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2019EE10143
Assignment-3

Part 1A.

In my implementation for NN, I have introduced a lot of flexibility, as follows:

- Number of hidden layers
- Number of units in each layer
- Activation function for each layer: ReLU, Tanh, Sigmoid
    - Last layer has softmax activation
- Learning rate
    - Initial learning rate can be specified
    - User can enable dynamic lr, which changes with epochs
- Number of epochs
- Batch size
- Mode of regularization: Early stopping
    - I skipped L2 as it had been covered in one of the assignments before. I instead focused on a new method of regularization
    - Patience and threshold can also be specified
- Cost function: MSE, SSE, Cross-Entropy
- Number of folds for using a k-folds CV
- Train-Dev-Test split
- Data normalization

This gave my implementation enough flexibility to work in any way that I want it to.
I did not add any data normalization in current set of experiments as the data we were given was already in the range of 0 to 1.

For data splitting, I adopted the following technique:

I first took my training set and split it into 2 parts in ratio 4:1. This gave me 2400 sentences in training data and 600 in testing. Further, I adopted a 5-folds CV in my implementation to get 1920 instances in my final training set and 480 in the development/validation set. I train on my training set, select the best hyperparameters based on the accuracy on my validation set and finally, report the accuracy on my test set

I ran a search for the following hyperparameters:

Epochs = [1, 10, 20, 50]
Learning rate = [0.001, 0.01, 0.1]
Cost_fn = ['mse', 'sse']
Batch_sizes = [1, 10, 100]

I adopted the early stopping for regularization which was true for the entire experiment.
In the models where early stopping did take place, I rechecked by disabling this

parameter, and validated that early stopping does help with the problem of overfitting

Further, I used a dynamic learning rate for the entirety of my executions as I had previously confirmed that these help in faster and better convergence as they make sure model is learnt more initially and as the epochs pass, it gets closer to the minima and should learn slowly so as not to miss the minima.

Note: I could have added more parameters, but on the CPU that I was using (Google Colab, 7~8 times faster than mine), even these were taking more than 10 hours and notebooks on Colab crash after 12 hours or a few hours of inactivity. This restricted my search. Even with these, for epochs=50 and 100, the model was taking more than 40 minutes for 1 iteration and it became impossible to work with these. So many iterations were then done with just 1 validation set

One thing I could have done (And tried as well) was to reduce the number of training instances and reported results on that. However, I noticed that there wasn't much difference among these two and I would still not have been able to incorporate the values that I wanted to. At least, currently the values reflect answers on the entire set.

These are the results that I received (Note: The time includes both training and testing as asked in the assignment):

The first model has following layers:

Layer type: Fully Connected
Input Dimension: 784 Output Dimension: 128
Layer type: Activation Layer
Activation Function: ReLU
Layer type: Fully Connected
Input Dimension: 128 Output Dimension: 10
Layer type: Softmax
Input Dimension: 10

```
--------------------------------------------------
Iteration Number: 1
Number of Epochs: 1
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
```

```
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.089184 | Final loss:0.089184
Fold Number: 2/5
Initial loss:0.092600 | Final loss:0.092600
Fold Number: 3/5
Initial loss:0.092868 | Final loss:0.092868
Fold Number: 4/5
Initial loss:0.092216 | Final loss:0.092216
Fold Number: 5/5
Initial loss:0.092947 | Final loss:0.092947
Mean train accuracy: 11.489583
Mean dev accuracy: 10.625000
Total time taken in 5-folds CV on given set of hyperparameters:
19.214358 seconds

--------------------------------------------------
Iteration Number: 2
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.089157 | Final loss:0.089157
Fold Number: 2/5
Initial loss:0.092313 | Final loss:0.092313
Fold Number: 3/5
Initial loss:0.091435 | Final loss:0.091435
Fold Number: 4/5
Initial loss:0.092364 | Final loss:0.092364
Fold Number: 5/5
Initial loss:0.092222 | Final loss:0.092222
Mean train accuracy: 11.322917
Mean dev accuracy: 11.541667
Total time taken in 5-folds CV on given set of hyperparameters:
18.889737 seconds

--------------------------------------------------
Iteration Number: 3
Number of Epochs: 1
```

```
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.089630 | Final loss:0.089630
Fold Number: 2/5
Initial loss:0.091634 | Final loss:0.091634
Fold Number: 3/5
Initial loss:0.091180 | Final loss:0.091180
Fold Number: 4/5
Initial loss:0.091191 | Final loss:0.091191
Fold Number: 5/5
Initial loss:0.090950 | Final loss:0.090950
Mean train accuracy: 14.343750
Mean dev accuracy: 14.000000
Total time taken in 5-folds CV on given set of hyperparameters:
18.920217 seconds

--------------------------------------------------
Iteration Number: 4
Number of Epochs: 1
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.443631 | Final loss:0.443631
Fold Number: 2/5
Initial loss:0.460160 | Final loss:0.460160
Fold Number: 3/5
Initial loss:0.442526 | Final loss:0.442526
Fold Number: 4/5
Initial loss:0.438810 | Final loss:0.438810
Fold Number: 5/5
Initial loss:0.450914 | Final loss:0.450914
```

```
Mean train accuracy: 24.864583
Mean dev accuracy: 24.625000
Total time taken in 5-folds CV on given set of hyperparameters:
18.785089 seconds

--------------------------------------------------
Iteration Number: 5
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.448467 | Final loss:0.448467
Fold Number: 2/5
Initial loss:0.443328 | Final loss:0.443328
Fold Number: 3/5
Initial loss:0.451519 | Final loss:0.451519
Fold Number: 4/5
Initial loss:0.448825 | Final loss:0.448825
Fold Number: 5/5
Initial loss:0.449321 | Final loss:0.449321
Mean train accuracy: 23.177083
Mean dev accuracy: 23.500000
Total time taken in 5-folds CV on given set of hyperparameters:
18.534141 seconds

--------------------------------------------------
Iteration Number: 6
Number of Epochs: 1
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.454173 | Final loss:0.454173
```

```
Fold Number: 2/5
Initial loss:0.459959 | Final loss:0.459959
Fold Number: 3/5
Initial loss:0.444918 | Final loss:0.444918
Fold Number: 4/5
Initial loss:0.441046 | Final loss:0.441046
Fold Number: 5/5
Initial loss:0.453390 | Final loss:0.453390
Mean train accuracy: 23.000000
Mean dev accuracy: 20.791667
Total time taken in 5-folds CV on given set of hyperparameters:
18.593548 seconds

--------------------------------------------------
Iteration Number: 7
Number of Epochs: 1
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.086340 | Final loss:0.086340
Fold Number: 2/5
Initial loss:0.088661 | Final loss:0.088661
Fold Number: 3/5
Initial loss:0.087401 | Final loss:0.087401
Fold Number: 4/5
Initial loss:0.086940 | Final loss:0.086940
Fold Number: 5/5
Initial loss:0.085239 | Final loss:0.085239
Mean train accuracy: 41.927083
Mean dev accuracy: 40.833333
Total time taken in 5-folds CV on given set of hyperparameters:
19.192737 seconds

--------------------------------------------------
Iteration Number: 8
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
```

```
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.086870 | Final loss:0.086870
Fold Number: 2/5
Initial loss:0.086973 | Final loss:0.086973
Fold Number: 3/5
Initial loss:0.087076 | Final loss:0.087076
Fold Number: 4/5
Initial loss:0.088169 | Final loss:0.088169
Fold Number: 5/5
Initial loss:0.087536 | Final loss:0.087536
Mean train accuracy: 39.760417
Mean dev accuracy: 37.583333
Total time taken in 5-folds CV on given set of hyperparameters:
18.877996 seconds

--------------------------------------------------
Iteration Number: 9
Number of Epochs: 1
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.087619 | Final loss:0.087619
Fold Number: 2/5
Initial loss:0.087288 | Final loss:0.087288
Fold Number: 3/5
Initial loss:0.085798 | Final loss:0.085798
Fold Number: 4/5
Initial loss:0.088445 | Final loss:0.088445
Fold Number: 5/5
Initial loss:0.085861 | Final loss:0.085861
Mean train accuracy: 39.697917
Mean dev accuracy: 39.541667
Total time taken in 5-folds CV on given set of hyperparameters:
18.821635 seconds

--------------------------------------------------
Iteration Number: 10
Number of Epochs: 1
Learning Rate: 0.001
```

```
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.293416 | Final loss:0.293416
Fold Number: 2/5
Initial loss:0.297315 | Final loss:0.297315
Fold Number: 3/5
Initial loss:0.311606 | Final loss:0.311606
Fold Number: 4/5
Initial loss:0.320506 | Final loss:0.320506
Fold Number: 5/5
Initial loss:0.313933 | Final loss:0.313933
Mean train accuracy: 80.395833
Mean dev accuracy: 78.416667
Total time taken in 5-folds CV on given set of hyperparameters:
18.715522 seconds

--------------------------------------------------
Iteration Number: 11
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.309683 | Final loss:0.309683
Fold Number: 2/5
Initial loss:0.301022 | Final loss:0.301022
Fold Number: 3/5
Initial loss:0.318283 | Final loss:0.318283
Fold Number: 4/5
Initial loss:0.328871 | Final loss:0.328871
Fold Number: 5/5
Initial loss:0.297979 | Final loss:0.297979
Mean train accuracy: 78.895833
```

```
Mean dev accuracy: 76.625000
Total time taken in 5-folds CV on given set of hyperparameters:
18.420845 seconds

--------------------------------------------------
Iteration Number: 12
Number of Epochs: 1
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.309502 | Final loss:0.309502
Fold Number: 2/5
Initial loss:0.317175 | Final loss:0.317175
Fold Number: 3/5
Initial loss:0.305725 | Final loss:0.305725
Fold Number: 4/5
Initial loss:0.318600 | Final loss:0.318600
Fold Number: 5/5
Initial loss:0.320567 | Final loss:0.320567
Mean train accuracy: 78.927083
Mean dev accuracy: 75.833333
Total time taken in 5-folds CV on given set of hyperparameters:
18.630308 seconds

--------------------------------------------------
Iteration Number: 13
Number of Epochs: 1
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.048697 | Final loss:0.048697
Fold Number: 2/5
```

```
Initial loss:0.048408 | Final loss:0.048408
Fold Number: 3/5
Initial loss:0.048678 | Final loss:0.048678
Fold Number: 4/5
Initial loss:0.047769 | Final loss:0.047769
Fold Number: 5/5
Initial loss:0.050086 | Final loss:0.050086
Mean train accuracy: 84.479167
Mean dev accuracy: 81.708333
Total time taken in 5-folds CV on given set of hyperparameters:
19.131150 seconds

--------------------------------------------------
Iteration Number: 14
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.049151 | Final loss:0.049151
Fold Number: 2/5
Initial loss:0.049256 | Final loss:0.049256
Fold Number: 3/5
Initial loss:0.049132 | Final loss:0.049132
Fold Number: 4/5
Initial loss:0.047404 | Final loss:0.047404
Fold Number: 5/5
Initial loss:0.048547 | Final loss:0.048547
Mean train accuracy: 84.635417
Mean dev accuracy: 81.625000
Total time taken in 5-folds CV on given set of hyperparameters:
18.947776 seconds

--------------------------------------------------
Iteration Number: 15
Number of Epochs: 1
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
```

```
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.047967 | Final loss:0.047967
Fold Number: 2/5
Initial loss:0.045006 | Final loss:0.045006
Fold Number: 3/5
Initial loss:0.050267 | Final loss:0.050267
Fold Number: 4/5
Initial loss:0.048341 | Final loss:0.048341
Fold Number: 5/5
Initial loss:0.048733 | Final loss:0.048733
Mean train accuracy: 84.729167
Mean dev accuracy: 81.375000
Total time taken in 5-folds CV on given set of hyperparameters:
18.871506 seconds

--------------------------------------------------
Iteration Number: 16
Number of Epochs: 1
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.193662 | Final loss:0.193662
Fold Number: 2/5
Initial loss:0.194130 | Final loss:0.194130
Fold Number: 3/5
Initial loss:0.188523 | Final loss:0.188523
Fold Number: 4/5
Initial loss:0.195295 | Final loss:0.195295
Fold Number: 5/5
Initial loss:0.192649 | Final loss:0.192649
Mean train accuracy: 86.427083
Mean dev accuracy: 83.875000
Total time taken in 5-folds CV on given set of hyperparameters:
18.681968 seconds

--------------------------------------------------
Iteration Number: 17
Number of Epochs: 1
Learning Rate: 0.01
Cost Function used: Sse
```

```
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.195767 | Final loss:0.195767
Fold Number: 2/5
Initial loss:0.191477 | Final loss:0.191477
Fold Number: 3/5
Initial loss:0.192583 | Final loss:0.192583
Fold Number: 4/5
Initial loss:0.187593 | Final loss:0.187593
Fold Number: 5/5
Initial loss:0.190711 | Final loss:0.190711
Mean train accuracy: 87.041667
Mean dev accuracy: 82.541667
Total time taken in 5-folds CV on given set of hyperparameters:
18.504767 seconds

--------------------------------------------------
Iteration Number: 18
Number of Epochs: 1
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.198288 | Final loss:0.198288
Fold Number: 2/5
Initial loss:0.188608 | Final loss:0.188608
Fold Number: 3/5
Initial loss:0.191898 | Final loss:0.191898
Fold Number: 4/5
Initial loss:0.194388 | Final loss:0.194388
Fold Number: 5/5
Initial loss:0.190813 | Final loss:0.190813
Mean train accuracy: 84.968750
Mean dev accuracy: 80.833333
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
18.472997 seconds

--------------------------------------------------
Iteration Number: 19
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.090711 | Final loss:0.083771
Fold Number: 2/5
Initial loss:0.092388 | Final loss:0.088256
Fold Number: 3/5
Initial loss:0.090054 | Final loss:0.085459
Fold Number: 4/5
Initial loss:0.092965 | Final loss:0.087129
Fold Number: 5/5
Initial loss:0.089747 | Final loss:0.082729
Mean train accuracy: 28.031250
Mean dev accuracy: 27.791667
Total time taken in 5-folds CV on given set of hyperparameters:
168.541337 seconds

--------------------------------------------------
Iteration Number: 20
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.090713 | Final loss:0.085337
Fold Number: 2/5
Initial loss:0.091367 | Final loss:0.086650
```

```
Fold Number: 3/5
Initial loss:0.090200 | Final loss:0.085164
Fold Number: 4/5
Initial loss:0.092579 | Final loss:0.085216
Fold Number: 5/5
Initial loss:0.090434 | Final loss:0.085096
Mean train accuracy: 29.979167
Mean dev accuracy: 29.083333
Total time taken in 5-folds CV on given set of hyperparameters:
166.744933 seconds

--------------------------------------------------
Iteration Number: 21
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.091859 | Final loss:0.086099
Fold Number: 2/5
Initial loss:0.091926 | Final loss:0.086962
Fold Number: 3/5
Initial loss:0.091690 | Final loss:0.087408
Fold Number: 4/5
Initial loss:0.092610 | Final loss:0.087948
Fold Number: 5/5
Initial loss:0.091495 | Final loss:0.086993
Mean train accuracy: 24.208333
Mean dev accuracy: 24.250000
Total time taken in 5-folds CV on given set of hyperparameters:
166.406268 seconds

--------------------------------------------------
Iteration Number: 22
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.447325 | Final loss:0.289692
Fold Number: 2/5
Initial loss:0.450968 | Final loss:0.285285
Fold Number: 3/5
Initial loss:0.449127 | Final loss:0.289756
Fold Number: 4/5
Initial loss:0.437152 | Final loss:0.293050
Fold Number: 5/5
Initial loss:0.448444 | Final loss:0.287238
Mean train accuracy: 67.822917
Mean dev accuracy: 66.666667
Total time taken in 5-folds CV on given set of hyperparameters:
163.995844 seconds

--------------------------------------------------
Iteration Number: 23
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.449905 | Final loss:0.275672
Fold Number: 2/5
Initial loss:0.461430 | Final loss:0.317015
Fold Number: 3/5
Initial loss:0.454640 | Final loss:0.326751
Fold Number: 4/5
Initial loss:0.442375 | Final loss:0.276670
Fold Number: 5/5
Initial loss:0.446320 | Final loss:0.292806
Mean train accuracy: 66.250000
Mean dev accuracy: 65.458333
Total time taken in 5-folds CV on given set of hyperparameters:
161.258500 seconds

--------------------------------------------------
Iteration Number: 24
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.445948 | Final loss:0.307689
Fold Number: 2/5
Initial loss:0.442789 | Final loss:0.312842
Fold Number: 3/5
Initial loss:0.442895 | Final loss:0.294331
Fold Number: 4/5
Initial loss:0.433873 | Final loss:0.260888
Fold Number: 5/5
Initial loss:0.455069 | Final loss:0.307590
Mean train accuracy: 66.437500
Mean dev accuracy: 66.125000
Total time taken in 5-folds CV on given set of hyperparameters:
160.470956 seconds

--------------------------------------------------
Iteration Number: 25
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.085488 | Final loss:0.034306
Fold Number: 2/5
Initial loss:0.086529 | Final loss:0.036729
Fold Number: 3/5
Initial loss:0.085166 | Final loss:0.034574
Fold Number: 4/5
Initial loss:0.086059 | Final loss:0.033066
Fold Number: 5/5
Initial loss:0.087036 | Final loss:0.034895
Mean train accuracy: 82.906250
Mean dev accuracy: 80.583333
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
167.488438 seconds

--------------------------------------------------
Iteration Number: 26
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.086225 | Final loss:0.037161
Fold Number: 2/5
Initial loss:0.085321 | Final loss:0.034208
Fold Number: 3/5
Initial loss:0.087323 | Final loss:0.043747
Fold Number: 4/5
Initial loss:0.087391 | Final loss:0.033151
Fold Number: 5/5
Initial loss:0.087301 | Final loss:0.038045
Mean train accuracy: 80.583333
Mean dev accuracy: 77.583333
Total time taken in 5-folds CV on given set of hyperparameters:
165.857730 seconds

--------------------------------------------------
Iteration Number: 27
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.083800 | Final loss:0.035450
Fold Number: 2/5
Initial loss:0.088626 | Final loss:0.037390
```

```
Fold Number: 3/5
Initial loss:0.085564 | Final loss:0.033351
Fold Number: 4/5
Initial loss:0.088148 | Final loss:0.035110
Fold Number: 5/5
Initial loss:0.087609 | Final loss:0.037893
Mean train accuracy: 82.218750
Mean dev accuracy: 80.291667
Total time taken in 5-folds CV on given set of hyperparameters:
165.353906 seconds

--------------------------------------------------
Iteration Number: 28
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.309262 | Final loss:0.063550
Fold Number: 2/5
Initial loss:0.325084 | Final loss:0.062349
Fold Number: 3/5
Initial loss:0.291381 | Final loss:0.061152
Fold Number: 4/5
Initial loss:0.318046 | Final loss:0.063188
Fold Number: 5/5
Initial loss:0.298222 | Final loss:0.062895
Mean train accuracy: 93.927083
Mean dev accuracy: 88.666667
Total time taken in 5-folds CV on given set of hyperparameters:
163.332933 seconds

--------------------------------------------------
Iteration Number: 29
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.310195 | Final loss:0.060118
Fold Number: 2/5
Initial loss:0.314623 | Final loss:0.061337
Fold Number: 3/5
Initial loss:0.309724 | Final loss:0.063225
Fold Number: 4/5
Initial loss:0.298862 | Final loss:0.061782
Fold Number: 5/5
Initial loss:0.296141 | Final loss:0.063179
Mean train accuracy: 94.104167
Mean dev accuracy: 88.583333
Total time taken in 5-folds CV on given set of hyperparameters:
162.035336 seconds

--------------------------------------------------
Iteration Number: 30
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.323202 | Final loss:0.062377
Fold Number: 2/5
Initial loss:0.322857 | Final loss:0.062232
Fold Number: 3/5
Initial loss:0.301145 | Final loss:0.063302
Fold Number: 4/5
Initial loss:0.322247 | Final loss:0.063759
Fold Number: 5/5
Initial loss:0.298618 | Final loss:0.062563
Mean train accuracy: 93.729167
Mean dev accuracy: 88.583333
Total time taken in 5-folds CV on given set of hyperparameters:
161.641979 seconds

--------------------------------------------------
Iteration Number: 31
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.048716 | Final loss:0.008250
Fold Number: 2/5
Initial loss:0.048349 | Final loss:0.008475
Fold Number: 3/5
Initial loss:0.049554 | Final loss:0.008093
Fold Number: 4/5
Initial loss:0.050945 | Final loss:0.008084
Fold Number: 5/5
Initial loss:0.049928 | Final loss:0.008425
Mean train accuracy: 96.291667
Mean dev accuracy: 89.541667
Total time taken in 5-folds CV on given set of hyperparameters:
168.239070 seconds

--------------------------------------------------
Iteration Number: 32
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.047079 | Final loss:0.007771
Fold Number: 2/5
Initial loss:0.047099 | Final loss:0.008233
Fold Number: 3/5
Initial loss:0.048829 | Final loss:0.008520
Fold Number: 4/5
Initial loss:0.052008 | Final loss:0.008691
Fold Number: 5/5
Initial loss:0.046940 | Final loss:0.008638
Mean train accuracy: 96.125000
Mean dev accuracy: 89.500000
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
167.005935 seconds

--------------------------------------------------
Iteration Number: 33
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.044595 | Final loss:0.008000
Fold Number: 2/5
Initial loss:0.051683 | Final loss:0.008199
Fold Number: 3/5
Initial loss:0.050208 | Final loss:0.008270
Fold Number: 4/5
Initial loss:0.048391 | Final loss:0.008408
Fold Number: 5/5
Initial loss:0.051770 | Final loss:0.008499
Mean train accuracy: 96.239583
Mean dev accuracy: 89.500000
Total time taken in 5-folds CV on given set of hyperparameters:
166.049908 seconds

--------------------------------------------------
Iteration Number: 34
Number of Epochs: 10
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.192039 | Final loss:0.010876
Fold Number: 2/5
Initial loss:0.192555 | Final loss:0.011648
```

```
Fold Number: 3/5
Initial loss:0.197304 | Final loss:0.011339
Fold Number: 4/5
Initial loss:0.192065 | Final loss:0.010159
Fold Number: 5/5
Initial loss:0.188796 | Final loss:0.012147
Mean train accuracy: 98.750000
Mean dev accuracy: 91.791667
Total time taken in 5-folds CV on given set of hyperparameters:
164.246516 seconds

--------------------------------------------------
Iteration Number: 35
Number of Epochs: 10
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.185720 | Final loss:0.010880
Fold Number: 2/5
Initial loss:0.191188 | Final loss:0.013088
Fold Number: 3/5
Initial loss:0.193368 | Final loss:0.011042
Fold Number: 4/5
Initial loss:0.192199 | Final loss:0.011842
Fold Number: 5/5
Initial loss:0.191095 | Final loss:0.011176
Mean train accuracy: 98.739583
Mean dev accuracy: 91.500000
Total time taken in 5-folds CV on given set of hyperparameters:
162.919835 seconds

--------------------------------------------------
Iteration Number: 36
Number of Epochs: 10
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.187583 | Final loss:0.009650
Fold Number: 2/5
Initial loss:0.191432 | Final loss:0.010623
Fold Number: 3/5
Initial loss:0.193160 | Final loss:0.011209
Fold Number: 4/5
Initial loss:0.196299 | Final loss:0.010835
Fold Number: 5/5
Initial loss:0.190077 | Final loss:0.012586
Mean train accuracy: 98.875000
Mean dev accuracy: 92.000000
Total time taken in 5-folds CV on given set of hyperparameters:
162.088841 seconds

--------------------------------------------------
Iteration Number: 37
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.092636 | Final loss:0.084300
Fold Number: 2/5
Initial loss:0.094182 | Final loss:0.085130
Fold Number: 3/5
Initial loss:0.091956 | Final loss:0.085217
Fold Number: 4/5
Initial loss:0.092082 | Final loss:0.084438
Fold Number: 5/5
Initial loss:0.091424 | Final loss:0.084035
Mean train accuracy: 30.656250
Mean dev accuracy: 31.041667
Total time taken in 5-folds CV on given set of hyperparameters:
335.102888 seconds

--------------------------------------------------
Iteration Number: 38
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.090344 | Final loss:0.082353
Fold Number: 2/5
Initial loss:0.092931 | Final loss:0.085410
Fold Number: 3/5
Initial loss:0.090679 | Final loss:0.083226
Fold Number: 4/5
Initial loss:0.091556 | Final loss:0.083163
Fold Number: 5/5
Initial loss:0.090784 | Final loss:0.083164
Mean train accuracy: 31.489583
Mean dev accuracy: 31.666667
Total time taken in 5-folds CV on given set of hyperparameters:
331.299529 seconds

--------------------------------------------------
Iteration Number: 39
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.090357 | Final loss:0.080398
Fold Number: 2/5
Initial loss:0.091560 | Final loss:0.084536
Fold Number: 3/5
Initial loss:0.093416 | Final loss:0.085669
Fold Number: 4/5
Initial loss:0.090522 | Final loss:0.081221
Fold Number: 5/5
Initial loss:0.091122 | Final loss:0.082416
Mean train accuracy: 33.885417
Mean dev accuracy: 32.333333
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
330.801880 seconds

--------------------------------------------------
Iteration Number: 40
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.445893 | Final loss:0.213558
Fold Number: 2/5
Initial loss:0.442643 | Final loss:0.220463
Fold Number: 3/5
Initial loss:0.453265 | Final loss:0.227279
Fold Number: 4/5
Initial loss:0.449725 | Final loss:0.222526
Fold Number: 5/5
Initial loss:0.455094 | Final loss:0.233298
Mean train accuracy: 76.666667
Mean dev accuracy: 74.791667
Total time taken in 5-folds CV on given set of hyperparameters:
329.882140 seconds

--------------------------------------------------
Iteration Number: 41
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.443897 | Final loss:0.222255
Fold Number: 2/5
Initial loss:0.456244 | Final loss:0.242997
```

```
Fold Number: 3/5
Initial loss:0.443657 | Final loss:0.211828
Fold Number: 4/5
Initial loss:0.447324 | Final loss:0.224877
Fold Number: 5/5
Initial loss:0.453284 | Final loss:0.221132
Mean train accuracy: 75.666667
Mean dev accuracy: 74.375000
Total time taken in 5-folds CV on given set of hyperparameters:
326.383376 seconds

--------------------------------------------------
Iteration Number: 42
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.444833 | Final loss:0.220060
Fold Number: 2/5
Initial loss:0.441068 | Final loss:0.205007
Fold Number: 3/5
Initial loss:0.444044 | Final loss:0.219536
Fold Number: 4/5
Initial loss:0.441849 | Final loss:0.219550
Fold Number: 5/5
Initial loss:0.441032 | Final loss:0.211579
Mean train accuracy: 77.479167
Mean dev accuracy: 75.708333
Total time taken in 5-folds CV on given set of hyperparameters:
324.575013 seconds

--------------------------------------------------
Iteration Number: 43
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.085505 | Final loss:0.025290
Fold Number: 2/5
Initial loss:0.086075 | Final loss:0.026456
Fold Number: 3/5
Initial loss:0.089088 | Final loss:0.024330
Fold Number: 4/5
Initial loss:0.086594 | Final loss:0.025087
Fold Number: 5/5
Initial loss:0.084632 | Final loss:0.024878
Mean train accuracy: 87.416667
Mean dev accuracy: 85.000000
Total time taken in 5-folds CV on given set of hyperparameters:
337.820194 seconds

--------------------------------------------------
Iteration Number: 44
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.087207 | Final loss:0.026119
Fold Number: 2/5
Initial loss:0.086238 | Final loss:0.024305
Fold Number: 3/5
Initial loss:0.086814 | Final loss:0.025099
Fold Number: 4/5
Initial loss:0.087614 | Final loss:0.026430
Fold Number: 5/5
Initial loss:0.083977 | Final loss:0.025186
Mean train accuracy: 87.166667
Mean dev accuracy: 84.541667
Total time taken in 5-folds CV on given set of hyperparameters:
335.111336 seconds

--------------------------------------------------
Iteration Number: 45
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.084126 | Final loss:0.024882
Fold Number: 2/5
Initial loss:0.087737 | Final loss:0.026037
Fold Number: 3/5
Initial loss:0.088209 | Final loss:0.024888
Fold Number: 4/5
Initial loss:0.086780 | Final loss:0.024789
Fold Number: 5/5
Initial loss:0.084543 | Final loss:0.024712
Mean train accuracy: 87.145833
Mean dev accuracy: 84.208333
Total time taken in 5-folds CV on given set of hyperparameters:
333.458325 seconds

--------------------------------------------------
Iteration Number: 46
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.318388 | Final loss:0.046586
Fold Number: 2/5
Initial loss:0.313409 | Final loss:0.045351
Fold Number: 3/5
Initial loss:0.317689 | Final loss:0.046476
Fold Number: 4/5
Initial loss:0.325837 | Final loss:0.046659
Fold Number: 5/5
Initial loss:0.315418 | Final loss:0.046770
Mean train accuracy: 95.656250
Mean dev accuracy: 89.333333
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
330.168711 seconds

--------------------------------------------------
Iteration Number: 47
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.331302 | Final loss:0.045272
Fold Number: 2/5
Initial loss:0.324225 | Final loss:0.045455
Fold Number: 3/5
Initial loss:0.314395 | Final loss:0.046092
Fold Number: 4/5
Initial loss:0.310854 | Final loss:0.047143
Fold Number: 5/5
Initial loss:0.323578 | Final loss:0.047692
Mean train accuracy: 95.677083
Mean dev accuracy: 89.458333
Total time taken in 5-folds CV on given set of hyperparameters:
325.048768 seconds

--------------------------------------------------
Iteration Number: 48
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.298376 | Final loss:0.044632
Fold Number: 2/5
Initial loss:0.321708 | Final loss:0.045587
```

```
Fold Number: 3/5
Initial loss:0.308578 | Final loss:0.047046
Fold Number: 4/5
Initial loss:0.338359 | Final loss:0.046885
Fold Number: 5/5
Initial loss:0.312120 | Final loss:0.047204
Mean train accuracy: 95.625000
Mean dev accuracy: 89.291667
Total time taken in 5-folds CV on given set of hyperparameters:
322.535774 seconds

--------------------------------------------------
Iteration Number: 49
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.049393 | Final loss:0.004816
Fold Number: 2/5
Initial loss:0.048952 | Final loss:0.005297
Fold Number: 3/5
Initial loss:0.049412 | Final loss:0.005964
Fold Number: 4/5
Initial loss:0.048550 | Final loss:0.005375
Fold Number: 5/5
Initial loss:0.050147 | Final loss:0.005691
Mean train accuracy: 97.437500
Mean dev accuracy: 89.833333
Total time taken in 5-folds CV on given set of hyperparameters:
335.084182 seconds

--------------------------------------------------
Iteration Number: 50
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.049598 | Final loss:0.005572
Fold Number: 2/5
Initial loss:0.047875 | Final loss:0.005337
Fold Number: 3/5
Initial loss:0.047878 | Final loss:0.005275
Fold Number: 4/5
Initial loss:0.049862 | Final loss:0.005381
Fold Number: 5/5
Initial loss:0.047753 | Final loss:0.005622
Mean train accuracy: 97.531250
Mean dev accuracy: 89.750000
Total time taken in 5-folds CV on given set of hyperparameters:
329.027363 seconds

--------------------------------------------------
Iteration Number: 51
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.047914 | Final loss:0.004976
Fold Number: 2/5
Initial loss:0.048056 | Final loss:0.005270
Fold Number: 3/5
Initial loss:0.051879 | Final loss:0.005345
Fold Number: 4/5
Initial loss:0.048067 | Final loss:0.005171
Fold Number: 5/5
Initial loss:0.047205 | Final loss:0.005623
Mean train accuracy: 97.572917
Mean dev accuracy: 89.291667
Total time taken in 5-folds CV on given set of hyperparameters:
329.554170 seconds

--------------------------------------------------
Iteration Number: 52
Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.196137 | Final loss:0.007752
Fold Number: 2/5
Initial loss:0.188990 | Final loss:0.005046
Fold Number: 3/5
Initial loss:0.192969 | Final loss:0.007627
Fold Number: 4/5
Initial loss:0.190407 | Final loss:0.006497
Fold Number: 5/5
Initial loss:0.188007 | Final loss:0.007877
Mean train accuracy: 99.145833
Mean dev accuracy: 92.125000
Total time taken in 5-folds CV on given set of hyperparameters:
323.303170 seconds

--------------------------------------------------
Iteration Number: 53
Number of Epochs: 20
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.184722 | Final loss:0.006518
Fold Number: 2/5
Initial loss:0.189425 | Final loss:0.005627
Fold Number: 3/5
Initial loss:0.192760 | Final loss:0.006450
Fold Number: 4/5
Initial loss:0.196816 | Final loss:0.006210
Fold Number: 5/5
Initial loss:0.193146 | Final loss:0.004685
Mean train accuracy: 99.333333
Mean dev accuracy: 91.500000
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
319.223392 seconds

--------------------------------------------------
Iteration Number: 54
Number of Epochs: 20
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.193597 | Final loss:0.006660
Fold Number: 2/5
Initial loss:0.196157 | Final loss:0.006855
Fold Number: 3/5
Initial loss:0.197749 | Final loss:0.006054
Fold Number: 4/5
Initial loss:0.187437 | Final loss:0.006769
Fold Number: 5/5
Initial loss:0.184562 | Final loss:0.007343
Mean train accuracy: 99.218750
Mean dev accuracy: 92.083333
Total time taken in 5-folds CV on given set of hyperparameters:
317.869963 seconds

--------------------------------------------------
Iteration Number: 55
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.091058 | Final loss:0.077547
Fold Number: 2/5
Initial loss:0.092375 | Final loss:0.081274
```

```
Fold Number: 3/5
Initial loss:0.090794 | Final loss:0.076293
Fold Number: 4/5
Initial loss:0.090123 | Final loss:0.074309
Fold Number: 5/5
Initial loss:0.092429 | Final loss:0.079531
Mean train accuracy: 46.354167
Mean dev accuracy: 45.541667
Total time taken in 5-folds CV on given set of hyperparameters:
829.361011 seconds

--------------------------------------------------
Iteration Number: 56
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.092762 | Final loss:0.080062
Fold Number: 2/5
Initial loss:0.092255 | Final loss:0.075880
Fold Number: 3/5
Initial loss:0.092387 | Final loss:0.073557
Fold Number: 4/5
Initial loss:0.091500 | Final loss:0.076067
Fold Number: 5/5
Initial loss:0.090507 | Final loss:0.075827
Mean train accuracy: 46.822917
Mean dev accuracy: 44.833333
Total time taken in 5-folds CV on given set of hyperparameters:
819.366637 seconds

--------------------------------------------------
Iteration Number: 57
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Mse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
```

```
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.090643 | Final loss:0.076096
Fold Number: 2/5
Initial loss:0.090497 | Final loss:0.076849
Fold Number: 3/5
Initial loss:0.091551 | Final loss:0.074132
Fold Number: 4/5
Initial loss:0.090965 | Final loss:0.074543
Fold Number: 5/5
Initial loss:0.093309 | Final loss:0.080013
Mean train accuracy: 44.260417
Mean dev accuracy: 42.833333
Total time taken in 5-folds CV on given set of hyperparameters:
822.360053 seconds

--------------------------------------------------
Iteration Number: 58
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.449144 | Final loss:0.139634
Fold Number: 2/5
Initial loss:0.437405 | Final loss:0.163928
Fold Number: 3/5
Initial loss:0.441808 | Final loss:0.136794
Fold Number: 4/5
Initial loss:0.446758 | Final loss:0.141017
Fold Number: 5/5
Initial loss:0.450937 | Final loss:0.139801
Mean train accuracy: 84.718750
Mean dev accuracy: 83.000000
Total time taken in 5-folds CV on given set of hyperparameters:
811.713399 seconds

--------------------------------------------------
Iteration Number: 59
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
```

```
Early Stopping Regularization being used?: Yes
Batch Size: 10
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.451829 | Final loss:0.149027
Fold Number: 2/5
Initial loss:0.449229 | Final loss:0.144982
Fold Number: 3/5
Initial loss:0.438258 | Final loss:0.143272
Fold Number: 4/5
Initial loss:0.440466 | Final loss:0.140574
Fold Number: 5/5
Initial loss:0.453115 | Final loss:0.144866
Mean train accuracy: 85.656250
Mean dev accuracy: 82.958333
Total time taken in 5-folds CV on given set of hyperparameters:
801.077369 seconds

--------------------------------------------------
Iteration Number: 60
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Fold Number: 1/5
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.446523 | Final loss:0.137578
Fold Number: 2/5
Initial loss:0.445172 | Final loss:0.138242
Fold Number: 3/5
Initial loss:0.447319 | Final loss:0.141913
Fold Number: 4/5
Initial loss:0.450528 | Final loss:0.143459
Fold Number: 5/5
Initial loss:0.440060 | Final loss:0.137309
Mean train accuracy: 86.041667
Mean dev accuracy: 83.791667
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
798.456491 seconds
```

Changing methods here

```
--------------------------------------------------
Iteration Number: 1
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.459827 | Final loss:0.446588
Train accuracy: 14.114583
Dev accuracy: 11.250000
Total time taken in 5-folds CV on given set of hyperparameters:
172.667468 seconds

--------------------------------------------------
Iteration Number: 2
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.460554 | Final loss:0.447577
Train accuracy: 15.000000
Dev accuracy: 10.625000
Total time taken in 5-folds CV on given set of hyperparameters:
165.907405 seconds

--------------------------------------------------
Iteration Number: 3
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
```

```
Batch Size: 50
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.460644 | Final loss:0.446887
Train accuracy: 16.354167
Dev accuracy: 11.041667
Total time taken in 5-folds CV on given set of hyperparameters:
169.892315 seconds

--------------------------------------------------
Iteration Number: 4
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.457932 | Final loss:0.445334
Train accuracy: 16.093750
Dev accuracy: 10.000000
Total time taken in 5-folds CV on given set of hyperparameters:
165.945735 seconds

--------------------------------------------------
Iteration Number: 5
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.455016 | Final loss:0.406463
Train accuracy: 37.604167
Dev accuracy: 8.333333
```

```
Total time taken in 5-folds CV on given set of hyperparameters:
173.109801 seconds

-------------------------------------------------
Iteration Number: 6
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.453991 | Final loss:0.408500
Train accuracy: 37.500000
Dev accuracy: 8.333333
Total time taken in 5-folds CV on given set of hyperparameters:
166.901206 seconds

-------------------------------------------------
Iteration Number: 7
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 50
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.454560 | Final loss:0.404301
Train accuracy: 37.239583
Dev accuracy: 12.916667
Total time taken in 5-folds CV on given set of hyperparameters:
170.298896 seconds

-------------------------------------------------
Iteration Number: 8
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
```

```
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.453337 | Final loss:0.404764
Train accuracy: 36.927083
Dev accuracy: 9.791667
Total time taken in 5-folds CV on given set of hyperparameters:
165.664031 seconds

--------------------------------------------------
Iteration Number: 9
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 1
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.453116 | Final loss:0.071524
Train accuracy: 90.052083
Dev accuracy: 8.958333
Total time taken in 5-folds CV on given set of hyperparameters:
172.120519 seconds

--------------------------------------------------
Iteration Number: 10
Number of Epochs: 50
Learning Rate: 0.001
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 10
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.453340 | Final loss:0.069505
Train accuracy: 89.375000
Dev accuracy: 10.833333
Total time taken in 5-folds CV on given set of hyperparameters:
165.738162 seconds

--------------------------------------------------
```

```
Iteration Number: 11
Number of Epochs: 50
Learning Rate: 0.01
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 50
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.452857 | Final loss:0.076003
Train accuracy: 88.906250
Dev accuracy: 7.083333
Total time taken in 5-folds CV on given set of hyperparameters:
169.543934 seconds

--------------------------------------------------
Iteration Number: 12
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: Sse
Learning Rate is being updated?: Yes
Early Stopping Regularization being used?: Yes
Batch Size: 100
Layer type: Fc
Input Dimension: 784    Output Dimension: 128
Layer type: Activation
Activation Function: Relu
Layer type: Fc
Input Dimension: 128    Output Dimension: 10
Layer type: Softmax
Input Dimension: 10
Training Size: (1920, 784)
Validation Size: (480, 784)
Initial loss:0.453919 | Final loss:0.069019
Train accuracy: 89.479167
Dev accuracy: 9.791667
Total time taken in 5-folds CV on given set of hyperparameters:
165.746456 seconds
```

From above, the biggest difference in accuracies came because of the cost function/loss function that I was using.
SSE performed significantly better than MSE as indicated. This might be because 1/N times the SSE cost function is the MSE cost function. So, the gradient descent update rule with small gradients is

$$\theta_{k+1} \leftarrow \theta_k - \alpha \cdot \nabla_\theta L(\theta)$$

Therefore, as N grows, the SSE cost function grows too, and so does its gradient. Conversely, while the MSE cost function *may* also grow in value as N increases, it does not grow as fast as the SSE cost function, and so its gradients are also growing slowly. This is probably the reason why SSE

outperforms MSE in my case. This is validated by seeing how much the loss decreases with time

Cross entropy gives much better performance in general as I saw in the case of a standard library. I could not use it even if there is an option, probably because of my initialization of weights. Because of those, some probabilities were so low or so high that the cost/error kept hitting NaN and therefore, I could not use it in my implementation.

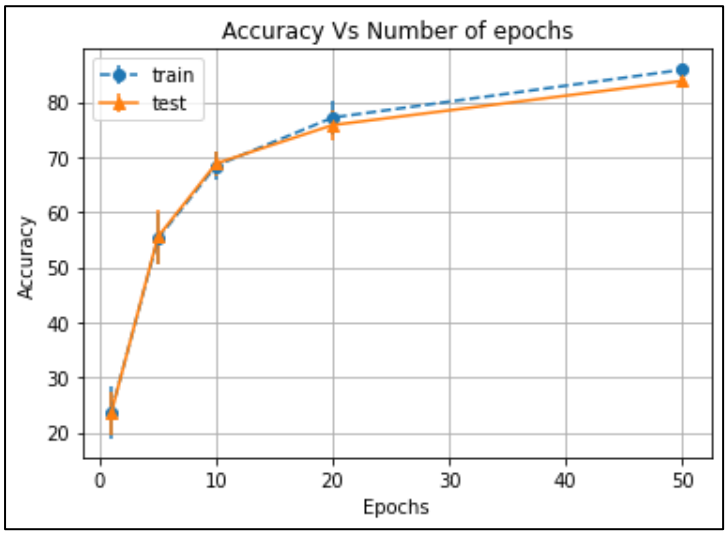
For comparisons, I have plotted for 1 hyperparameter at a time as there were too many variables for simultaneous plotting (i.e., 6D plots etc.)

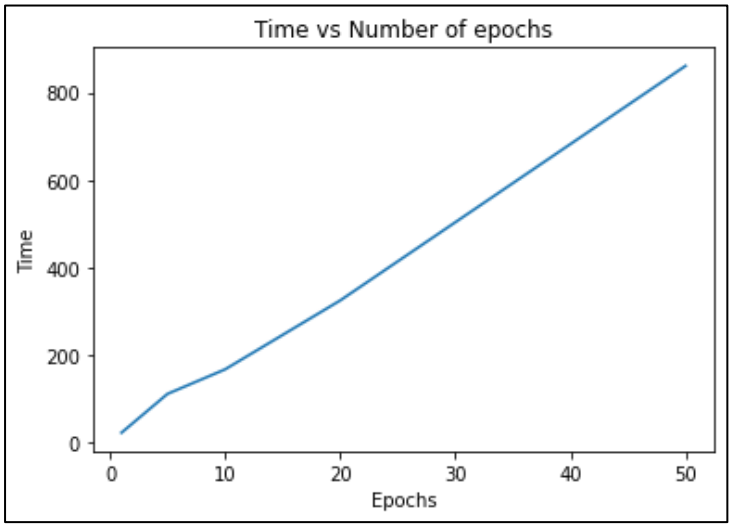
Among all these models, the best performing one was the 52nd iteration with a dev set accuracy of 92.125%. Therefore, for plotting trends for various hyperparameters, I will keep rest of the values constant to:

Number of Epochs: 20
Learning Rate: 0.001
Cost Function used: SSE
Learning Rate is being updated? Yes
Early Stopping Regularization being used? Yes
Batch Size: 1

For number of epochs, the following results are produced. The training accuracy increases with epochs but after some time, the test accuracy starts decreasing i.e., as epochs increase, the model goes from underfitting to overfitting.

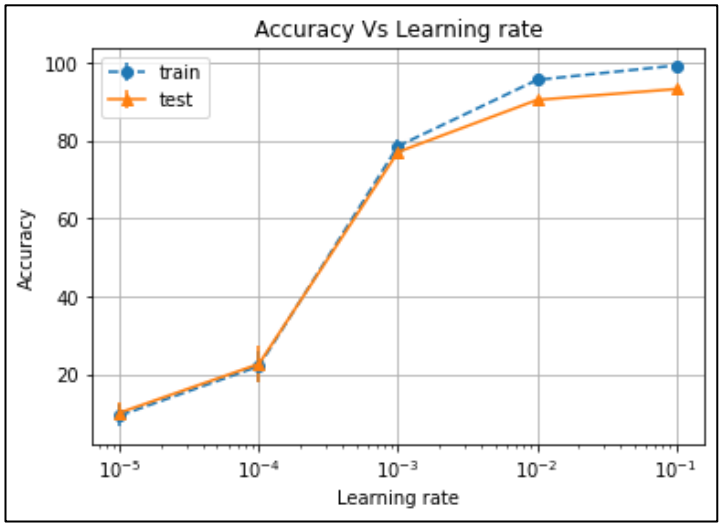
As we can see in the plot below it, the time taken by the model to train, as expected, increases with number of epochs. This is because we need to go over the training data that many times. This is the largest increase among the plots

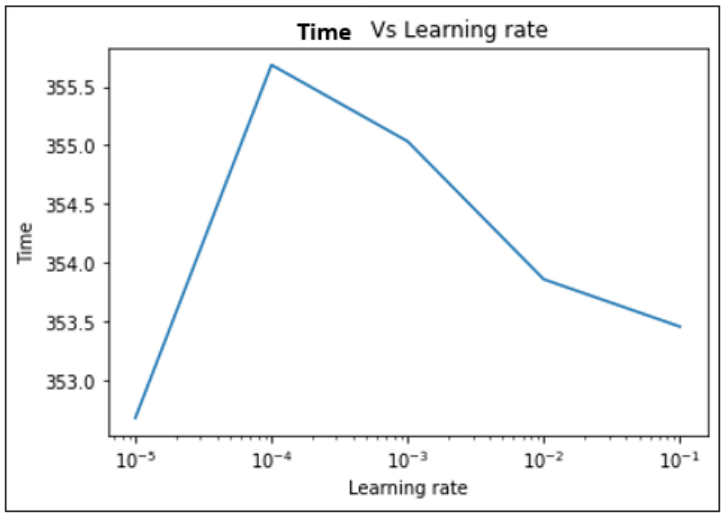




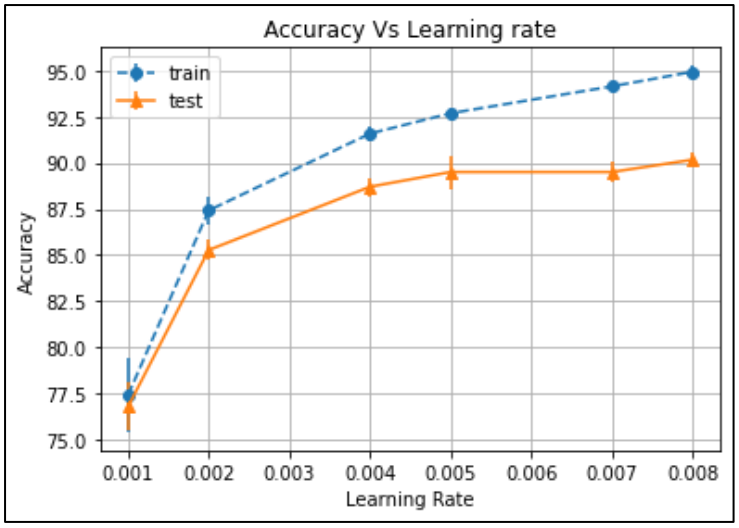
For learning rate, the accuracy trend is similar as before, it goes from underfitting to overfitting. The learning rate affects how quickly our model can converge to a local-minima. Increasing this may affect the training in a way that it converges to a local-minima, instead of a global-minima.

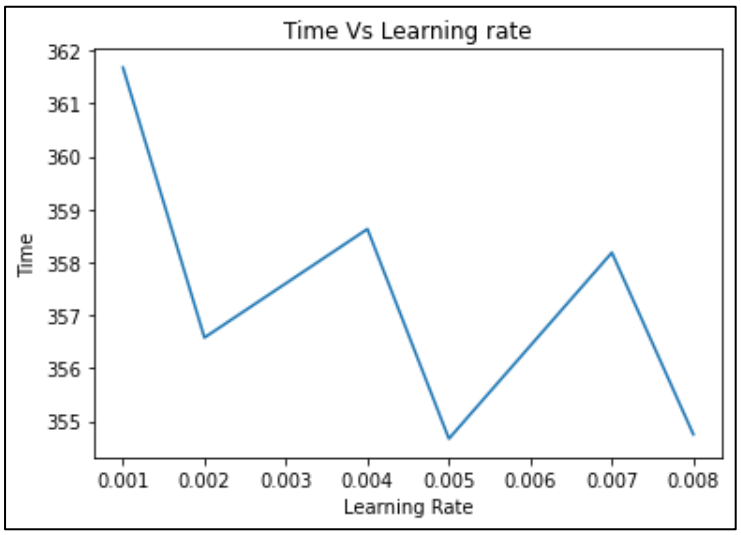
Further, for the time plot, we don't see any clear trend. This could partially be by the virtue of the dynamic learning rate policy that I had adopted. After a few iterations, the initial learning rate has lower bearing on the training time





Here is another set of plots for the learning rate but on a linear scale. Too small learning rate make learning slow and under fitting and too big learning rate leads to divergence.

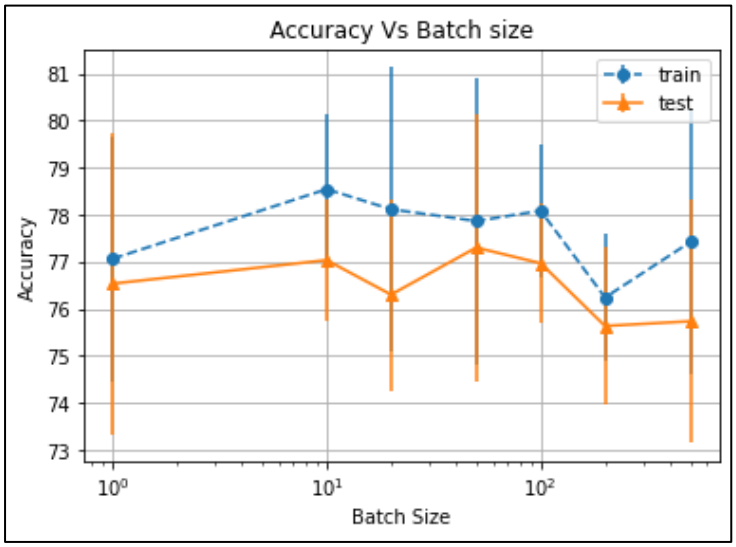


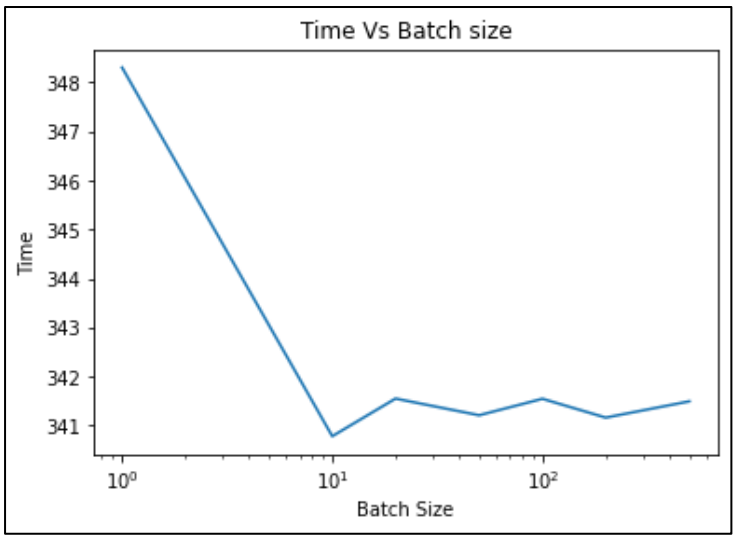


Finally, I have plots against batch size. One peculiar observation here is that there is a lot of error among the 5-folds that I have used. Even though the mean

value is more or less constant, the range they covered on being trained on different parts of data varies a lot.

For time, there isn't much difference either as the max difference is of mere 7 seconds





For the next experiment with **2 layers**, I don't use 5-folds CV as it would naturally take a lot of time. However, I have used them for the trends.
I am using tanh here but in my setting, it isn't advisable because it is known to cause vanishing gradient problem at times. That coupled with my dynamic learning rate might make learning way worse than we want. I tried with both tanh and relu and found relu to perform better.

Layer type: Fully Connected
Input Dimension: 784 Output Dimension: 256
Layer type: Activation Layer
Activation Function: ReLU
Layer type: Fully Connected
Input Dimension: 256 Output Dimension: 64
Layer type: Activation Layer

Activation Function: ReLU
Layer type: Fully Connected
Input Dimension: 64 Output Dimension: 10
Layer type: Softmax
Input Dimension: 10

Finally, I repeated the experiment that I did earlier and found better accuracy than before. <Results are skipped>

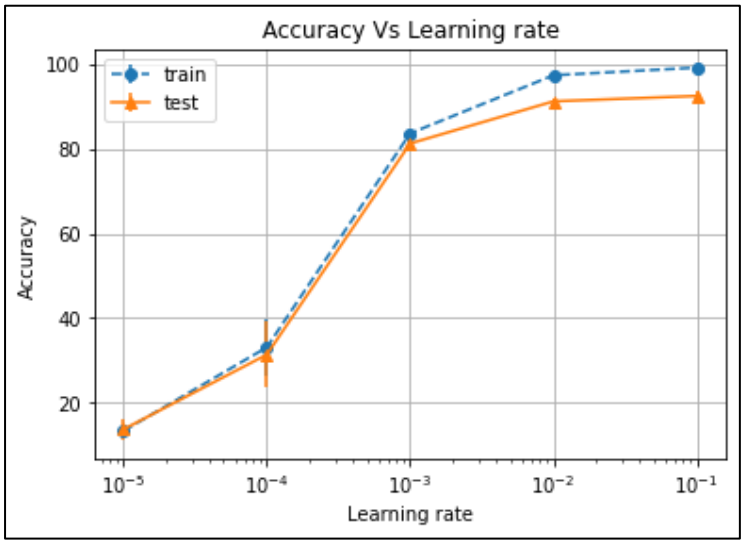
I used the following hyperparameters which gave 90.14% accuracy on test set and 97.98% on training set:

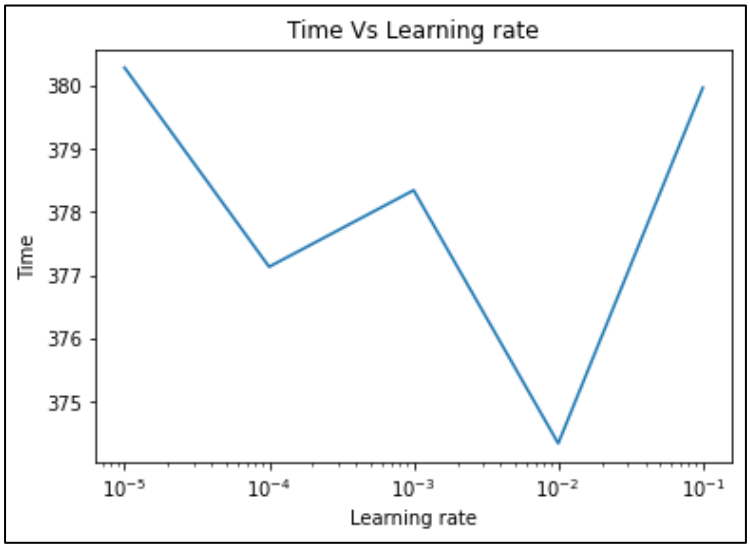
ReLU layer

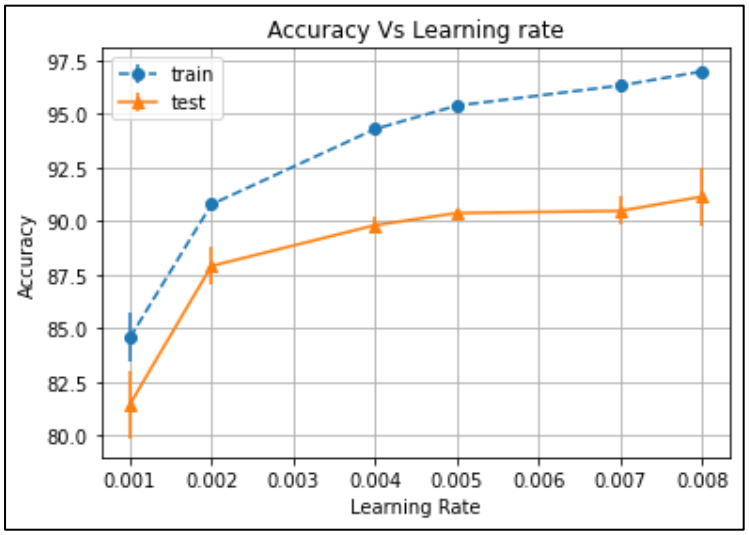
Number of Epochs: 50
Learning Rate: 0.1
Cost Function used: SSE
Learning Rate is being updated? Yes
Early Stopping Regularization being used? Yes
Batch Size: 30

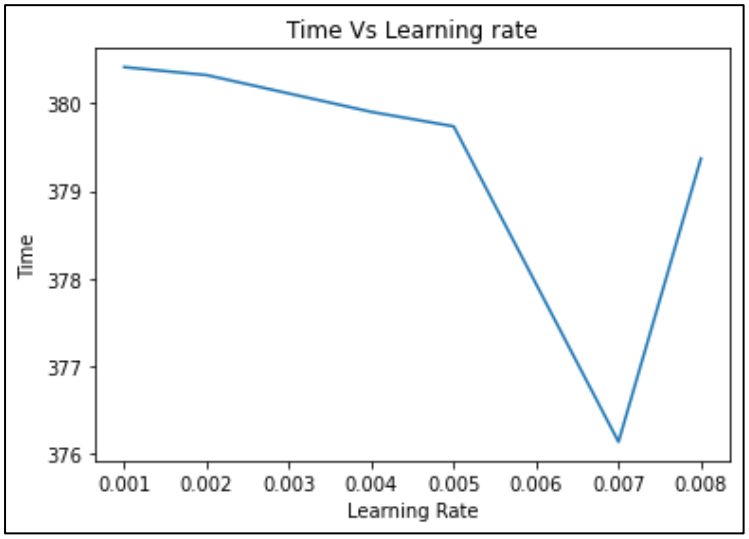
Here is the analysis of individual hyperparameters:

For learning rate (log and linear), we see a similar trend as before. Note that the test accuracy isn't dropping from an earlier value, but constantly rising. Implying that there is no overfitting happening here. For time taken, it is somewhat irregular but max difference is of 1.5% and is therefore insignificant.

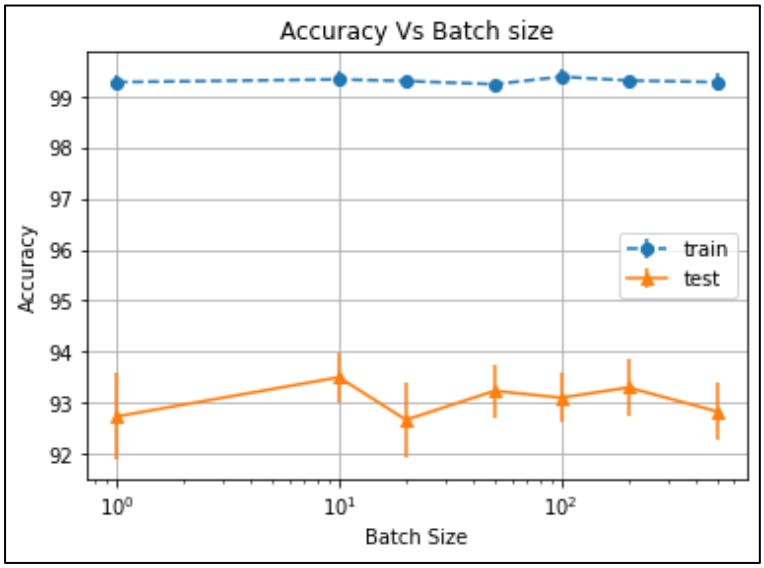


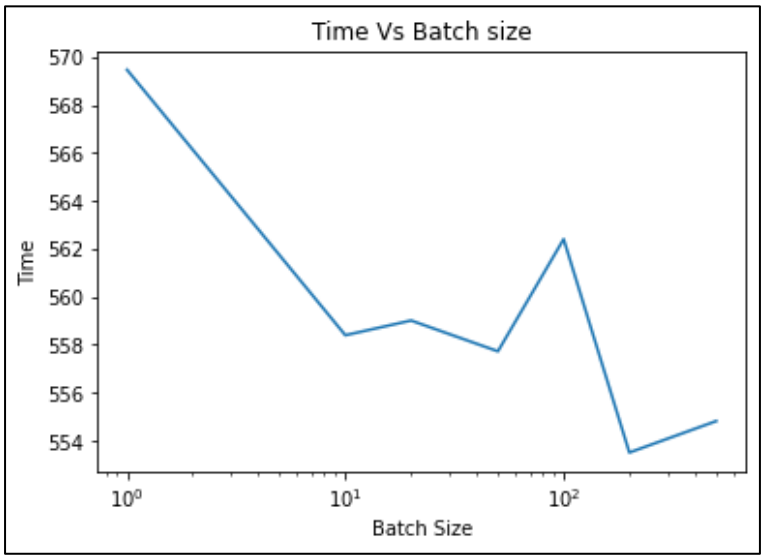




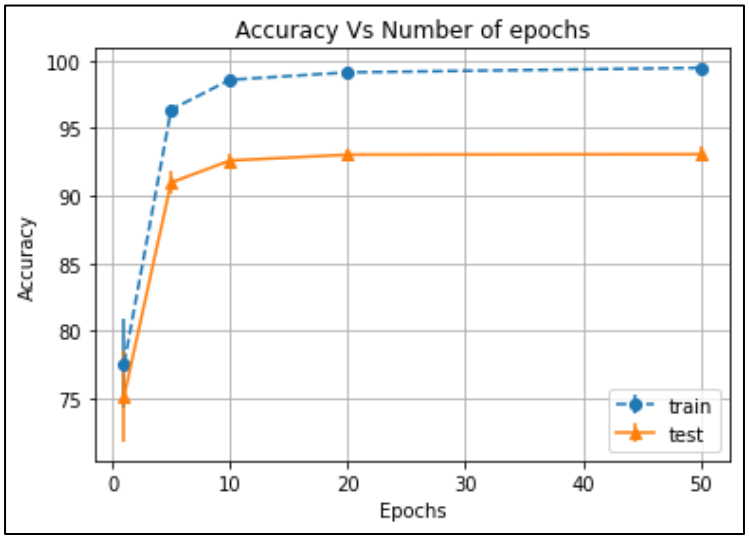


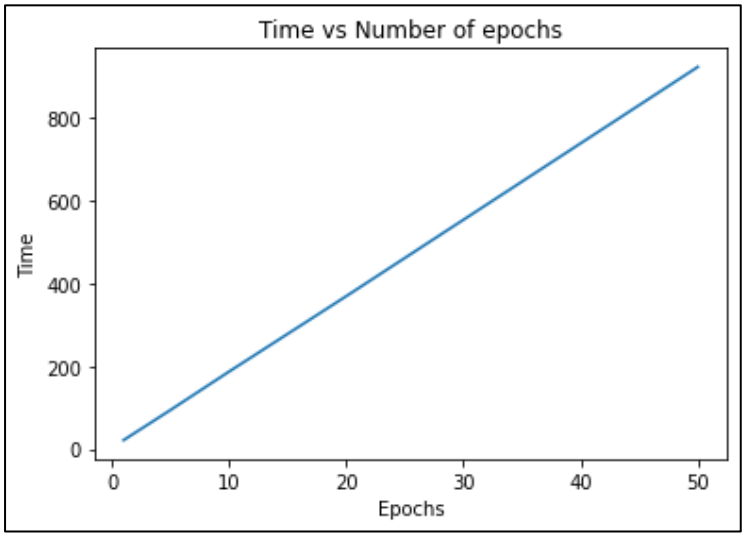
For batch size, we see that the accuracy is more or less independent of the choice of batch size, however time decreases as batch size increases, which is also as expected





For number of epochs, the trend start with underfitting and gradually moves to rightly fit. We see that the test accuracy doesn't increase after a point, but that is still not overfitting as it is not harming the performance.





The most significant observation here was that the accuracy with the right hyperparameters increased.

One thing that I noticed from the trends was that there wasn't much dip in test set accuracies, which means that at least in my models there was not much problem of overfitting and that L2 regularization will most probably not improve the performance by much.

For the error analysis and standard library part, I went with the model with best test set accuracy on hyperparameters. The following model was used:

keras.layers.Dense(256, activation='relu'),

keras.layers.Dense(64, activation='relu'),

keras.layers.Dense(10, activation='softmax')

Along with this, an SGD optimizer was used with a learning rate of 0.1, and categorical_crossentropy loss function as it is known to perform better. Finally, I used mean_squared_error metrics.

The results were quite astonishing. The training time was a mere 9 seconds which was must faster than my implementation. One prime reason can be that keras now works with tensorflow which is created by Google, and offers GPU support for that on Google Colab by itself, along with a tensorflow processing unit (TPU) of its own. These speed up the process by a lot. Another can be in-built parallelization in keras.

Finally, we get a slightly better results than my own implementation (possibly because of the loss function) with a training accuracy of 98.1% and test accuracy of ~91%
Some more possible reasons can be better initialisation of weight matrix and using a modified version of ReLU

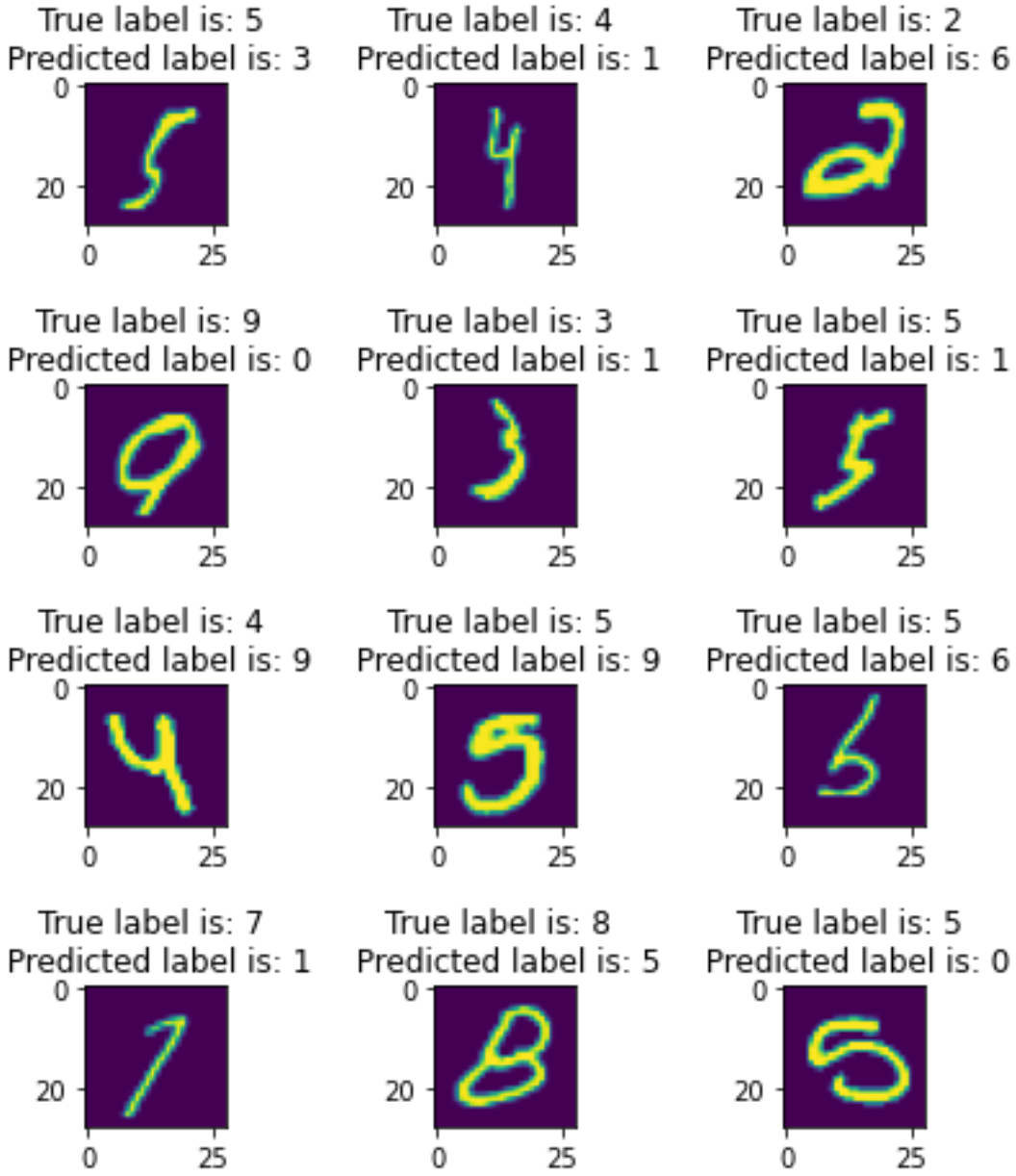
ERROR ANALYSIS

Finally, I will do bit of an error analysis

```
              precision    recall  f1-score   support

         0.0       0.96      0.93      0.95        59
         1.0       0.91      1.00      0.95        62
         2.0       0.95      0.97      0.96        58
         3.0       0.87      0.88      0.88        69
         4.0       0.93      0.86      0.89        59
         5.0       0.86      0.80      0.83        70
         6.0       0.87      0.96      0.92        56
         7.0       0.93      0.93      0.93        60
         8.0       0.94      0.89      0.92        57
         9.0       0.84      0.84      0.84        50

    accuracy                           0.91       600
   macro avg       0.91      0.91      0.91       600
weighted avg       0.91      0.91      0.91       600

Confusion matrix
[[55  0  0  1  0  2  1  0  0  0]
 [ 0 62  0  0  0  0  0  0  0  0]
 [ 0  0 56  0  0  0  1  0  1  0]
 [ 0  1  2 61  0  2  0  2  1  0]
 [ 0  1  0  0 51  0  1  0  0  6]
 [ 1  2  0  5  0 56  4  0  1  1]
 [ 0  0  1  0  0  1 54  0  0  0]
 [ 0  1  0  0  2  0  0 56  0  1]
 [ 0  1  0  0  0  4  1  0 51  0]
 [ 1  0  0  3  2  0  0  2  0 42]]
```

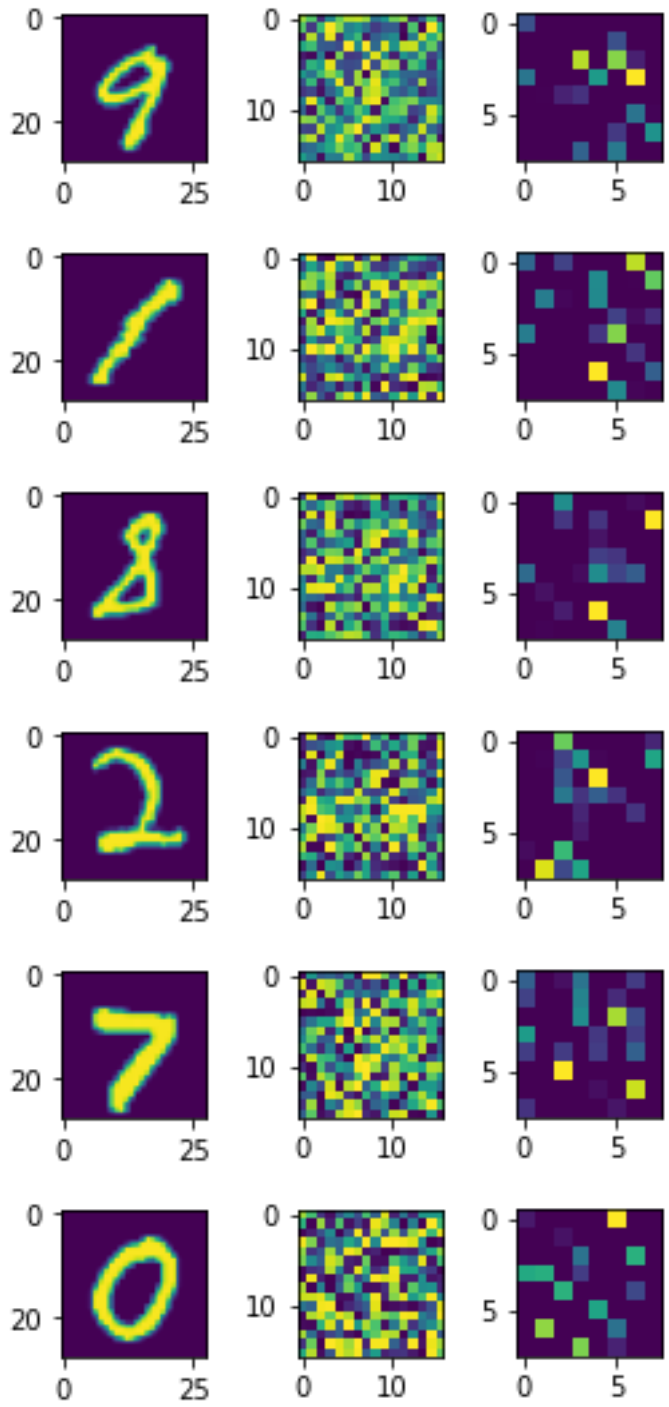
We see that all the labels are almost equally distributed with label 5 having highest frequency, therefore we can be assured that our model works uniformly well on all the labels and not on specific few.

Next, from the confusion matrix, I see that the main points of confusion for the model is the number 9. 8 times a number was wrongly predicted as 9 and 8 times 9 was predicted as some other number. Here are some incorrectly classified images:



A lot of images are understandably misclassified. For the others, a possible reason can be that many of the images when rotated, will look a lot like the predicted labels

Finally, let’s look at some outputs of hidden layers:



To most of us, these look like random noises, but for the model, these are some really high space representation of the input data that helps it classify these. We see that the input layer is distinguishable to the human eye, which after going through a tanh layer results in something that is not understandable to us. But after the ReLU layer, it seems to have started assigning each of them some separate identity that helps it distinguish between them. And then it outputs the labels as we require it to.

References:

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- https://towardsdatascience.com/math-neural-network-from-scratch-in-python-d6da9f29ce65
- https://colab.research.google.com/github/casperbh96/Neural-Network-From-Scratch/blob/master/NN_From_Scratch.ipynb#scrollTo=5IucezTTXiSM
- https://github.com/sar-gupta/neural-network-from-scratch/blob/master/neuralnetwork.py
- https://hackernoon.com/dl03-gradient-descent-719aff91c7d6
- https://scikit-learn.org/stable/auto_examples/semi_supervised/plot_label_propagation_digits_active_learning.html#sphx-glr-auto-examples-semi-supervised-plot-label-propagation-digits-active-learning-py