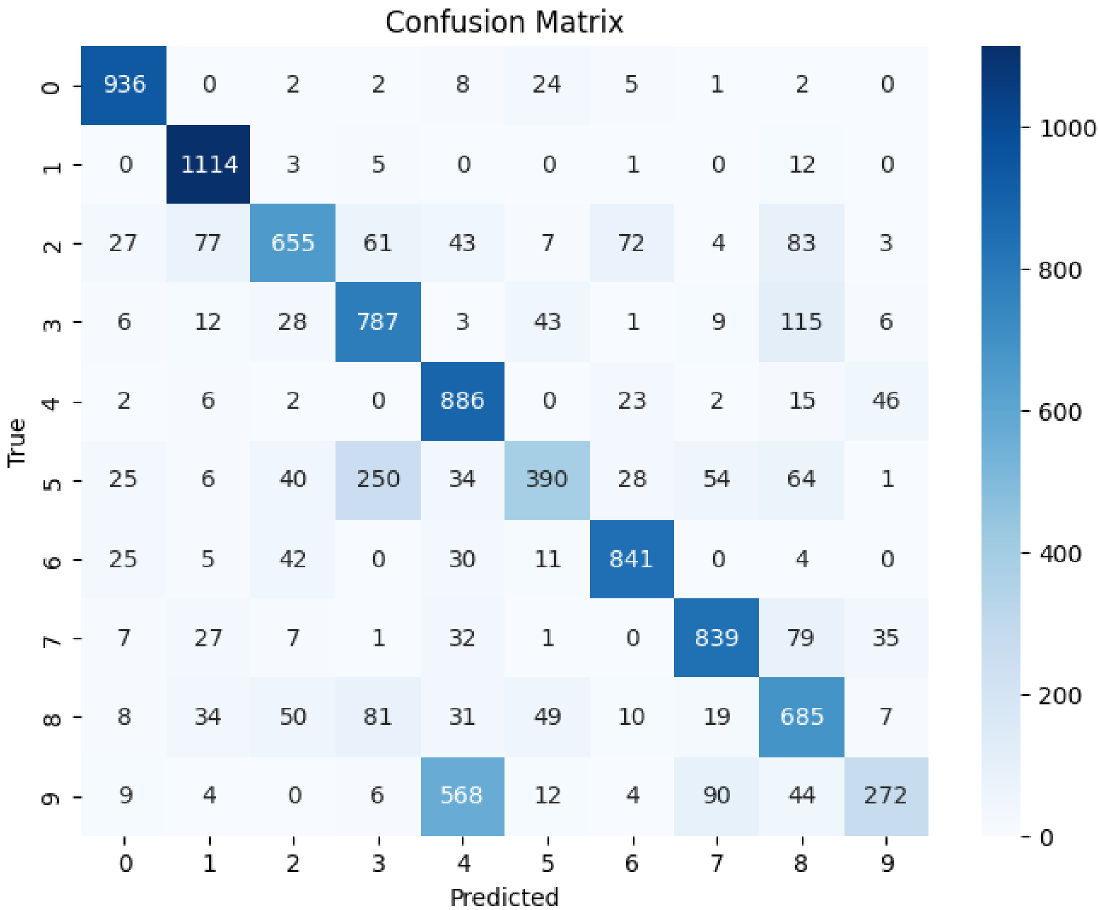

```
test loss is:  0.7571557574272155
test accuracy is:  tensor(0.7672)
experiment:  4  completed
```

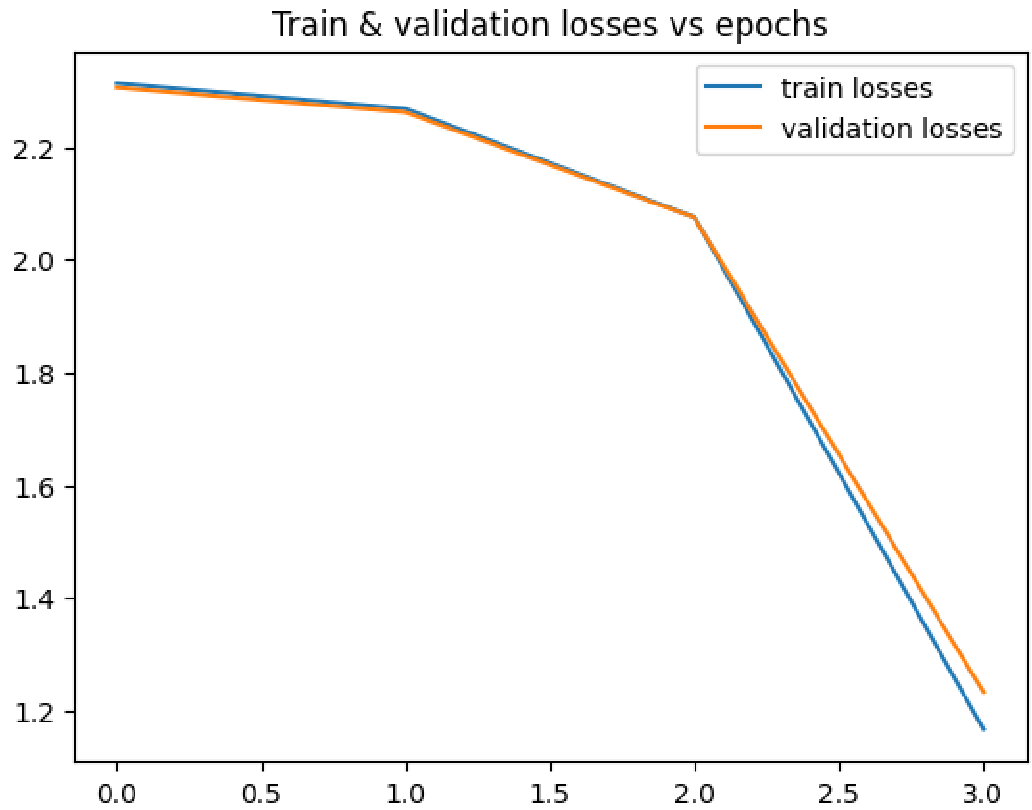
Experiment: Using sgd as optimizer and both dropout and l2 regularizer, Obtained accuracy: 74%

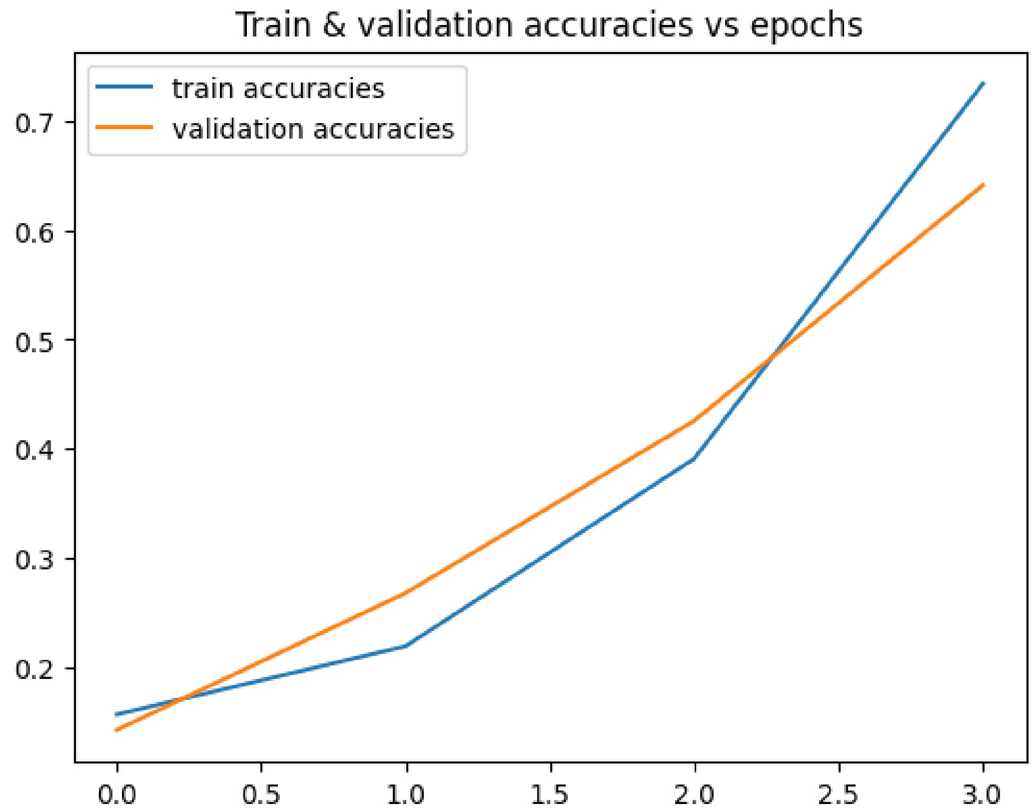
[ ]:
```
#experiment : using both
experiment(exp_id = 5, batch_size = 64, opt = "sgd", weight_decay = 0.01,␣
 ↪hidden_layer_dimensions = [500, 250, 100], dropout = 0.02, epochs = 1,␣
 ↪log_interval = 200)
```

```
experiment  5 started
data loaded
Net(
  (dropout): Dropout(p=0.02, inplace=False)
  (linears): ModuleList(
    (0): Linear(in_features=784, out_features=500, bias=True)
    (1): Linear(in_features=500, out_features=250, bias=True)
    (2): Linear(in_features=250, out_features=100, bias=True)
    (3): Linear(in_features=100, out_features=10, bias=True)
  )
)
```

1
0


Confusion Matrix
True
Predicted
0
1
2
3
4
5
6
7
8
9
1000
800
600
400
200
0


Train & validation losses vs epochs
train losses
validation losses
2.2
2.0
1.8
1.6
1.4
1.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0




```
test loss is:  0.8179346004486084
test accuracy is:  tensor(0.7405)
experiment:  5  completed
```

Observation: The SGD and Adam performs realitively very similar i.e the accuracy difference is lower. But performance with use of regilarizers and optimizers are not significantly found to be improved.