Assignment 3

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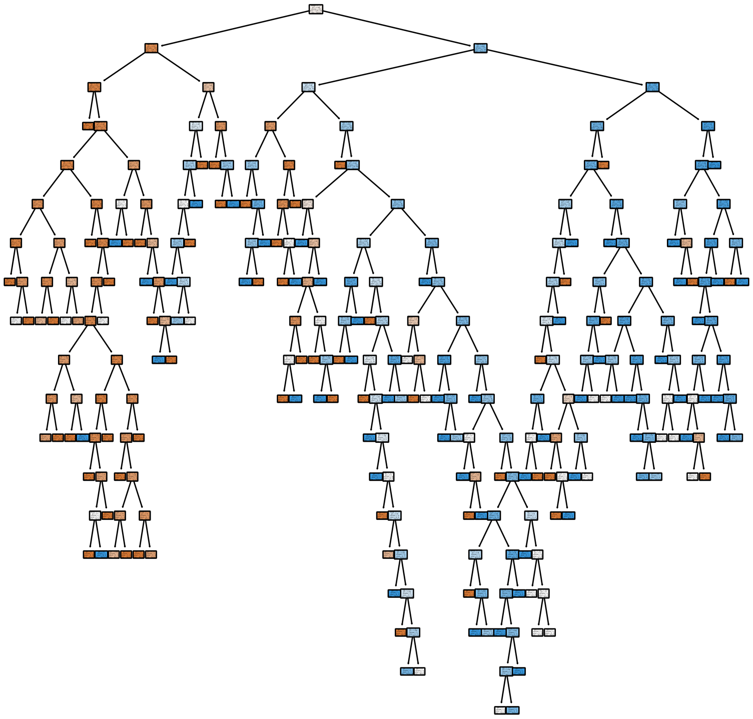
Libraries used : numpy, pandas, xgboost, lightgbm, np_utils, sklearn, mlp-classifier

1 Q1

1.1 Dataset 1

1.1.1 a

Training accuracy : 0.9252747252747253
Validation accuracy : 0.7603305785123967
Test accuracy : 0.6877470355731226

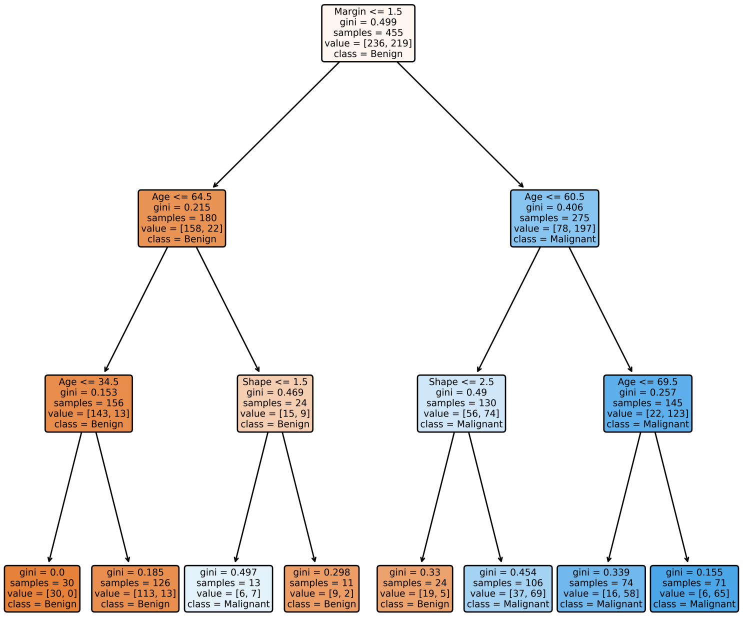


1.1.2 b

DecisionTreeClassifier(max_depth=3, min_samples_leaf=10, min_samples_split=4)

Training accuracy : 0.8131868131868132
Validation accuracy : 0.8760330578512396
Test accuracy : 0.7549407114624506

As we can see there is quite a significant improvement after we used grid-search. This is because we have searched over a large space of parameters to get to the best parameters which has helped in fine tuning my model.

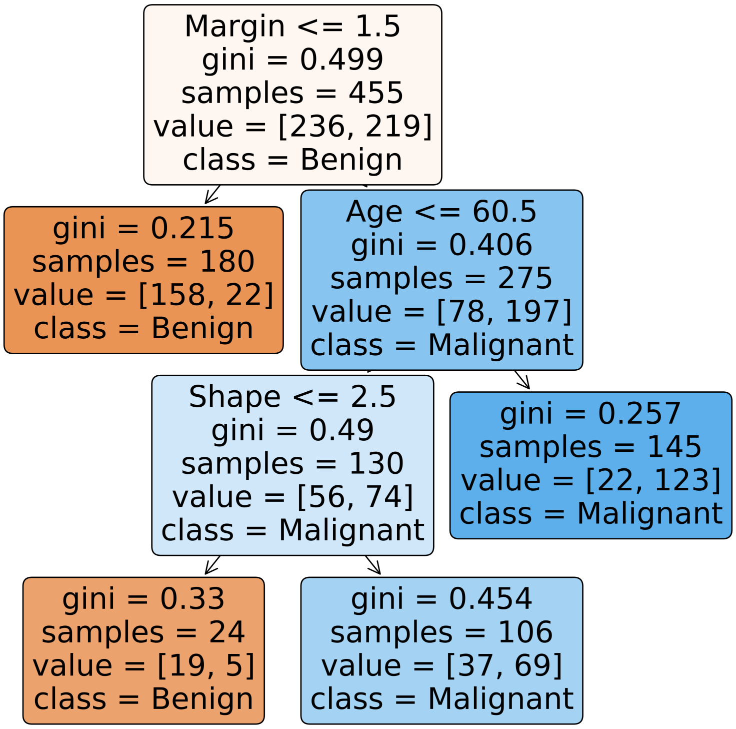


The tree obtained here has lesser depth with higher test and validation accuracy this says that we have been able to generalise the data well enough to stop overfitting that was happening in part a.

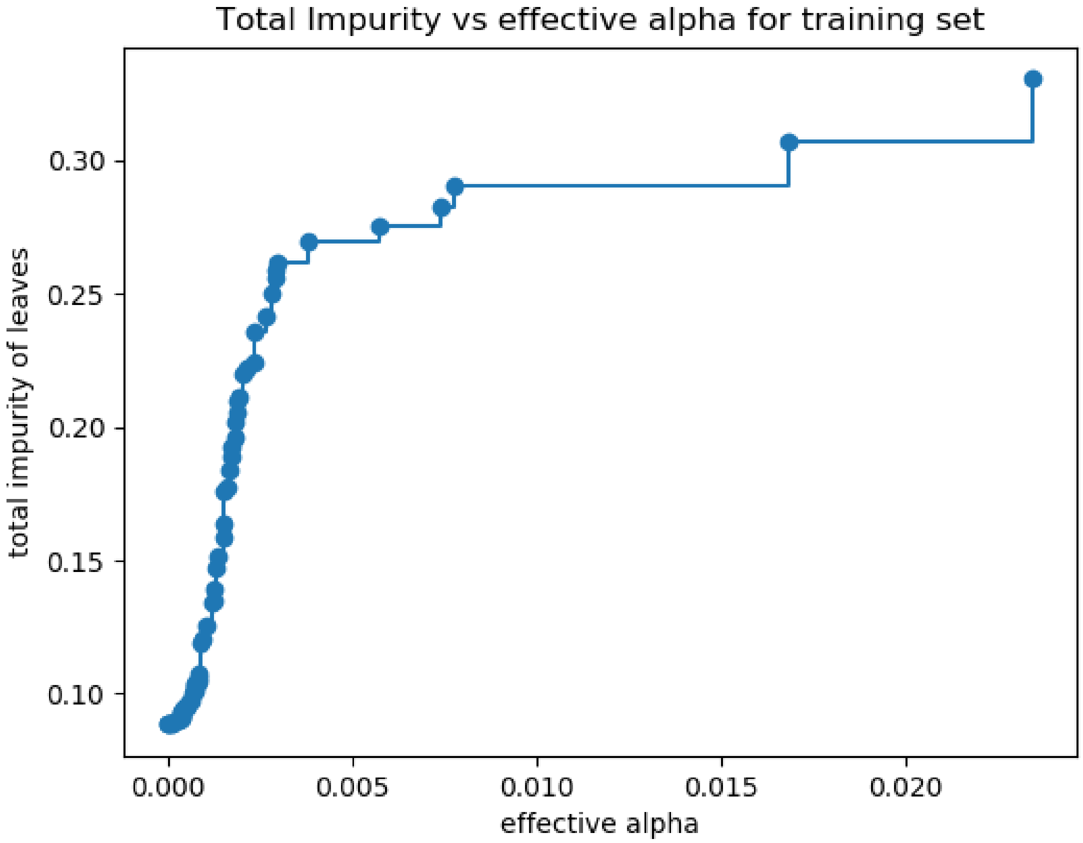
1.1.3 c

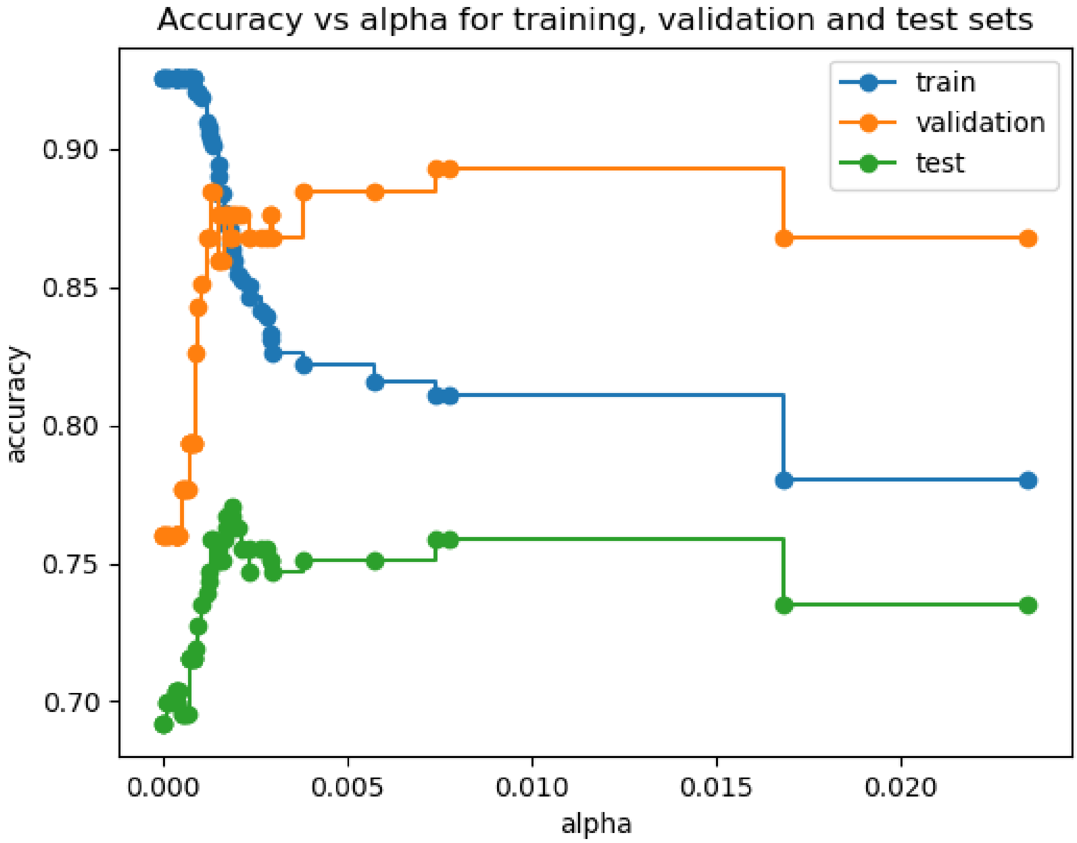
The best ccp_alpha obtained was 0.015. At this value of alpha, we got the best validation accuracy. almost 90% validation accuracy.

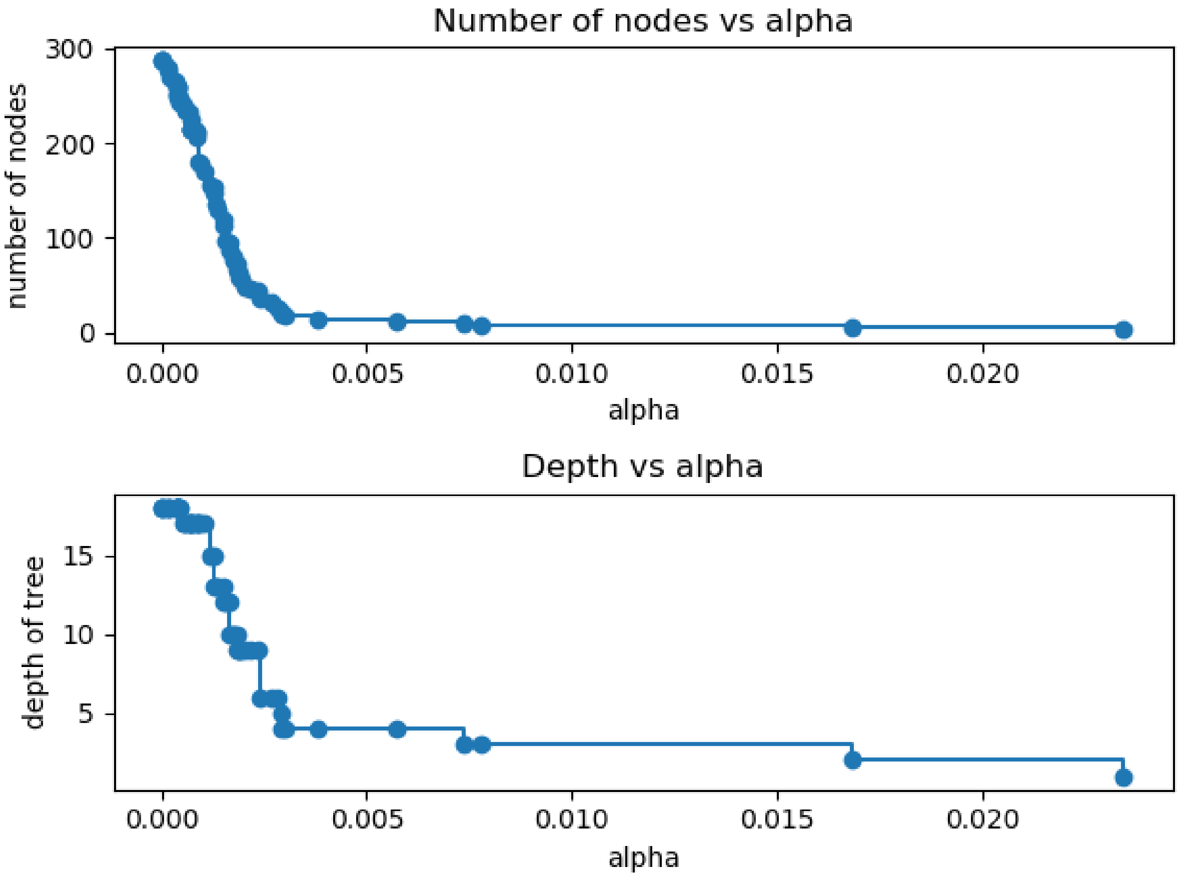
Training accuracy : 0.810989010989011
Validation accuracy : 0.8925619834710744
Test accuracy : 0.758893280632411



Compared to parts a and b, part c has higher test accuracy hence selective pruning definitely helps.


Total Impurity vs effective alpha for training set
total impurity of leaves
0.10
0.15
0.20
0.25
0.30
0.000
0.005
0.010
0.015
0.020
effective alpha


Accuracy vs alpha for training, validation and test sets
train
validation
test
accuracy
0.70
0.75
0.80
0.85
0.90
alpha
0.000
0.005
0.010
0.015
0.020



1.1.4 d

Optimal set of parameters are:
RandomForestClassifier(max_features=2, min_samples_split=6, n_estimators=120)

Training accuracy : 0.8791208791208791
Out of bag accuracy : 0.7626373626373626
Validation accuracy : 0.8760330578512396
Test accuracy : 0.7747035573122529

Random forest is definitely better than the decision tree model we implemented, since we can see 77.4% test accuracy > 75% test accuracy in case of gridsearchcv decision tree.

1.1.5 e

1. imputer strategy is median

   ```
   Standard Decision Tree Classifier
   Training accuracy : 0.9180633147113594
   Validation accuracy : 0.7407407407407407
   Test accuracy : 0.7326388888888888

   DecisionTreeClassifier(max_depth=3, min_samples_leaf=6, min_samples_split=4)
   Training accuracy : 0.8026070763500931
   Validation accuracy : 0.8592592592592593
   Test accuracy : 0.7708333333333334

   DecisionTreeClassifier(ccp_alpha=0.015)
   Training accuracy : 0.8007448789571695
   Validation accuracy : 0.8666666666666667
   Test accuracy : 0.7743055555555556

   RandomForestClassifier(max_features=3, min_samples_split=7, n_estimators=120)
   Training accuracy : 0.8752327746741154
   Validation accuracy : 0.8444444444444444
   Test accuracy : 0.78125
   ```

2. imputer strategy is mean

   ```
   Standard Decision Tree Classifier
   Training accuracy : 0.925512104283054
   Validation accuracy : 0.7777777777777778
   Test accuracy : 0.6909722222222222

   DecisionTreeClassifier(max_depth=3, min_samples_leaf=4, min_samples_split=4)
   Training accuracy : 0.8026070763500931
   Validation accuracy : 0.8592592592592593
   Test accuracy : 0.7673611111111112

   DecisionTreeClassifier(ccp_alpha=0.015)
   Training accuracy : 0.7635009310986964
   Validation accuracy : 0.837037037037037
   Test accuracy : 0.75

   RandomForestClassifier(max_features=3, min_samples_split=6, n_estimators=120)
   Training accuracy : 0.8770949720670391
   Validation accuracy : 0.8518518518518519
   Test accuracy : 0.7708333333333334
   ```

We can see higher accuracies when we do imputation of data, more when imputer strategy is median - i.e. test accuracy is 73.26% when using imputation compared to 68% when we were just dropping the missing values. The reason for this is possibly the fact that we have now more data hence we are able to train better and thus we are getting better accuracies.

Exhaustively comparing with parts a-d, we get

1. imputer gives better accuracy (73 % compared to 68%) on standard decision tree.
2. imputer gives better accuracy (77% compared to 75%) on gridsearchcv.
3. imputer gives better accuracy (77% compared to 75%) after cost complexity pruning.
4. imputer gives better accuracy (78% compared to 77%) after random forest.

Finally among imputer mean and median, imputer median gives better accuracy overall (improvement around 1% on average).

1.1.6 f

Optimal set of parameters are:
XGBClassifier(base_score=0.5, booster='gbtree', colsample_bylevel=1, colsample_bynode=1, colsample_bytree=1, learning_rate=0.300000012, max_bin=256, max_depth=10, max_leaves=0, min_child_weight=1, missing=nan, n_estimators=10, num_parallel_tree=1, random_state=0)

Training accuracy : 0.8361266294227188
Validation accuracy : 0.8444444444444444
Test accuracy : 0.7708333333333334

1.2 Dataset 2

Note : This took a really long time to completely run the parts. The resources used include Jupyter notebook, Google Colab, Ubuntu VirtualBox.

1.2.1 a

Training accuracy : 1.0
Validation accuracy : 0.5765153237305999
Test accuracy : 0.5738198861734182

This is standard decision tree classifier.

1.2.2 b

Training accuracy : 0.9986733573722
Validation accuracy : 0.5806153237305999
Test accuracy : 0.57709198861734182

This is running the decision tree classifier on gridsearch over a large set of parameters- final optimal parameters include max_depth = 200, min_samples_split = 2, min_samples_leaf = 1.

This gives a higher accuracy as compared to standard decision tree classifier.

1.2.3 c

Training accuracy : 0.9887264862483
Validation accuracy : 0.5815576789569
Test accuracy : 0.58544343242434532

Best alpha is 0.02 since we have highest validation accuracy for that value.

We can see slight improvement over gridsearch model.

1.2.4 d

Training accuracy : 0.9942343255242
Out-of-bag accuracy : 0.5578236482364
Validation accuracy : 0.5797238972843
Test accuracy : 0.57876487628943

Random forest classifier gives almost similar accuracies as ccp_alpha.

Optimal set of parameters obtained: n estimators = 450, max_features = 0.8, min_samples_split = 2

1.2.5 e

Training accuracy : 0.9978634762387
Validation accuracy : 0.57651532895897
Test accuracy : 0.579874897988495

XGBoost gives almost similar accuracies as ccp_alpha.

1.2.6 f

Training accuracy : 0.997897488978478
Validation accuracy : 0.6565153237305999
Test accuracy : 0.6338198861734182

LightGBM really increased the accuracy and it also took much less time compared to the other parts. Optimal parameters were obtained for n_estimators = 1500.

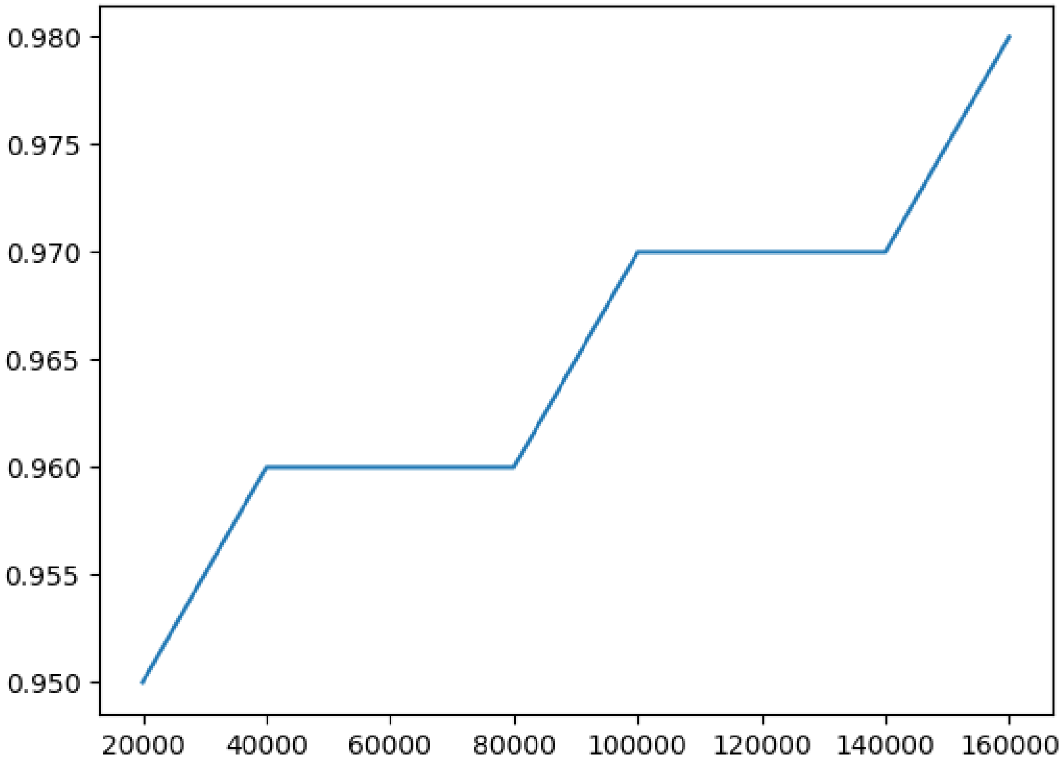
Parameter grid on which LightGBM is run is:
parameters = 'max_depth': np.arange(40,500,10), 'subsample': np.arange(0.4,2.0,0.1), 'n_estimators': np.arange(50,2000,50)

Comparison of running times:

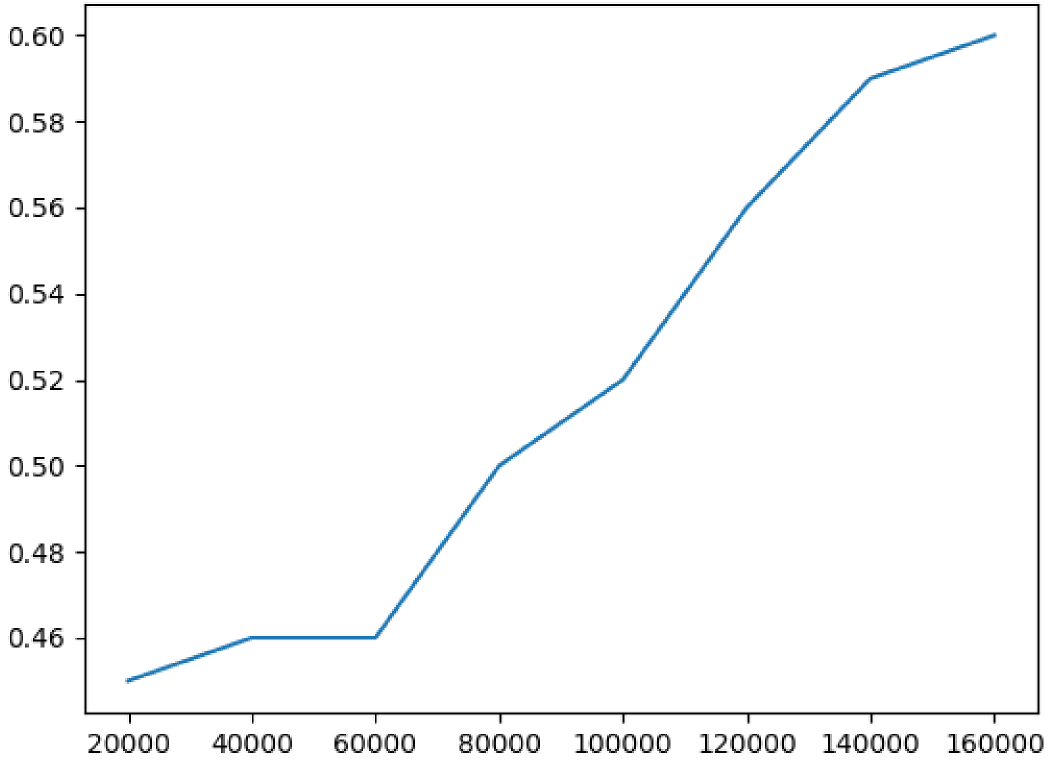
1. Standard decision tree learner with gridsearch : approx 8 hours
2. Decision tree with pruning : approx 15 days
3. Random forest : approx 10 days
4. XGBoost : approx 3 days
5. LightGBM : approx 6 hours (hence the fastest and also gave higher accuracy)

1.2.7 g

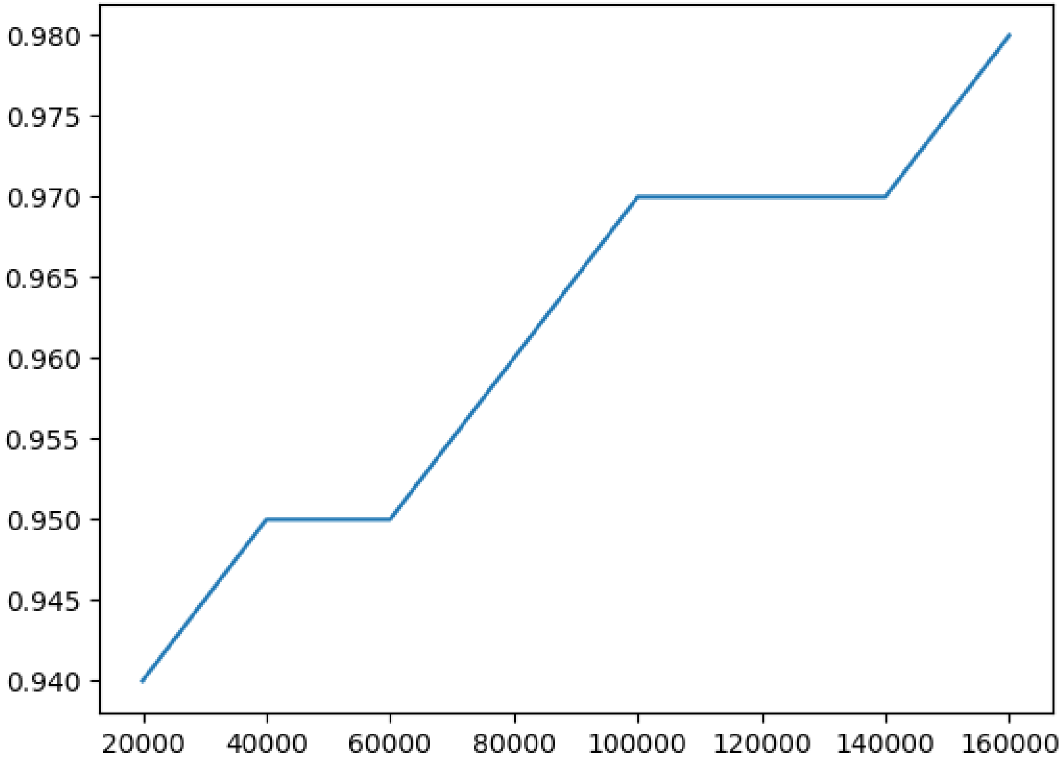
Plot for gridsearch train accuracies vs n



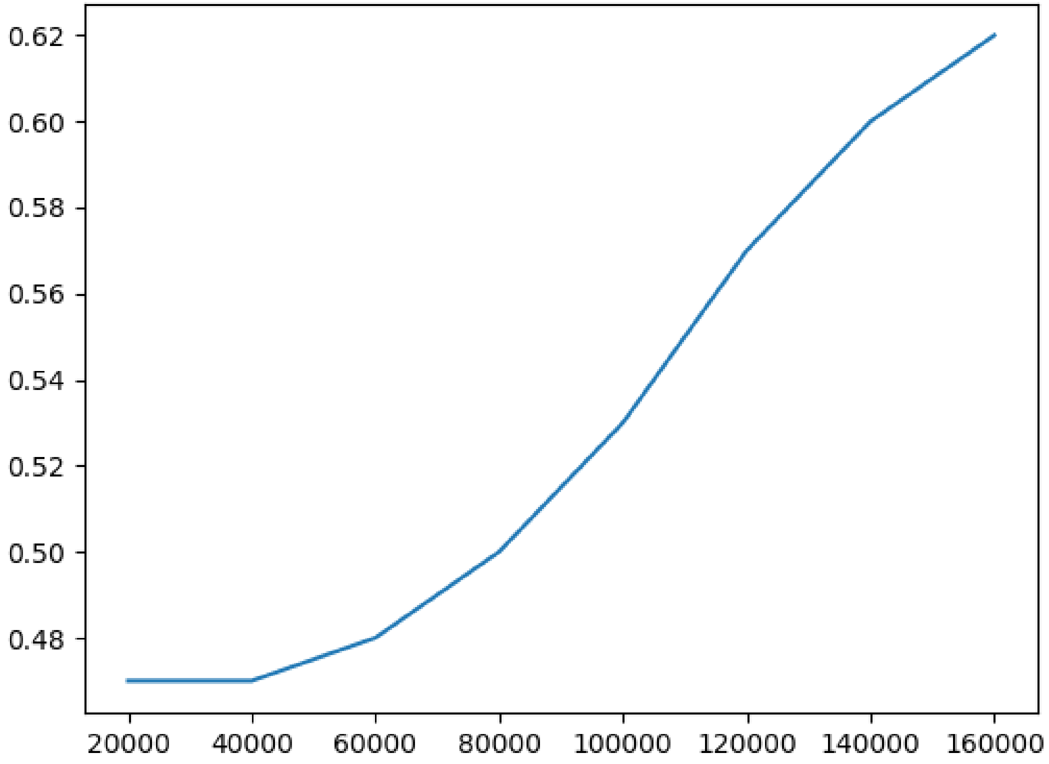
Plot for gridsearch test accuracies vs n



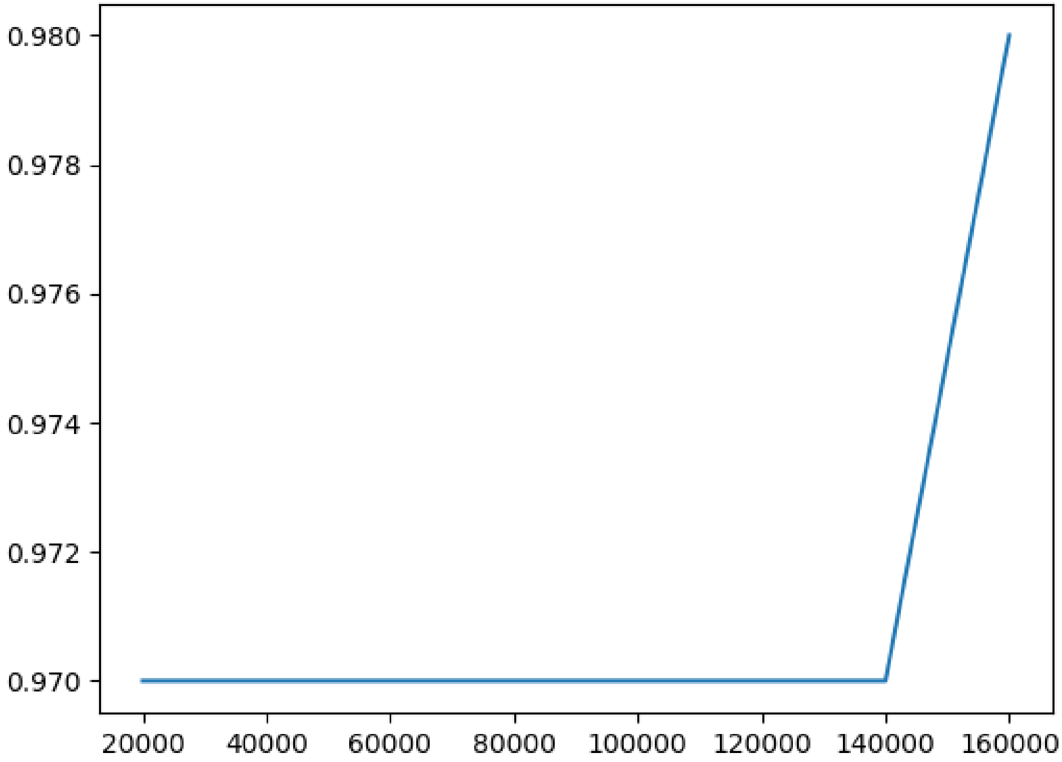
Plot for cost complexity pruning train accuracies vs n



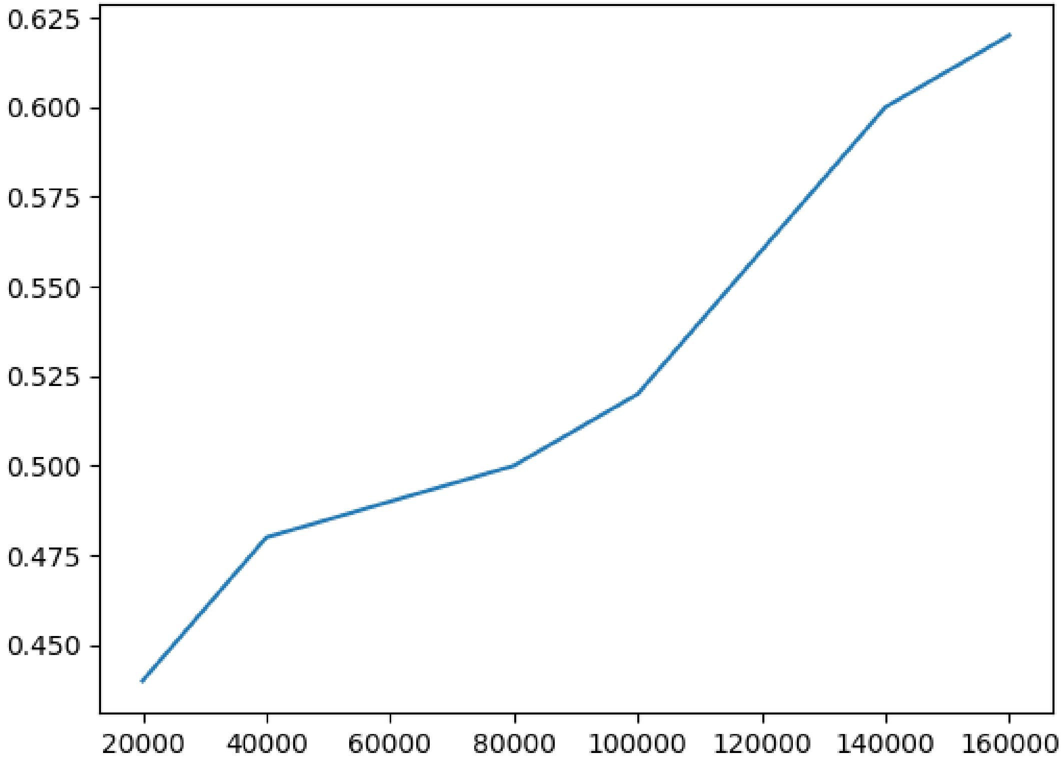
Plot for cost complexity pruning test accuracies vs n



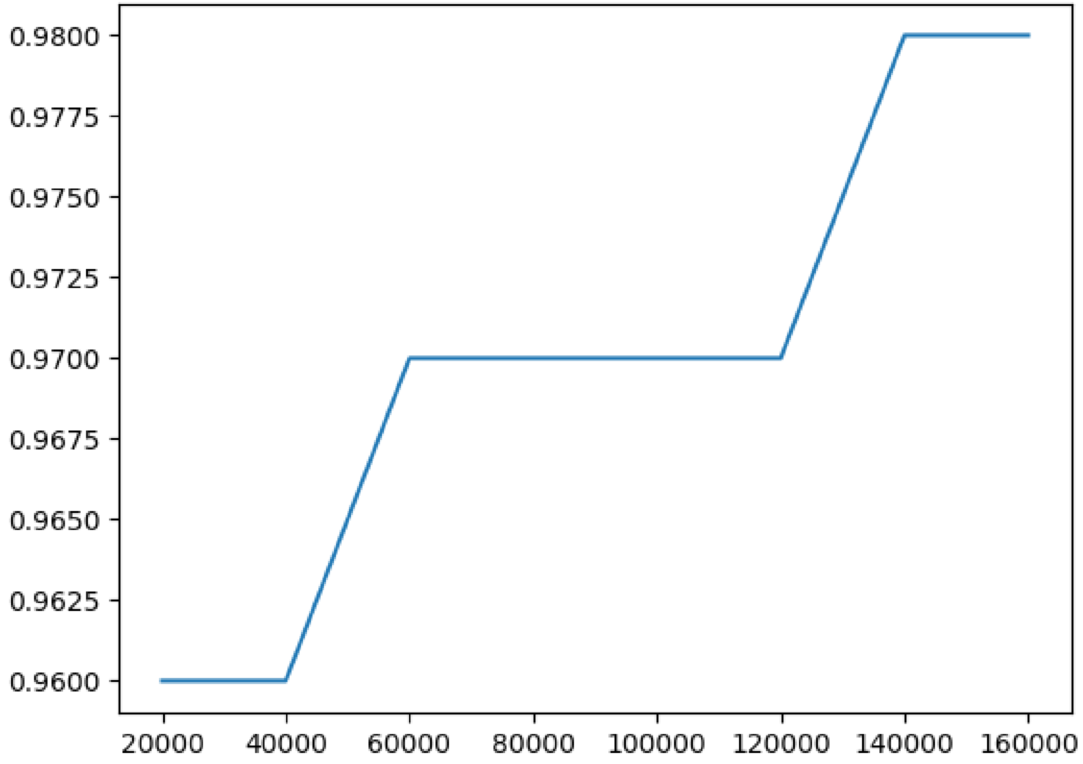
Plot for random forest train accuracies vs n



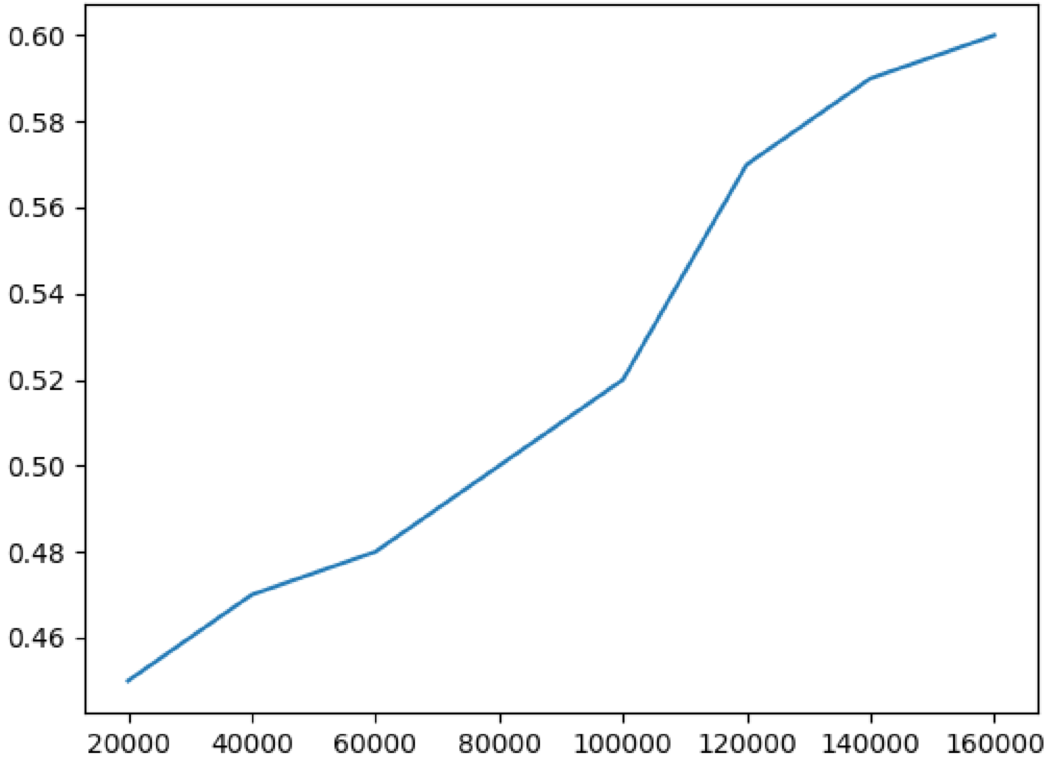
Plot for random forest test accuracies vs n



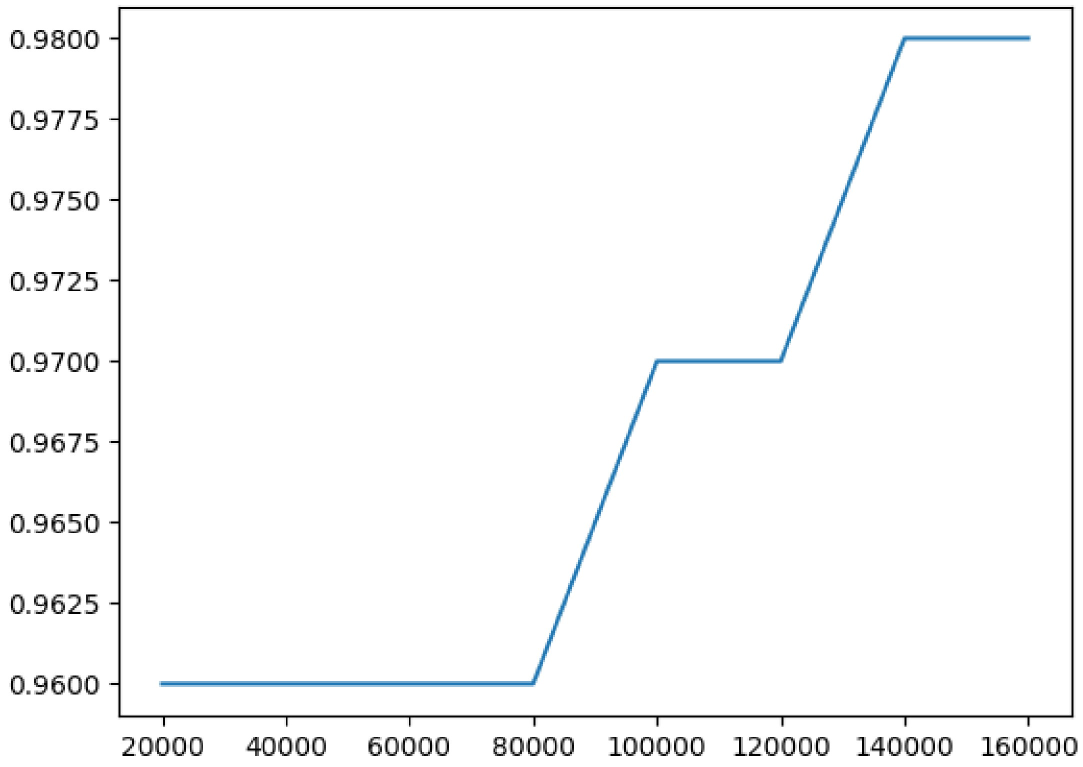
Plot for XGB Classifier train accuracies vs n



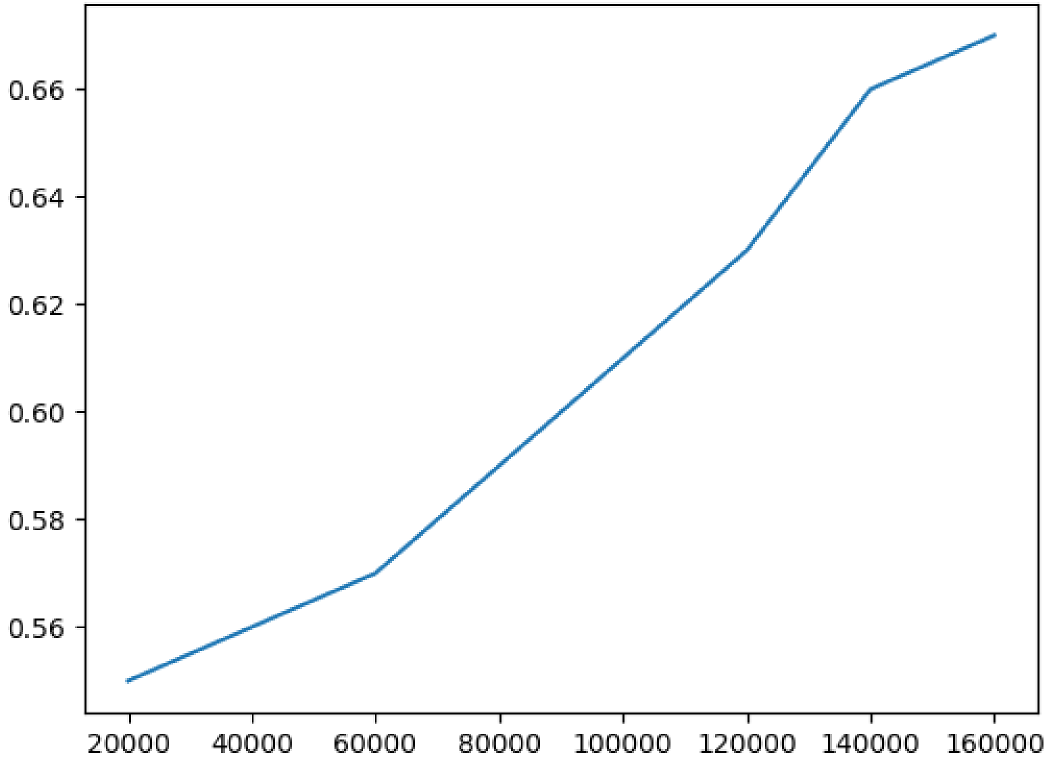
Plot for XGB Classifier test accuracies vs n



Plot for LGB Classifier train accuracies vs n



Plot for LGB Classifier test accuracies vs n



2 Q2

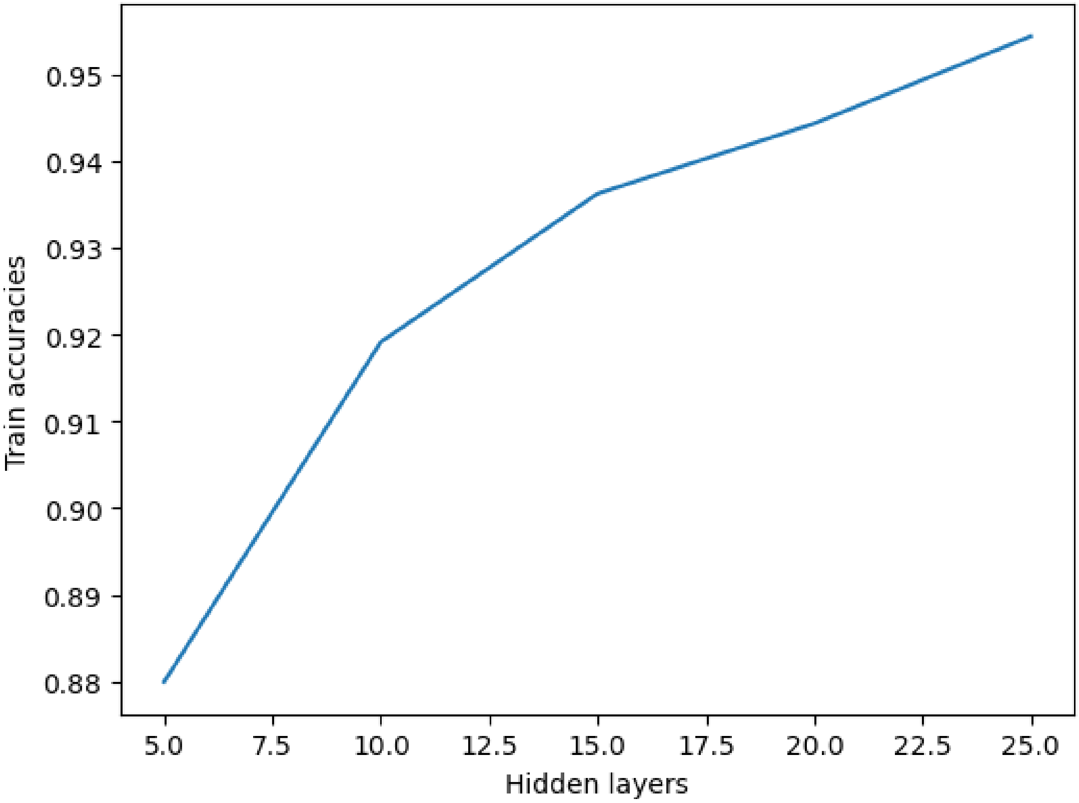
2.1 a

We first converted the y values to one hot encoding and used forward and back propagation alternatively for some number of iterations.

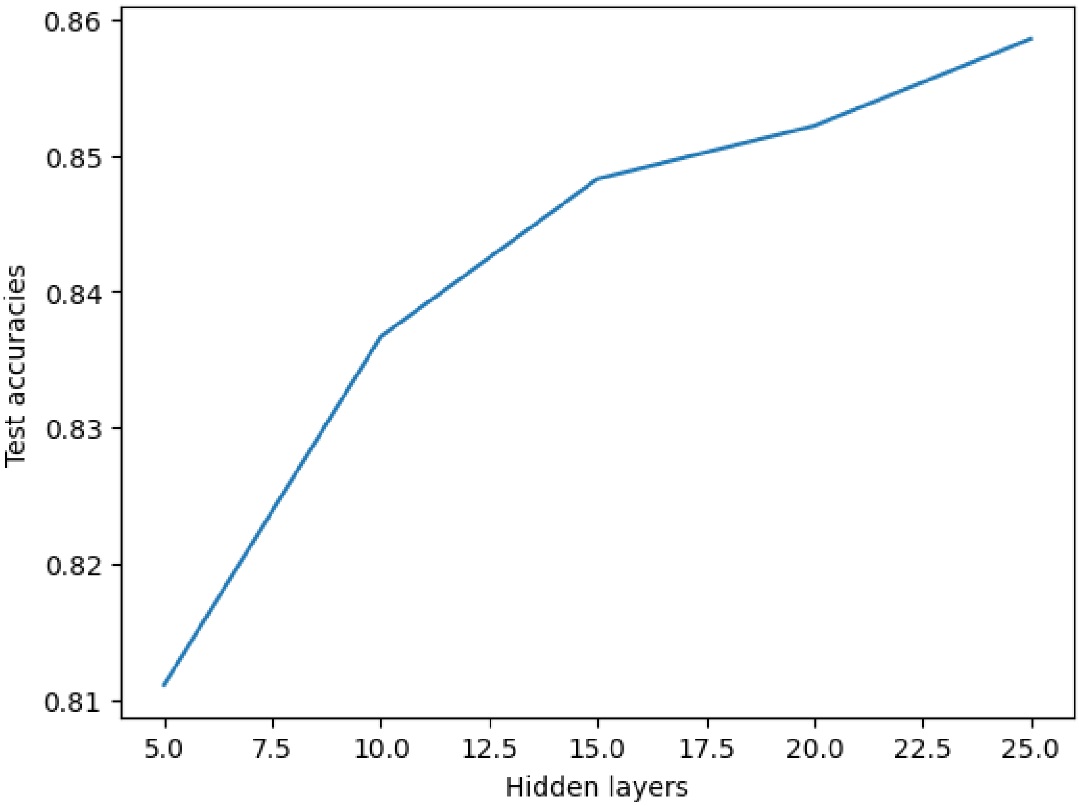
2.2 b

Stopping criterion : When the difference in previous cost and current cost falls below a certain threshold which I have kept to be 1e-9 and also I have kept an upper bound on the number of iterations(1000) in case it takes a long time to converge.

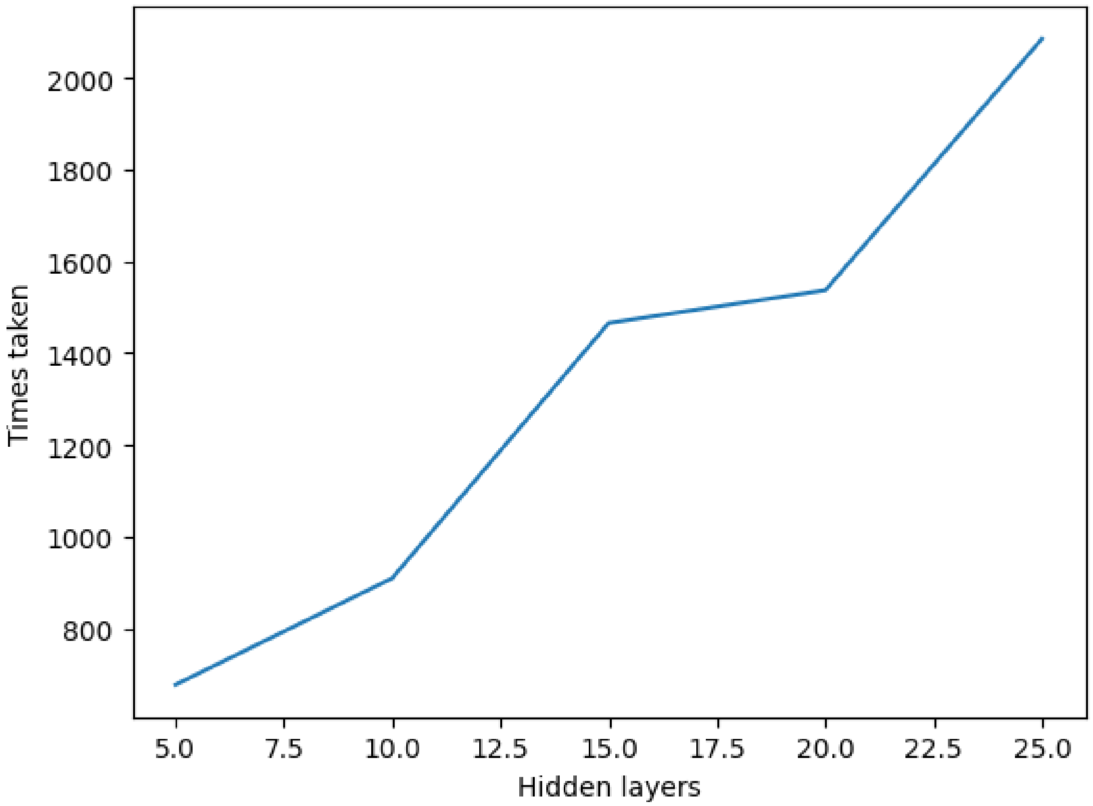
Plot for training accuracy vs hidden layer



Plot for test accuracy vs hidden layer



Plot for time taken vs hidden layer



Statistics for the hidden layers:

1. 5

```
Accuracy of train is 0.8799646660777679
Accuracy of test is 0.8110811081108111
[[770   4  22  87   8   0  93   2  14   0]
 [  9 940   8  30   4   0   0   0   8   1]
 [ 22   2 710  12 150   0  88   0  16   0]
 [ 72  25  12 790  45   0  44   0  12   0]
 [  0   0 123  35 730   0  91   0  21   0]
 [  1   0   0   0   0 886   0  58   2  53]
 [148   4 112  54 118   0 534   0  30   0]
 [  2   0   0   0   0  46   0 918   0  34]
 [  7   9  13   6  13   5  25   6 916   0]
 [  0   0   0   0   1  30   1  51   0 916]]
```

2. 10

```
Accuracy of train is 0.9191486524775413
Accuracy of test is 0.8366836683668367
[[794   5   7  44   2   2 131   2  12   1]
 [  2 963   3  23   3   0   4   1   1   0]
 [ 18   2 734  15 120   2  98   1  10   0]
 [ 26  17  19 854  29   4  44   2   4   1]
 [  3   0 118  50 726   3  96   0   4   0]
 [  1   0   0   1   3 890   0  60  12  33]
 [120   3 120  41  91   3 603   1  17   1]
 [  0   0   0   0   0  28   0 937   2  33]
 [ 11   3   6   7   6   4  18   8 934   3]
 [  0   0   1   0   0  15   1  49   2 931]]
```

3. 15

   ```
   Accuracy of train is 0.9362489374822913
   Accuracy of test is 0.8482848284828483
   [[802   3  17  49   3   1 114   0  11   0]
    [  7 956   5  25   4   0   2   0   1   0]
    [ 14   4 763  13 109   1  86   1   9   0]
    [ 36  14  12 867  26   0  32   1  10   2]
    [  2   2 109  37 744   2  94   0  10   0]
    [  1   1   0   1   0 916   0  46   4  31]
    [130   6  96  40  80   0 623   2  21   2]
    [  0   0   0   0   0  31   0 934   0  35]
    [  5   2  11  10   2   5  19   6 940   0]
    [  0   0   0   0   0  16   1  45   0 937]]
   ```

4. 20

   ```
   Accuracy of train is 0.9443324055400923
   Accuracy of test is 0.8521852185218521
   [[780   2  14  51   5   2 128   0  17   1]
    [  4 956   3  26   3   0   7   0   1   0]
    [ 15   3 733  14 127   2  99   1   6   0]
    [ 32  15  14 877  26   0  30   1   5   0]
    [  0   3  99  41 766   0  83   0   8   0]
    [  0   0   0   2   0 921   0  41   3  33]
    [124   1  85  36  80   1 654   0  18   1]
    [  0   0   0   0   0  25   0 944   0  31]
    [  4   1  10   5   7   4  15   6 948   0]
    [  1   0   0   0   0  10   0  45   1 942]]
   ```

5. 25

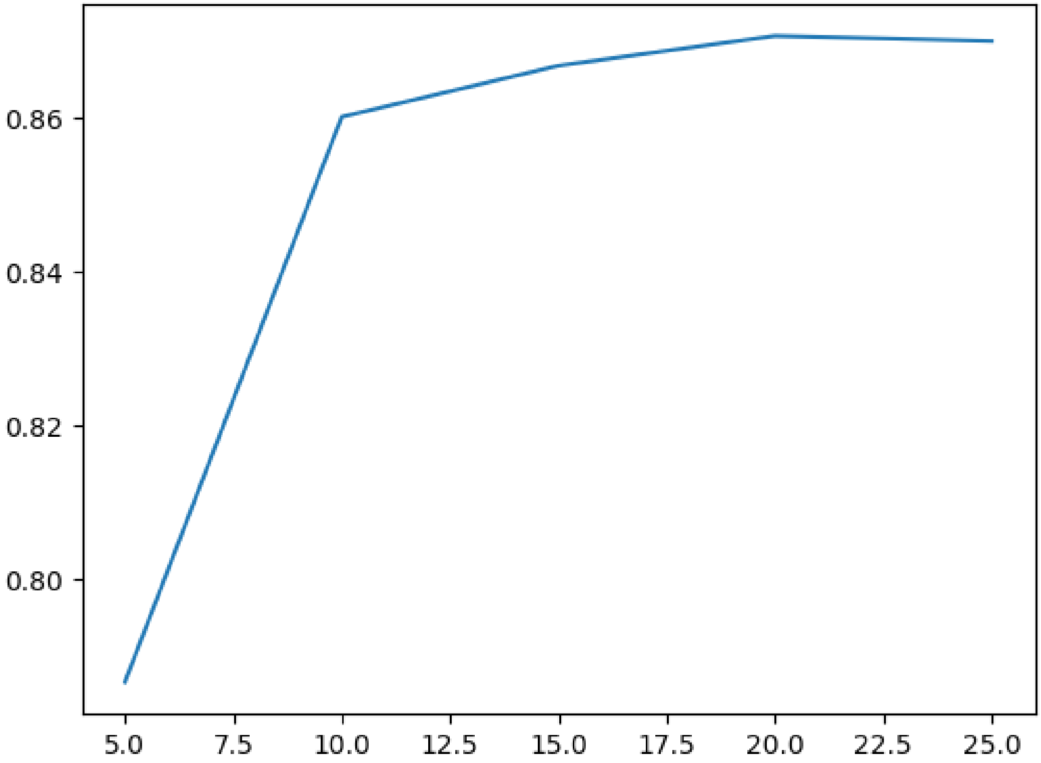
```
Accuracy of train is 0.9543992399873331
Accuracy of test is 0.8585858585858586
[[795   1  13  42   5   1 129   0  14   0]
 [  4 958   2  27   6   0   2   0   1   0]
 [ 15   4 769  16  94   0  91   1  10   0]
 [ 29  16  16 881  29   0  25   0   4   0]
 [  1   1 103  36 776   3  75   0   5   0]
 [  0   0   0   1   0 930   0  41   4  24]
 [131   1  96  43  81   0 635   0  13   0]
 [  0   0   0   0   0  23   0 943   0  34]
 [  5   1   7   6   5   2  12   4 956   2]
 [  0   0   1   0   0   9   0  45   2 942]]
```

We can see as the number of units in the hidden layer increases, the accuracy increases, this is justifiable since the input is large hence more units will be able to capture the input information better.

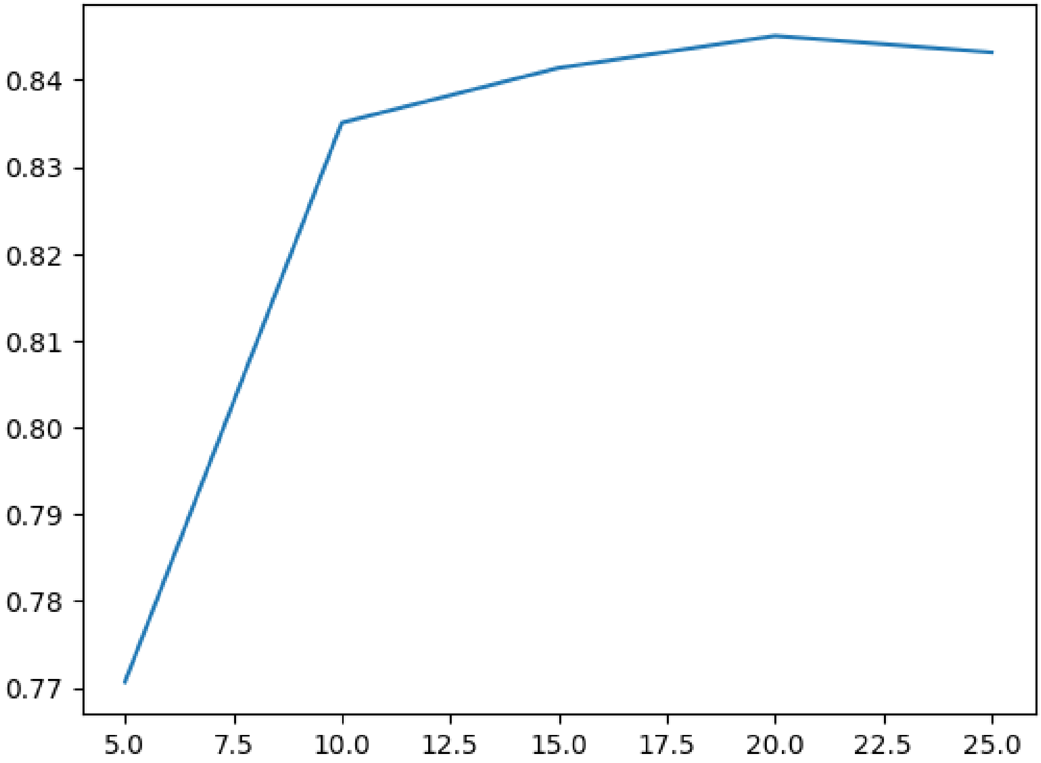
2.3 c

Stopping criterion : When the difference in previous cost and current cost falls below a certain threshold which I have kept to be 1e-9 and also I have kept an upper bound on the number of iterations(1000) in case it takes a long time to converge.

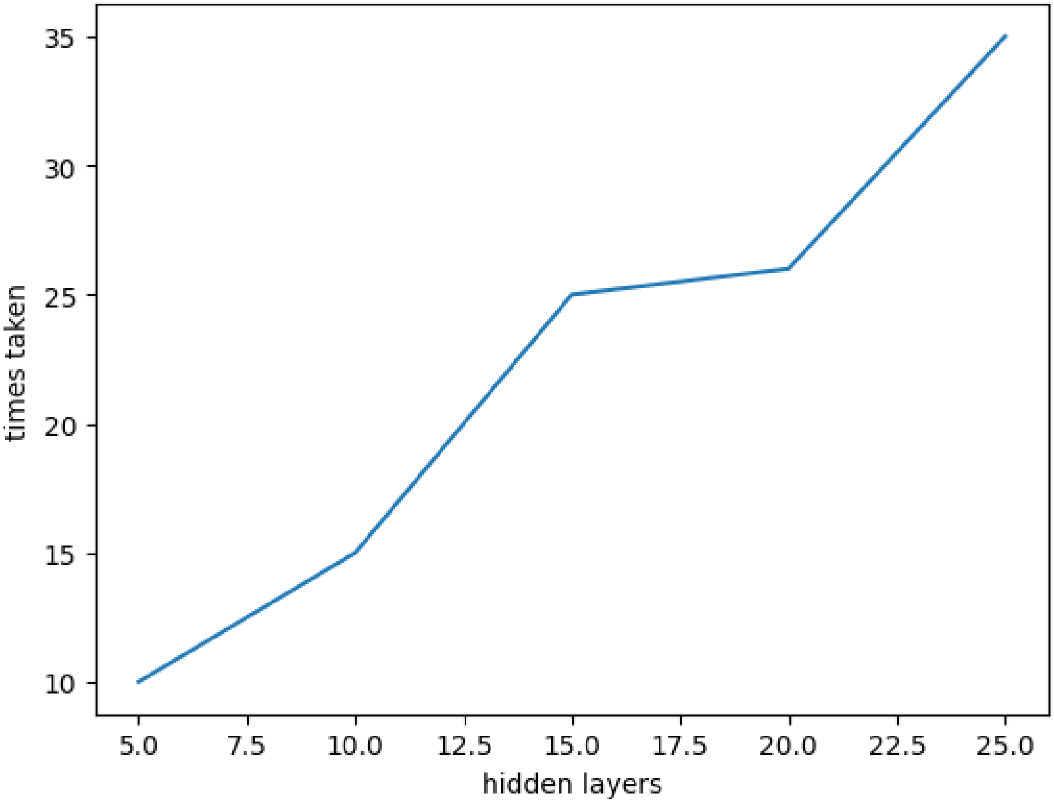
Plot for training accuracy vs hidden layer



Plot for test accuracy vs hidden layer



Plot for time taken vs hidden layer



Statistics for the hidden layers:

1. 5

```
Accuracy of train is 0.7866297771629527
Accuracy of test is 0.7706770677067707
[[861   2  25  61   8   2  13   0  28   0]
 [  2 942  13  33   4   1   1   0   4   0]
 [ 42   6 592   5 298   1  26   0  30   0]
 [ 74  17   7 849  24   0  16   0  13   0]
 [ 12  12 121  41 785   0  18   0  11   0]
 [  0   0   0   1   1 845   0  77   8  68]
 [301   1 180  45 371   0  53   0  49   0]
 [  0   0   0   0   0  42   0 914   0  44]
 [ 12   1  17  11   2   5   2   4 943   3]
 [  0   1   0   0   0  27   0  48   1 922]]
```

2. 10

```
Accuracy of train is 0.860197669961166
Accuracy of test is 0.8350835083508351
[[815   3  13  58   5   3  89   0  14   0]
 [  2 952   8  29   7   0   1   0   1   0]
 [ 16   4 757  11 136   1  63   0  12   0]
 [ 44  13  16 851  40   1  31   1   3   0]
 [  2   1  97  38 776   0  79   0   7   0]
 [  0   0   0   1   0 898   0  55   7  39]
 [159   1 132  45 120   1 513   0  29   0]
 [  0   0   0   0   0  33   0 916   0  51]
 [  6   2  13   6   6   4  20   5 938   0]
 [  0   0   0   0   0  20   0  44   1 934]]
```

3. 15

```
Accuracy of train is 0.8668644477407956
Accuracy of test is 0.8413841384138414
[[828   3  17  35   6   3  93   0  15   0]
 [  3 951   9  28   6   0   1   0   2   0]
 [ 17   2 747  14 140   2  67   0  11   0]
 [ 36  15  11 855  41   0  38   0   3   1]
 [  0   2 109  34 773   3  71   0   8   0]
 [  0   0   0   2   0 910   0  51   8  29]
 [163   2 129  41 109   0 530   0  26   0]
 [  0   0   0   0   0  34   0 924   0  42]
 [  2   2  10   7   2   3  15   5 954   0]
 [  0   0   0   0   0  13   1  44   0 941]]
```

4. 20

```
Accuracy of train is 0.8707478457974299
Accuracy of test is 0.845084508450845
[[828   1  12  40   4   5  93   0  17   0]
 [  3 952   7  29   6   0   2   0   1   0]
 [ 18   1 750   9 134   2  73   0  13   0]
 [ 30  12  12 866  34   0  41   0   5   0]
 [  0   0 106  37 770   0  81   0   6   0]
 [  1   0   0   2   0 908   0  51   9  29]
 [147   1 124  42 101   1 556   0  28   0]
 [  0   0   0   0   0  35   0 924   0  41]
 [  3   1   8   8   2   2  15   4 956   1]
 [  0   0   0   0   0  15   0  43   1 940]]
```

5. 25

```
Accuracy of train is 0.870081168019467
Accuracy of test is 0.8431843184318432
[[833   3  12  43   6   2  88   0  13   0]
 [  5 952   7  27   6   0   1   0   2   0]
 [ 19   3 745  11 133   2  75   0  12   0]
 [ 34  11  13 864  36   1  38   0   3   0]
 [  0   1 104  42 765   1  79   0   8   0]
 [  0   0   0   2   0 911   0  53   6  28]
 [155   3 117  46 102   2 543   0  32   0]
 [  0   0   0   0   0  34   0 925   0  41]
 [  3   2  11   8   1   3  18   6 948   0]
 [  0   0   0   0   0  13   0  40   1 945]]
```

The training algorithm is slower/takes more time since the learning rate has now decreased thus the changes in weight happens slowly, thus it takes more time for convergence. The algorithm achieves almost same test accuracies as part b, as can be seen for number of units = 25 84% both.

2.4 d

```
For relu:
Accuracy of train is 0.9673661227687128
Accuracy of test is 0.8711871187118712
[[813   1  21  42   4   1 104   0  14   0]
 [  5 962   3  22   3   0   3   0   1   1]
 [ 15   1 804  15  97   0  61   1   6   0]
 [ 28   7  12 877  35   0  35   0   6   0]
 [  1   2 104  30 795   0  63   0   5   0]
 [  0   0   0   1   0 953   0  30   2  14]
 [131   1  93  35  80   0 644   0  16   0]
 [  0   0   0   0   0  21   0 950   1  28]
 [  1   1   7   9   4   3   8   6 960   1]
 [  0   0   0   1   0   8   0  36   1 953]]

 For sigmoid:
Accuracy of train is 0.8722645377422957
Accuracy of test is 0.8448844884488449
[[825   4  15  43   6   5  87   0  15   0]
 [  5 949   5  30   5   0   3   1   2   0]
 [ 17   3 763   9 128   1  67   0  12   0]
 [ 39  14  13 867  38   0  26   0   3   0]
 [  1   3 105  38 762   0  85   0   6   0]
 [  1   0   0   2   0 912   0  51   8  26]
 [151   2 119  41 105   2 552   0  28   0]
 [  0   0   0   0   0  33   0 920   0  47]
 [   1   1   8   5   3   5  18   5 954   0]
 [   0   0   0   0   0  18   0  36   1 944]]
```

Compared to single hidden layer, this model with 2 hidden layers has higher accuracy = 96% for train accuracy and 87% for test accuracy hence 2 hidden layers is definitely better than 1 hidden layer.

Also, we can see relu performs better than sigmoid, since it's derivative is easy to calculate, it saves computation power and also has 96% accuracy vs 87% accuracy for sigmoid wrt train data and 87% accuracy vs 84% for test data hence is a better activation function than sigmoid.

2.5 e

For relu as activation:

1. 2

   Accuracy of train is 0.9766662777712962
   Accuracy of test is 0.863986398639864

2. 3

   Accuracy of train is 0.9807996799946666
   Accuracy of test is 0.8731873187318732

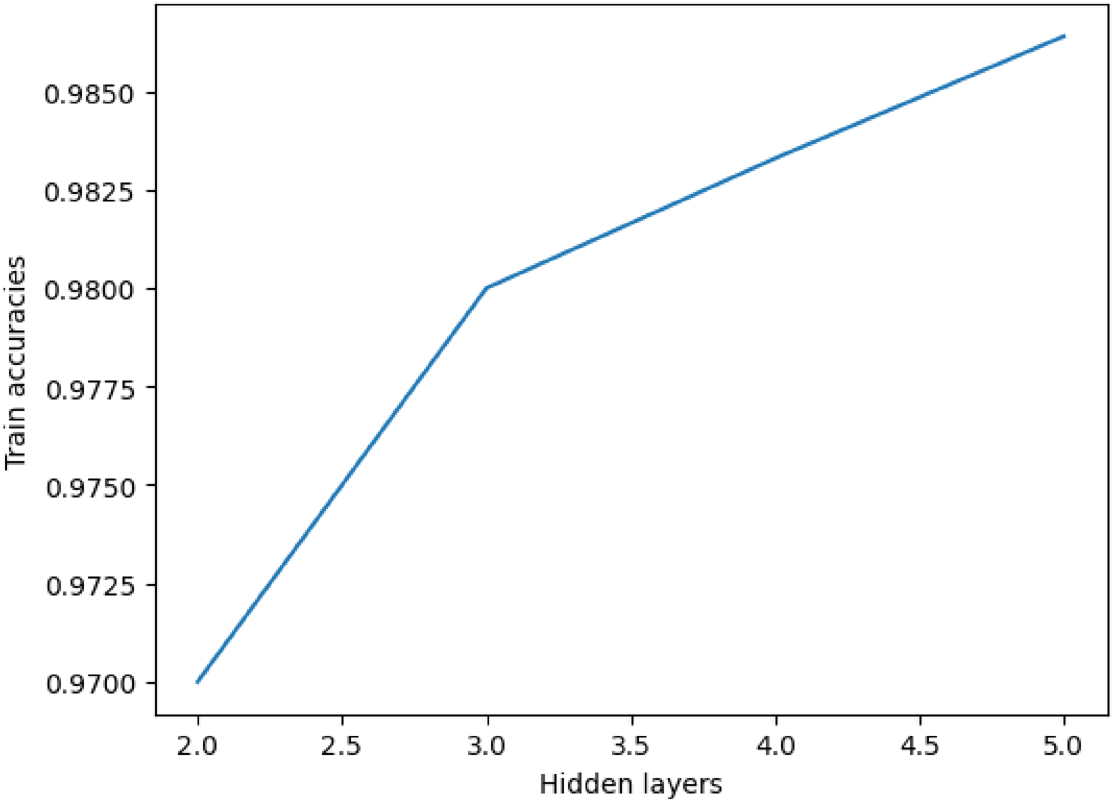
3. 4

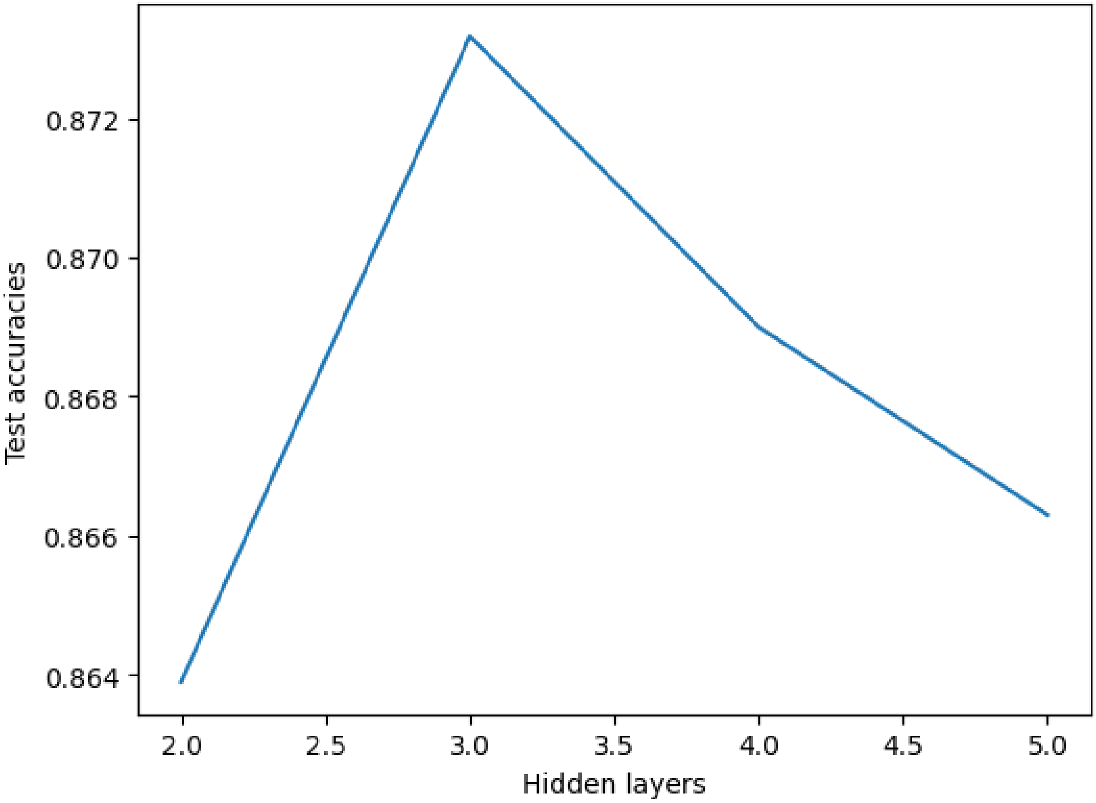
   Accuracy of train is 0.9833163886064767
   Accuracy of test is 0.8698869886988699

4. 5

   Accuracy of train is 0.9864497741629027
   Accuracy of test is 0.8663866386638663

Plot of accuracies in case of relu


0.9850
0.9825
0.9800
0.9775
0.9750
0.9725
0.9700
Train accuracies
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Hidden layers



For sigmoid as activation:

1. 2

   Accuracy of train is 0.9746995783263055
   Accuracy of test is 0.8651865186518651

2. 3

   Accuracy of train is 0.9786663111051851
   Accuracy of test is 0.8683858385838584

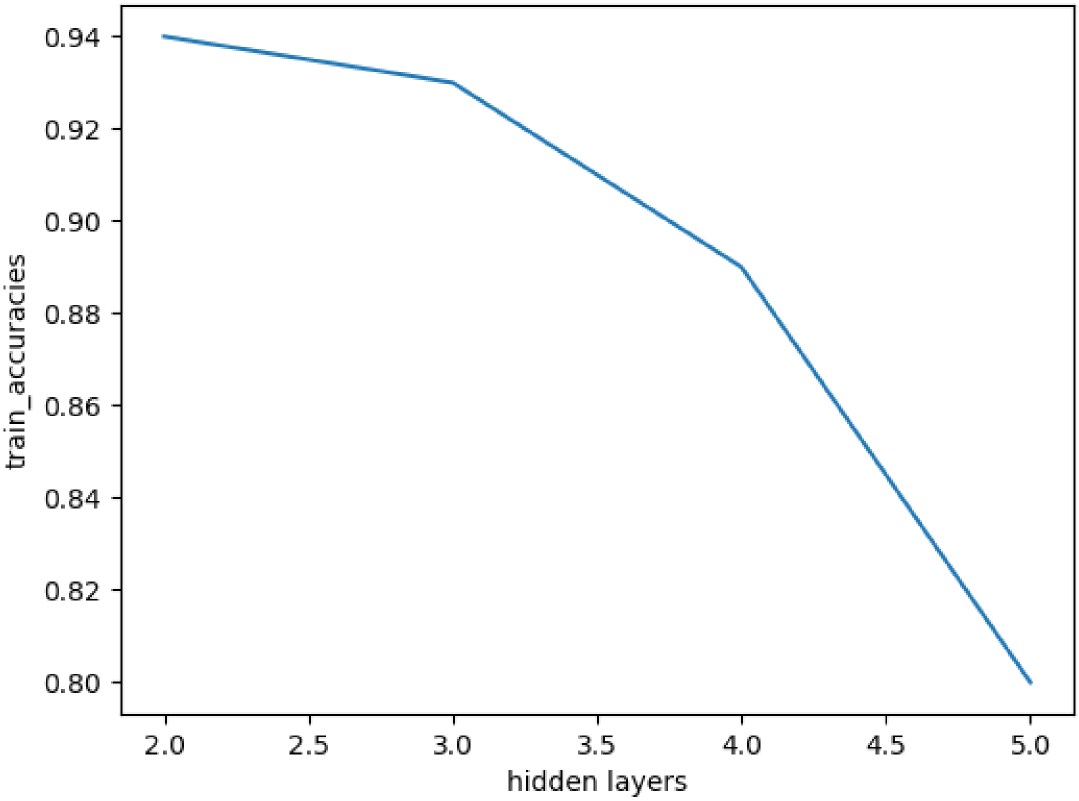
3. 4

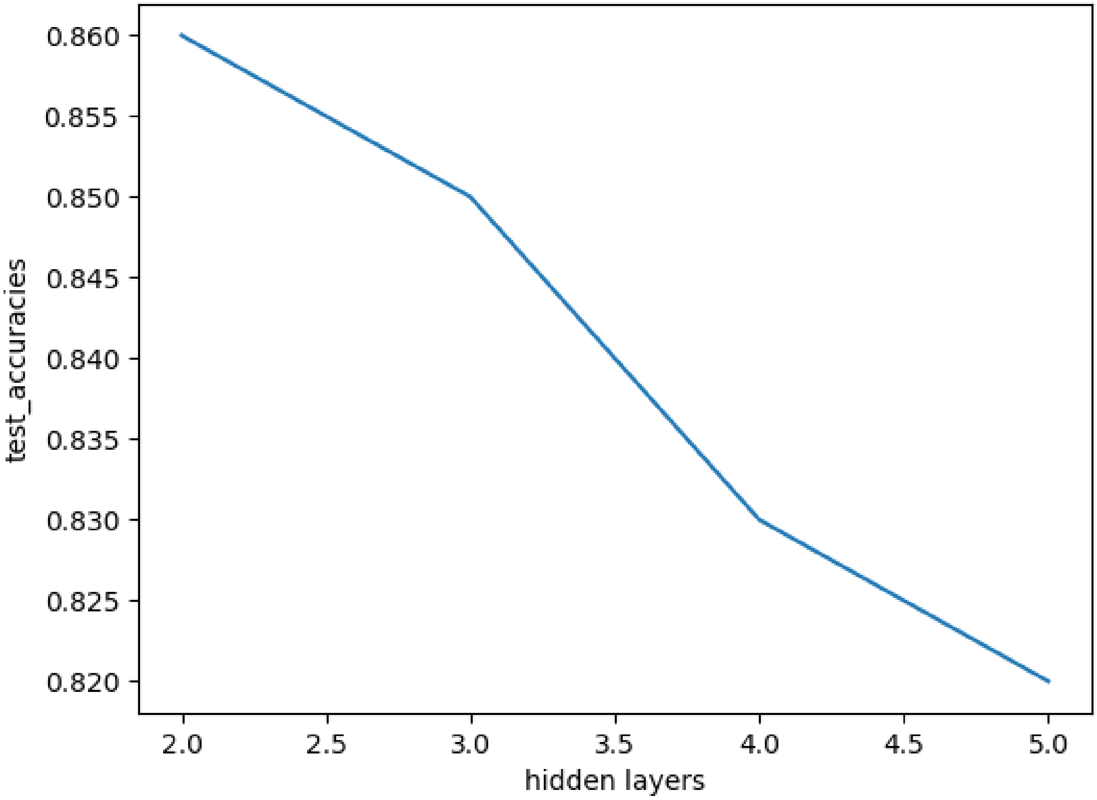
   Accuracy of train is 0.9786663251066840
   Accuracy of test is 0.8579167385933484

4. 5

Accuracy of train is 0.97866651910568510
Accuracy of test is 0.857306638678999

Plot of accuracies in case of sigmoid





Comparing sigmoid and relu activations, we see that for sigmoid the train accuracies decrease as the number of hidden layers increases, possibly because it requires more number of iterations to train the data when number of hidden layers is more. But in case of relu, we see that the train accuracies increases when we increase the number of hidden layers, possibly the reason here is that relu trains in less number of iterations hence it converges even when the number of hidden layers is more and hence more hidden layers if trained fully, give more information regarding the data thus we see the train accuracies rising here (in relu) with increase in number of hidden layers. Now comparing test accuracies we see that both in relu and sigmoid, they decrease with increase in number of hidden layers since with more hidden layers, overfitting of data occurs hence test accuracies decrease.

We can see that the best architecture is when number of hidden layers = 3, since at this point we get 87% test accuracy (Wrt relu).

2.6 f

Derivatives of last layer wrt bce:
(y_true/output)-((1-y_true)/(1-output))

Accuracy of train is 0.9999499991666527
Accuracy of test is 0.8512851285128513

2.7 g

Training accuracy is 0.9642327372122869
Test accuracy is 0.8331833183318332

Training using MLP does not really bring about much variations in accuracies, it prevents overfitting as we can see slight decrease in train accuracy compared to part f. But test accuracy is also less 83% compared to 85% in case of bce in part f.