ECE 763 – Computer Vision

Project 03

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Dataset Preparation:

The dataset used for this project is the large-scale CelebFaces Attributes (CelebA) Dataset, which is a dataset with more than 200K celebrity images. The images contain large pose variations and background clutter. The face images are taken as it is without cropping so that the model becomes robust to real world situations where a face image may contain background noise.

The images are taken in RGB format and re-sized to 60x60 to maintain uniformity. For non-face images, a random 60x60 block is cropped from the face images from regions which does not contain any face attributes. A total of 6000 images of face and non-face each are considered for training and 600 images of face and non-face each are taken for testing.

Methodology:

I have implemented a Convolutional Neural Network (CNN) to train on the images. The input for the network is the images with dimensions of 60x60x3. The architecture of the network includes two Convolutional layers with 16 filters of size 5x5 each and two layers of Max-Pooling of size 2x2 and stride 1. The activation function used is ReLu activation. After these layers, to derive the output I have implemented two fully connected layers, one with 16 filters of size 15x15 (3600 neurons) and the other one with 128 neurons, both with ReLu activation. Finally, the last layer comprises of a fully connected layer with 2 neurons for the classification output using SoftMax activation function. The optimizer used is Adam Optimizer.

The batch size is limited to 64 and the number of epochs for training is kept at 10. The dropout probability is kept constant at 0.2. Also, the training data is standardized to lie between 0 and 1.

Baby Sitting Procedure:

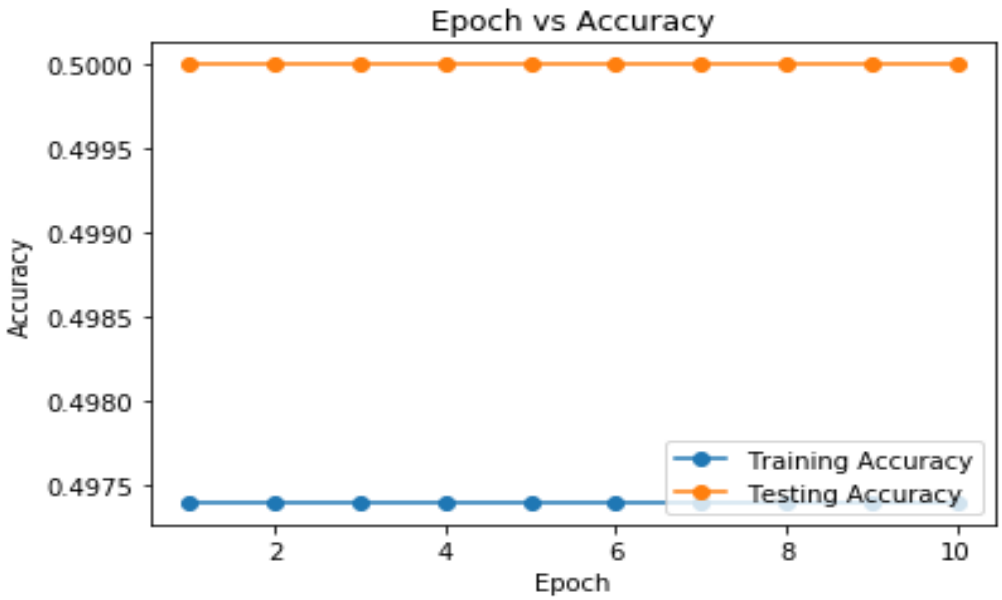
The hyper-parameters which I am trying to tune are the learning rate and regularization constant of the network. Baby sitting the learning process is the process of choosing the optimum parameters.

Learning Rate:

First, we keep the regularization constant and vary the learning rate to check the performance of the network. The following are the results:

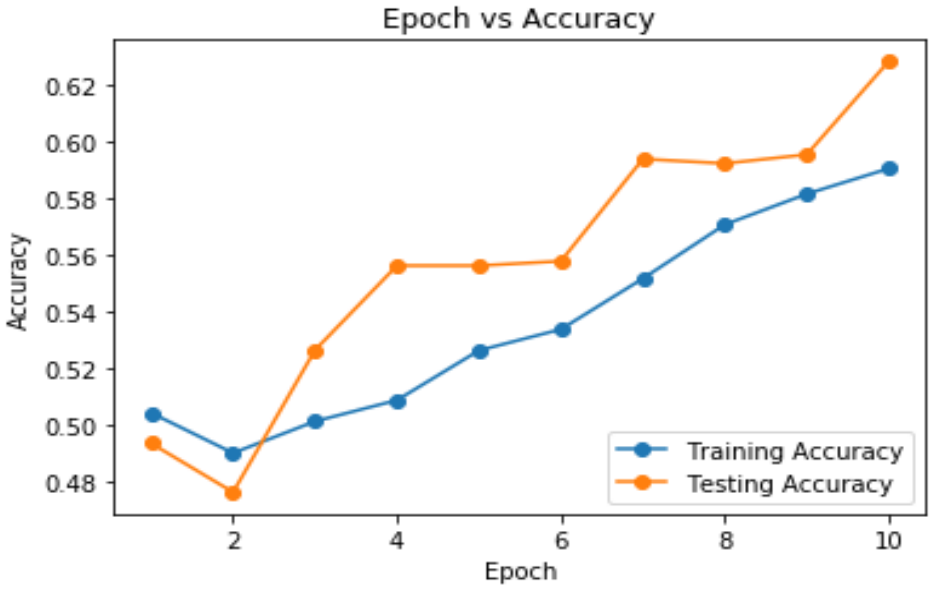
(i) LR = 1e6 and Regularization = 0

```
Learning Rate:  1000000.0
Regularization: 0
Epoch: 1 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 2 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 3 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 4 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 5 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 6 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 7 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 8 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
Epoch: 9 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
No handles with labels found to put in legend.
Epoch: 10 cost: nan Train accuracy: 0.49739583333333337 Val accuracy: 0.5
```



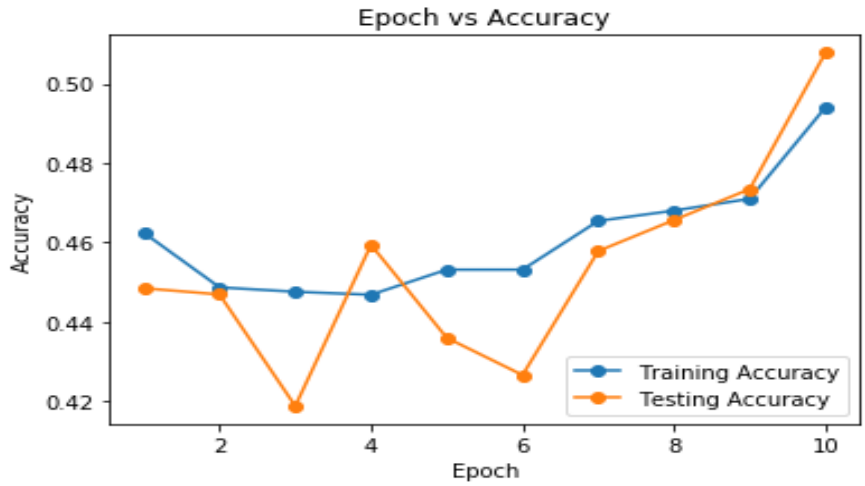
(ii) LR = 1e-6 and Regularization = 0

```
Learning Rate:  1e-06
Regularization: 0
Epoch: 1 cost: 585.1831657772973 Train accuracy: 0.5044642857142856 Val accuracy: 0.4937499999999999
Epoch: 2 cost: 460.6556411016556 Train accuracy: 0.490327380952381 Val accuracy: 0.4765625
Epoch: 3 cost: 353.5261197771344 Train accuracy: 0.5014880952380953 Val accuracy: 0.5265625
Epoch: 4 cost: 269.0726816086542 Train accuracy: 0.5089285714285715 Val accuracy: 0.55625
Epoch: 5 cost: 225.82700674874442 Train accuracy: 0.5264136904761904 Val accuracy: 0.55625
Epoch: 6 cost: 197.9786057245164 Train accuracy: 0.5338541666666664 Val accuracy: 0.5578125
Epoch: 7 cost: 180.0448141552153 Train accuracy: 0.5517113095238096 Val accuracy: 0.5937499999999999
Epoch: 8 cost: 173.1618948436919 Train accuracy: 0.5706845238095237 Val accuracy: 0.5921875
Epoch: 9 cost: 176.6370905921573 Train accuracy: 0.5814732142857142 Val accuracy: 0.5953125
No handles with labels found to put in legend.
Epoch: 10 cost: 159.1546401977539 Train accuracy: 0.5904017857142857 Val accuracy: 0.628125
```



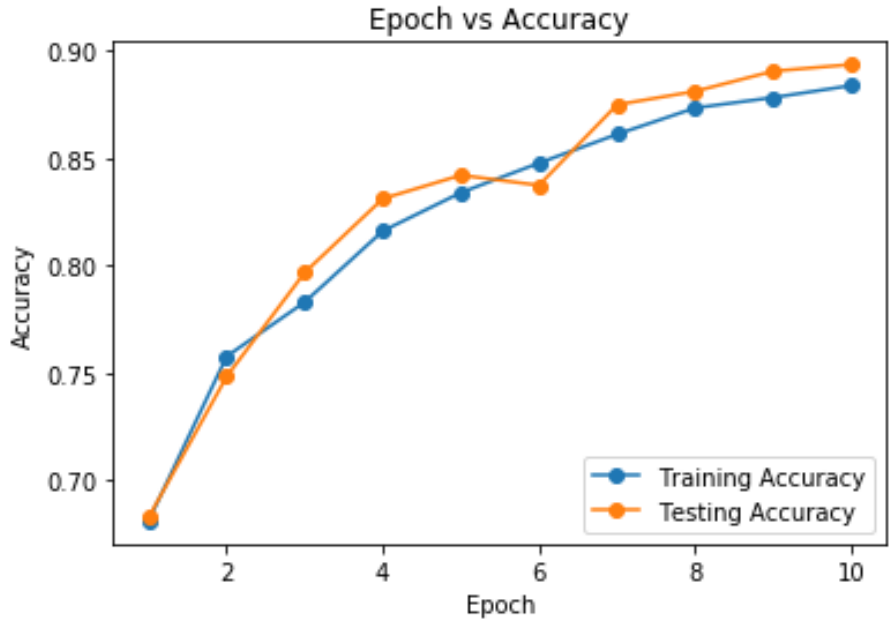
(iii) LR = 1e-6 and Regularization = 0.000001

```
Learning Rate:  1e-06
Regularization: 1e-06
Epoch: 1 cost: 882.4398440406436 Train accuracy: 0.4624255952380952 Val accuracy: 0.4484375
Epoch: 2 cost: 778.9627075195312 Train accuracy: 0.4486607142857142 Val accuracy: 0.44687499999999997
Epoch: 3 cost: 663.3678646995909 Train accuracy: 0.4475446428571429 Val accuracy: 0.41875
Epoch: 4 cost: 575.3004005068825 Train accuracy: 0.4468005952380953 Val accuracy: 0.45937500000000003
Epoch: 5 cost: 509.9184345063709 Train accuracy: 0.45312500000000006 Val accuracy: 0.4359375
Epoch: 6 cost: 442.01987057640446 Train accuracy: 0.4531250000000001 Val accuracy: 0.4265625
Epoch: 7 cost: 407.372095017206 Train accuracy: 0.46540178571428564 Val accuracy: 0.4578125
Epoch: 8 cost: 382.9500107538132 Train accuracy: 0.46800595238095244 Val accuracy: 0.46562500000000007
Epoch: 9 cost: 344.7836212884812 Train accuracy: 0.4709821428571428 Val accuracy: 0.47343749999999996
No handles with labels found to put in legend.
Epoch: 10 cost: 330.8754108973912 Train accuracy: 0.494047619047619 Val accuracy: 0.5078125
```



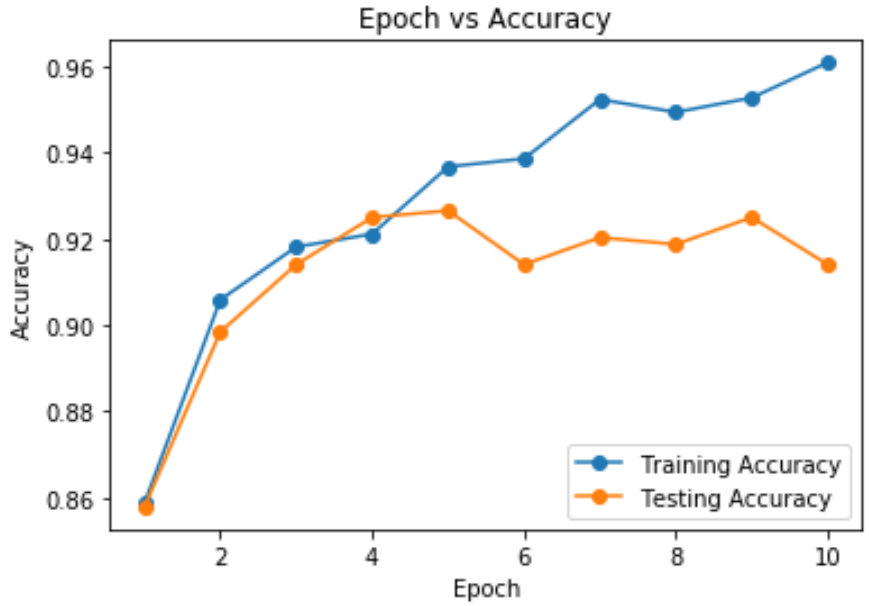
(iv) LR = 1e-5 and Regularization = 0.000001

```
Learning Rate:  1e-05
Regularization: 1e-06
Epoch: 1 cost: 109.01541328430176 Train accuracy: 0.6811755952380953 Val accuracy: 0.6828125
Epoch: 2 cost: 62.97167905171712 Train accuracy: 0.7578125 Val accuracy: 0.7484375000000001
Epoch: 3 cost: 45.32744487126669 Train accuracy: 0.7831101190476188 Val accuracy: 0.796875
Epoch: 4 cost: 38.22735536666143 Train accuracy: 0.816220238095238 Val accuracy: 0.8312499999999999
Epoch: 5 cost: 29.706290449414936 Train accuracy: 0.8340773809523808 Val accuracy: 0.8421874999999999
Epoch: 6 cost: 25.9013717855726 Train accuracy: 0.8478422619047618 Val accuracy: 0.8375
Epoch: 7 cost: 21.142394554047353 Train accuracy: 0.861235119047619 Val accuracy: 0.875
Epoch: 8 cost: 17.21023120198931 Train accuracy: 0.8735119047619045 Val accuracy: 0.8812499999999999
Epoch: 9 cost: 15.306292596317475 Train accuracy: 0.8783482142857143 Val accuracy: 0.8906249999999999
No handles with labels found to put in legend.
Epoch: 10 cost: 12.65105818566822 Train accuracy: 0.8839285714285713 Val accuracy: 0.89375
```



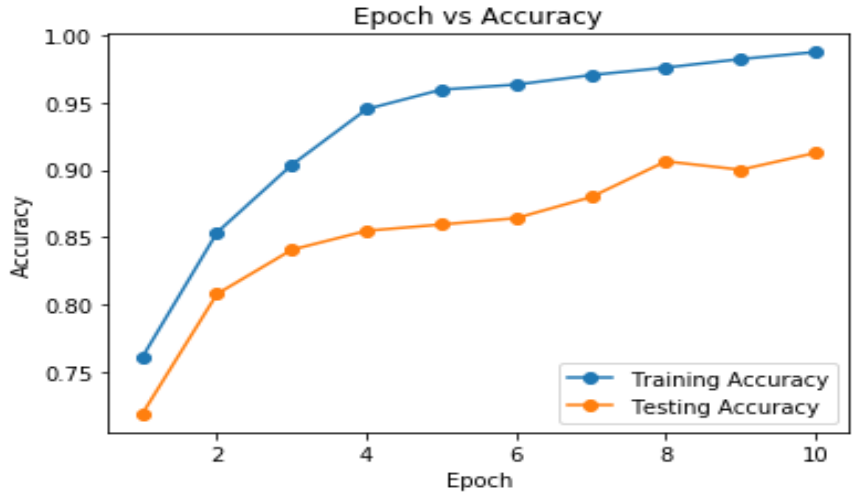
(v) LR = 1e-4 and Regularization = 0.000001

```
Learning Rate:  0.0001
Regularization: 1e-06
Epoch: 1 cost: 68.38285660743713 Train accuracy: 0.8586309523809522 Val accuracy: 0.8578125000000001
Epoch: 2 cost: 12.406280395641392 Train accuracy: 0.9058779761904759 Val accuracy: 0.8984374999999999
Epoch: 3 cost: 5.56076200022584 Train accuracy: 0.9181547619047615 Val accuracy: 0.9140625
Epoch: 4 cost: 3.4883125580270735 Train accuracy: 0.9211309523809523 Val accuracy: 0.9249999999999999
Epoch: 5 cost: 2.621331806693759 Train accuracy: 0.9367559523809519 Val accuracy: 0.9265625000000001
Epoch: 6 cost: 1.855486837703558 Train accuracy: 0.9386160714285712 Val accuracy: 0.9140625
Epoch: 7 cost: 1.4325691219640986 Train accuracy: 0.952380952380952 Val accuracy: 0.9203125
Epoch: 8 cost: 0.8275154340302663 Train accuracy: 0.9494047619047616 Val accuracy: 0.91875
Epoch: 9 cost: 0.7480001917020198 Train accuracy: 0.9527529761904762 Val accuracy: 0.9249999999999998
No handles with labels found to put in legend.
Epoch: 10 cost: 0.5487094430829441 Train accuracy: 0.9609374999999996 Val accuracy: 0.9140624999999999
```



(vi) LR = 1e-3 and Regularization = 0.000001

```
Learning Rate:  0.001
Regularization: 1e-06
Epoch: 1 cost: 47.01901855922877 Train accuracy: 0.7607886904761905 Val accuracy: 0.71875
Epoch: 2 cost: 0.8035403951292946 Train accuracy: 0.8534226190476187 Val accuracy: 0.8078124999999999
Epoch: 3 cost: 0.3984398735421043 Train accuracy: 0.903645833333333 Val accuracy: 0.840625
Epoch: 4 cost: 0.2331328954370249 Train accuracy: 0.944940476190476 Val accuracy: 0.8546875
Epoch: 5 cost: 0.14898389400470824 Train accuracy: 0.9594494047619043 Val accuracy: 0.859375
Epoch: 6 cost: 0.13240406103432178 Train accuracy: 0.9631696428571423 Val accuracy: 0.8640625000000001
Epoch: 7 cost: 0.09706910841521764 Train accuracy: 0.970238095238095 Val accuracy: 0.8796875
Epoch: 8 cost: 0.08867691741103217 Train accuracy: 0.9758184523809523 Val accuracy: 0.90625
Epoch: 9 cost: 0.06896880912106662 Train accuracy: 0.9821428571428571 Val accuracy: 0.9
No handles with labels found to put in legend.
Epoch: 10 cost: 0.05465398174488827 Train accuracy: 0.9873511904761907 Val accuracy: 0.9125
```



Form the above results, we observe that after around 7 epochs the training accuracy starts to converge. When the learning rate is set to 1e6, the resulting cost is Nan, meaning the learning rate is too high. Similarly, with the learning rate set to 1e-6, the resulting cost hardly changes. So, it is not a good choice to begin with.

On the other hand, a learning rate of 1e-5 gives above 80% accuracy after just 3 epochs. Similarly, learning rate of 1e-3 gives very good results in 5 epochs while the results with 1e-4 are intermediate.

Grid Search:

With the help of the above obtained results, we choose the interval of {1e-5, 1e-3} as the optimum range for learning rate to perform a grid search. We randomly choose the interval {1e-6, 1e-1} as the interval for the regularization parameter.

The result of the grid search in the given interval are as follows:

```
Learning Rate: 0.0007739715701574621    Regularization: 0.027232221317058124
cost: 279.429115   train_acc: 0.914435   val_acc: 0.895833   learning_rate: 0.000774   regularization: 0.027232
cost: 194.118621   train_acc: 0.939360   val_acc: 0.922619   learning_rate: 0.000774   regularization: 0.027232
cost: 164.289490   train_acc: 0.965030   val_acc: 0.930060   learning_rate: 0.000774   regularization: 0.027232
cost: 143.291798   train_acc: 0.968006   val_acc: 0.947917   learning_rate: 0.000774   regularization: 0.027232
cost: 127.339594   train_acc: 0.980655   val_acc: 0.944940   learning_rate: 0.000774   regularization: 0.027232
cost: 114.591085   train_acc: 0.980655   val_acc: 0.961310   learning_rate: 0.000774   regularization: 0.027232
cost: 104.042154   train_acc: 0.986607   val_acc: 0.958333   learning_rate: 0.000774   regularization: 0.027232
cost: 95.099321   train_acc: 0.989583   val_acc: 0.964286   learning_rate: 0.000774   regularization: 0.027232
cost: 87.386940   train_acc: 0.982143   val_acc: 0.952381   learning_rate: 0.000774   regularization: 0.027232
cost: 80.653858   train_acc: 0.986979   val_acc: 0.964286   learning_rate: 0.000774   regularization: 0.027232
Learning Rate: 0.0009684275476647981    Regularization: 0.0930561458922304
cost: 827.764087   train_acc: 0.921503   val_acc: 0.898810   learning_rate: 0.000968   regularization: 0.093056
cost: 514.005814   train_acc: 0.947173   val_acc: 0.907738   learning_rate: 0.000968   regularization: 0.093056
cost: 419.468503   train_acc: 0.945685   val_acc: 0.912202   learning_rate: 0.000968   regularization: 0.093056
cost: 362.786183   train_acc: 0.970238   val_acc: 0.916667   learning_rate: 0.000968   regularization: 0.093056
cost: 321.657953   train_acc: 0.976562   val_acc: 0.937500   learning_rate: 0.000968   regularization: 0.093056
```

These results show that the cost is lower, and the train accuracy is maximum when the values of the learning rate are {0.000408, 0.000997, 0.000650} and those of the regularization parameter are {0.004467, 0.021295, 0.028364}.

So, to fine tune the parameters, for the next iteration we choose the interval of learning rate as {0.0003, 0.001} and that of regularization parameter as {0.004, 0.03}. The results are as follows:

```
Learning Rate: 0.0008979434014032659    Regularization: 0.022926700295143553
cost: 259.755096   train_acc: 0.925967   val_acc: 0.913690   learning_rate: 0.000898   regularization: 0.022927
cost: 168.542673   train_acc: 0.944940   val_acc: 0.904762   learning_rate: 0.000898   regularization: 0.022927
cost: 148.802040   train_acc: 0.887649   val_acc: 0.867560   learning_rate: 0.000898   regularization: 0.022927
cost: 134.661575   train_acc: 0.950521   val_acc: 0.913690   learning_rate: 0.000898   regularization: 0.022927
cost: 123.270767   train_acc: 0.942336   val_acc: 0.909226   learning_rate: 0.000898   regularization: 0.022927
cost: 113.623345   train_acc: 0.957961   val_acc: 0.925595   learning_rate: 0.000898   regularization: 0.022927
cost: 105.224940   train_acc: 0.969866   val_acc: 0.937500   learning_rate: 0.000898   regularization: 0.022927
cost: 97.715623   train_acc: 0.969866   val_acc: 0.937500   learning_rate: 0.000898   regularization: 0.022927
cost: 91.007600   train_acc: 0.978423   val_acc: 0.938988   learning_rate: 0.000898   regularization: 0.022927
cost: 84.925499   train_acc: 0.979539   val_acc: 0.941964   learning_rate: 0.000898   regularization: 0.022927
Learning Rate: 0.0003678891002707259    Regularization: 0.02018182998546159
cost: 209.058387   train_acc: 0.875744   val_acc: 0.877976   learning_rate: 0.000368   regularization: 0.020182
cost: 155.999784   train_acc: 0.939360   val_acc: 0.922619   learning_rate: 0.000368   regularization: 0.020182
cost: 136.219992   train_acc: 0.955729   val_acc: 0.913690   learning_rate: 0.000368   regularization: 0.020182
cost: 122.332850   train_acc: 0.959449   val_acc: 0.936012   learning_rate: 0.000368   regularization: 0.020182
cost: 111.858970   train_acc: 0.957961   val_acc: 0.912202   learning_rate: 0.000368   regularization: 0.020182
cost: 103.595679   train_acc: 0.974330   val_acc: 0.947917   learning_rate: 0.000368   regularization: 0.020182
```

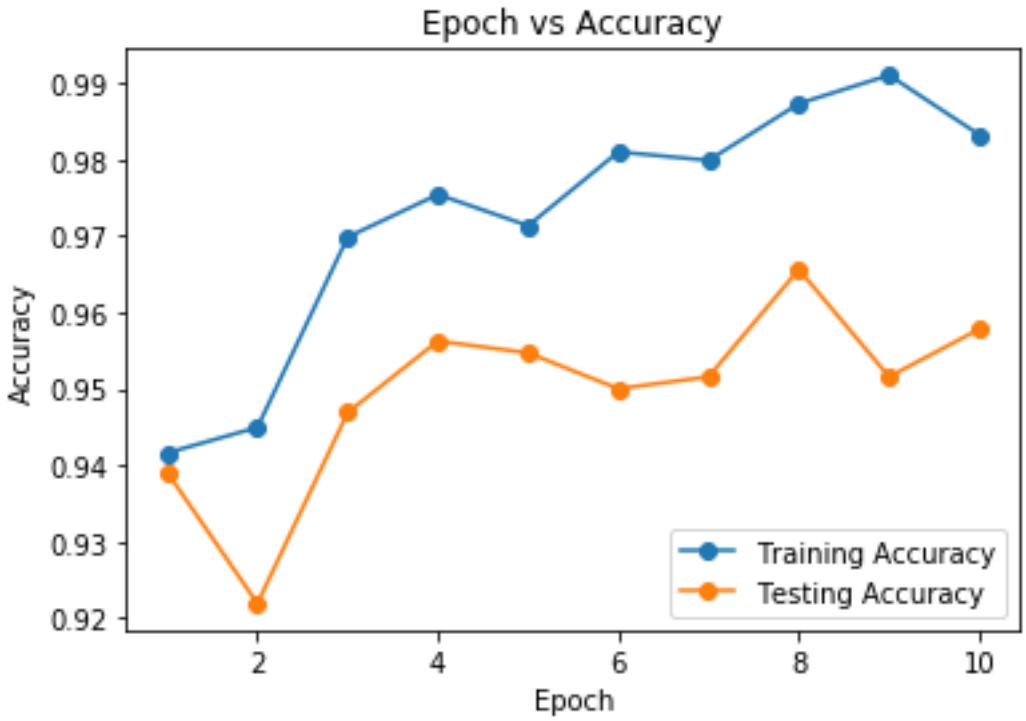
These results show that the minimum cost and maximum accuracy occurs at the learning rates of {0.000754, 0.000916, 0.000725} and regularization parameters of {0.008611, 0.011862, 0.009613}.

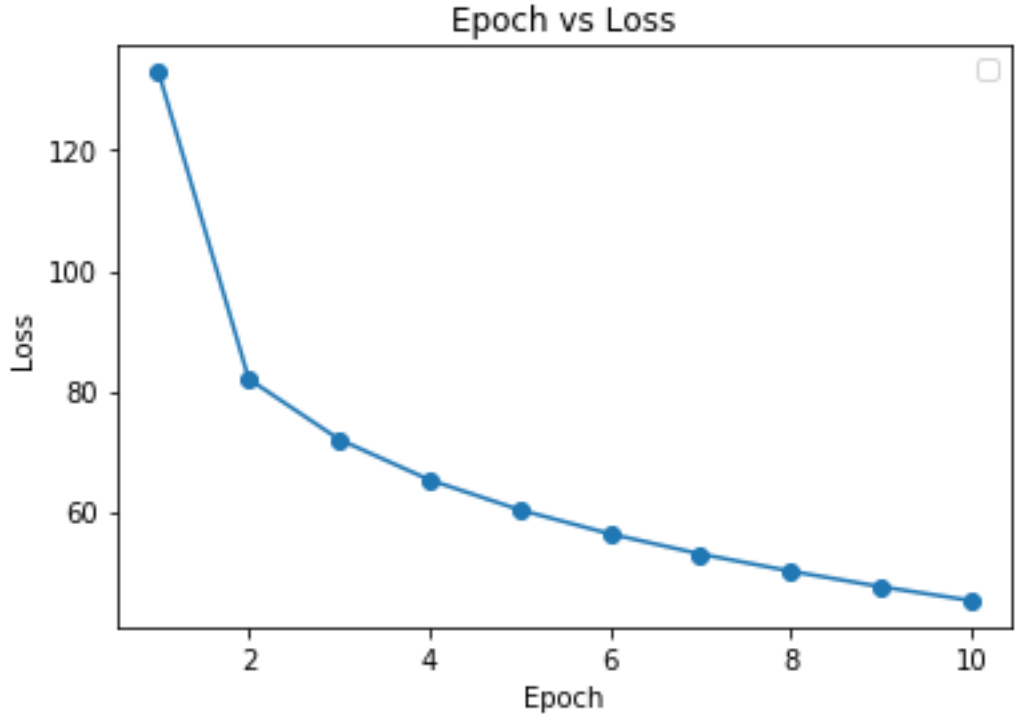
So, on an average, the ideal parameters for the neural network would be at learning rate of 0.0007983 and regularization parameter of 0.0100286.

Now the network is trained on the entire data with these hyper-parameters. The training and the testing data are standardized (lie between 0 to 1) for pre-processing.

The results on pre-processed data are as follows:

```
Learning Rate:  0.0007983
Regularization: 0.0100286
Epoch: 1 cost: 132.99868683587937 Train accuracy: 0.9415922619047616 Val accuracy: 0.9390625
Epoch: 2 cost: 81.98008074079242 Train accuracy: 0.9449404761904757 Val accuracy: 0.9218749999999999
Epoch: 3 cost: 71.95983850388302 Train accuracy: 0.9698660714285713 Val accuracy: 0.9468749999999999
Epoch: 4 cost: 65.2314524877639 Train accuracy: 0.9754464285714284 Val accuracy: 0.95625
Epoch: 5 cost: 60.23896117437454 Train accuracy: 0.9713541666666664 Val accuracy: 0.9546875
Epoch: 6 cost: 56.24353381565641 Train accuracy: 0.9810267857142856 Val accuracy: 0.95
Epoch: 7 cost: 52.89785548618861 Train accuracy: 0.9799107142857143 Val accuracy: 0.9515624999999999
Epoch: 8 cost: 50.04372696649462 Train accuracy: 0.9873511904761906 Val accuracy: 0.9656250000000001
Epoch: 9 cost: 47.457935787382574 Train accuracy: 0.991071428571429 Val accuracy: 0.9515625000000001
Epoch: 10 cost: 45.15886551993233 Train accuracy: 0.9832589285714286 Val accuracy: 0.9578125
```


Epoch vs Accuracy
Accuracy
Epoch
Training Accuracy
Testing Accuracy
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
2
4
6
8
10


Epoch vs Loss
Loss
Epoch
120
100
80
60
2
4
6
8
10