EE559_Code_HW1

February 2, 2022

1 Homework 1

Problem 1 (a-b)

[27]:

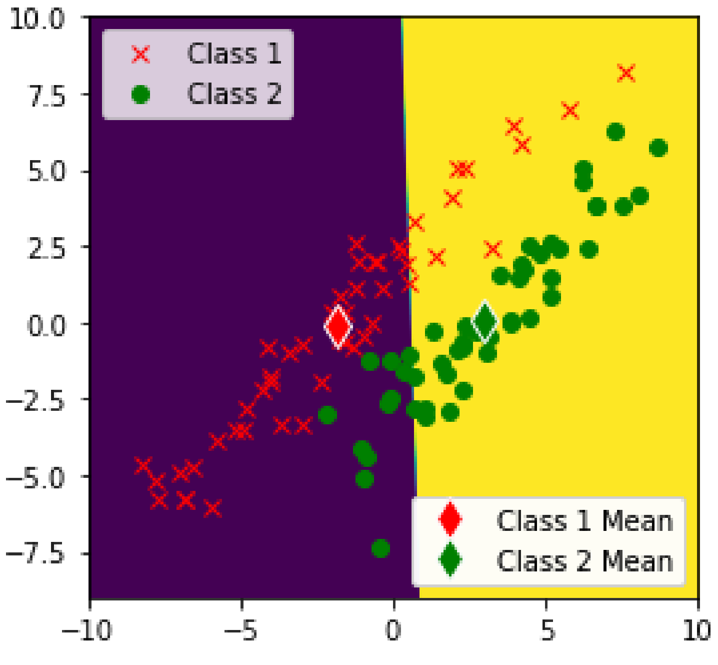
```python
##################################################
# Author:   Sarthak Kumar Maharana
# Email:    maharana@usc.edu
# Date:     01/29/2022
# Course:   EE 559
# Project:  Homework 1
# Instructor: Prof. B Keith Jenkins
##################################################

import os
import numpy as np
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
import matplotlib.gridspec as gridspec


from data.plotDecBoundaries import plotDecBoundaries


ROOTDIR = '~/Desktop/spring_22/EE_559/hw1/codes_2/data/'
train_file = 'synthetic1_train.csv'
test_file = 'synthetic1_test.csv'


class Homework1_ab:
    """
    Nearest Means Classifier
    """
    def __init__(self,
                train_file,
                test_file,
                mode
                ):
```

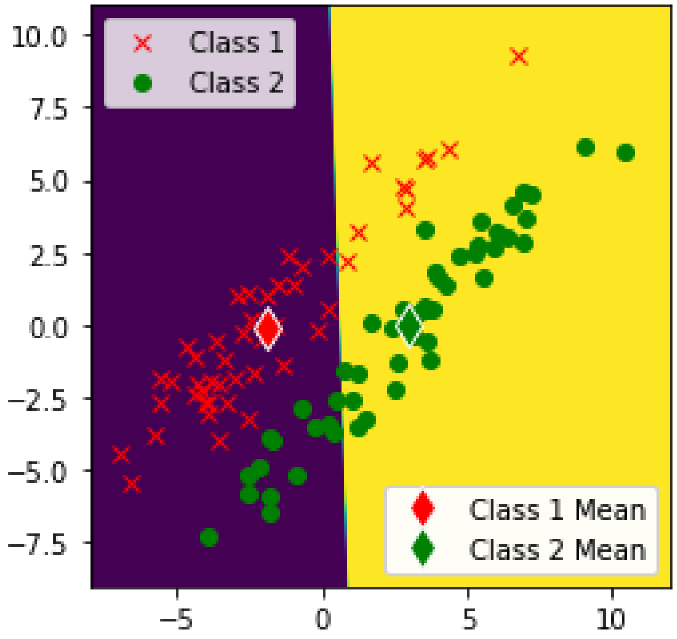
```
        self.train_file = train_file
        self.test_file = test_file
        self.mode = mode


    def _read_csv_get_features(self,
                              filename
                              ):
        """ Read csv files and return features, labels, and dataframe. """
        df = pd.read_csv(os.path.join(ROOTDIR, filename),
                        header = None
                        )
        x, y = df.iloc[:, : -1].values, df.iloc[:, -1].values
        return x, y, df


    def _load(self):
        """ Utility function to load data. """
        self.train_x, self.train_y, _ = self._read_csv_get_features(self.
↪train_file)
        self.test_x, self.test_y, _ = self._read_csv_get_features(self.
↪test_file)
        return self.train_x, self.train_y, self.test_x, self.test_y


    def _plot_data(self):
        """ Plot for visualization. """
        plt.scatter(self.train_x[:, 0],
                    self.train_x[:, 1],
                    c = self.train_y,
                    s = 50,
                    cmap = 'viridis'
                    )
        plt.show()


    @staticmethod
    def L2distance(x, y):
        """ Compute L2 (Euclidean) distance between two vectors. """
        return np.sqrt(np.sum((x - y)**2))


    def _sample_mean(self,
                    data_x,
                    data_y
                    ):
        """ Compute the sample mean for the data. """
        c_1_mean = np.mean(data_x[data_y == 1], axis = 0) # mean of class 1
        c_2_mean = np.mean(data_x[data_y == 2], axis = 0) # mean of class 2
        if len(np.unique(data_y)) >= 3:
            c_3_mean = np.mean(data_x[data_y == 3], axis = 0) # mean of class␣
↪3, if it exists
            self.sample_mean = np.vstack((c_1_mean, c_2_mean, c_3_mean))
            return self.sample_mean
        self.sample_mean = np.vstack((c_1_mean, c_2_mean))
        return self.sample_mean


    def _error_rate(self,
                    data_x,
                    data_y,
                    mean
                    ):
        """ Compute error rate, based on the data and sample mean that are␣
↪passed. """
        self.error = 0.0
        for idx in range(len(data_x)):
            e_feat_1 = self.L2distance(data_x[idx],
                                      mean[0]
                                      ) # label 1 error
            e_feat_2 = self.L2distance(data_x[idx],
                                      mean[1]
                                      ) # label 2 error
            if e_feat_1 > e_feat_2 and data_y[idx] == 1:
                self.error += 1
            if e_feat_1 < e_feat_2 and data_y[idx] == 2:
                self.error += 1
        return round(self.error / len(data_x), 3) # total error rate


    def _solver(self):
        """ Solver for the problem. """
        self.train_x, self.train_y, self.test_x, self.test_y = self._load()  #␣
↪load data
        means = self._sample_mean(self.train_x, self.train_y) # train the␣
↪"classifier" by computing the sample mean.
        return self._error_rate(self.test_x, self.test_y, means) if self.mode␣
↪== 'test' \
        else self._error_rate(self.train_x, self.train_y, means) # return error␣
↪rate on training data or test data based on user config.
```

[28]:

```
if __name__ == '__main__':
    """
    Available "mode" options: train, test.
    Configure train_file and test_file accordingly.
    """
    print(f"{train_file.split('_')[0]} is being used....")
    for mode_type in ['train', 'test']:
        hw1 = Homework1_ab(train_file, test_file, mode = mode_type)
        train_x, train_y, test_x, test_y = hw1._load()
        means = hw1._sample_mean(train_x, train_y)
        print(f'Error rate on the {hw1.mode} set:\
        {hw1._solver()}'
        )
    print("Plots of data points, class means, decision boundaries and regions for train and test sets respectively:")
    plotDecBoundaries(train_x, train_y, means) # plot decision boundaries and regions of the training data
    plotDecBoundaries(test_x, test_y, means) # plot decision boundaries and regions of the test data
```

```
synthetic1 is being used…
Error rate on the train set:        0.21
Error rate on the test set:        0.24
Plots of data points, class means, decision boundaries and regions for train and
test sets respectively:
```





Problem 1 (c-e)

[29]:

```
##################################################
# Author:    Sarthak Kumar Maharana
# Email:     maharana@usc.edu
# Date:      02/01/2022
# Course:    EE 559
# Project:   Homework 1
# Instructor: Prof. B Keith Jenkins
##################################################

import argparse
import itertools
import seaborn as sns
import matplotlib.gridspec as gridspec
import matplotlib.pyplot as plt

from data.plotDecBoundaries import plotDecBoundaries
from runner_synthetic import *


ROOTDIR = '~/Desktop/spring_22/EE_559/hw1/codes_2/data/'
train_file = 'wine_train.csv'
test_file = 'wine_test.csv'
```

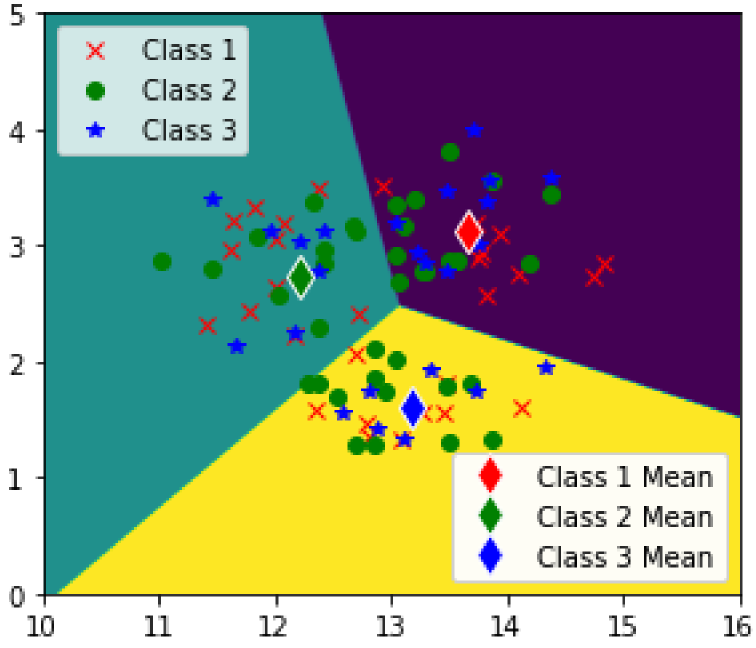
```
class Homework1_ce(Homework1_ab):
    """
    Nearest Means Classifier
    """
    def __init__(self,
                train_file,
                test_file,
                q_no,
                mode
                ):
        self.train_file = train_file
        self.test_file = test_file
        self.q_no = q_no
        self.mode = mode

    def _3class_error_rate(self,
                            data_x,
                            data_y,
                            means
                            ):
        """ Utility function to calculate the error rate of the classifier,␣
 ↪based on the data and the means.   """
        self.error = 0.0
        for idx in range(len(data_x)):
            e_feat_1 = self.L2distance(data_x[idx],
                                      means[0]
                                      ) # label 1 error
            e_feat_2 = self.L2distance(data_x[idx],
                                      means[1]
                                      ) # label 2 error
            e_feat_3 = self.L2distance(data_x[idx],
                                      means[2]
                                      ) # label 3 error

            if e_feat_1 < e_feat_2 and \
                e_feat_1 < e_feat_3 and \
                data_y[idx] != 1:
                    self.error += 1   # misclassified as 1

            elif e_feat_2 < e_feat_1 and \
                e_feat_2 < e_feat_3 and \
                data_y[idx] != 2:
                    self.error += 1 # misclassified as 2

            elif e_feat_3 < e_feat_1 and \
                e_feat_3 < e_feat_2 and \
                data_y[idx] != 3:
                    self.error += 1 # misclassified as 3

        return round(self.error / len(data_x), 3) # total_error rate


    def _eda(self):
        """ Perform exploratory data analysis. """
        x, y, df = self._read_csv_get_features(self.train_file)
        df.describe()
        return self._plot_utils(df)

    def _plot_utils(self, df):
        """ Plot the distribution of the data, for analysis. """
        for idx in df.columns:
            gs1 = gridspec.GridSpec(3,1)
            ax1 = plt.subplot(gs1[:-1])
            gs1.update(right = 0.60)
            sns.kdeplot(df.iloc[:,idx][df.iloc[:,-1] == 1], ax = ax1, label =␣
↪'1')
            sns.kdeplot(df.iloc[:,idx][df.iloc[:,-1] == 2], ax = ax1, label =␣
↪'2')
            sns.kdeplot(df.iloc[:,idx][df.iloc[:,-1] == 3], ax = ax1, label =␣
↪'3')
            ax1.xaxis.set_visible(False)
            ax1.title.set_text(f"x_{idx}")
            plt.legend()
            plt.show()
        return None


    def _best_features(self, means):
        """ Return a combination of features that minimizes the error rate. """
        print("Finding best features w/ their errors.....")
        feats_combos = list(itertools.combinations(range(13), 2))  # generate␣
↪all possible combos of features
        best_feats = {}
        for idx in feats_combos:
            x1, x2 = idx[0], idx[1] # current features
            self.error_best = 0.0
            for count, jdx in enumerate(self.train_x[:,[x1,x2]]):
                e_feat_1 = self.L2distance(jdx,
                                    means[0][[x1, x2]]
                                      ) # label 1 error
                e_feat_2 = self.L2distance(jdx,
                                     means[1][[x1, x2]]
                                      ) # label 2 error
                e_feat_3 = self.L2distance(jdx,
                                    means[2][[x1, x2]]
                                      ) # label 3 erro
                if e_feat_1 < e_feat_2 and \
                e_feat_1 < e_feat_3 and \
                self.train_y[count] != 1:
                    self.error_best += 1

                elif e_feat_2 < e_feat_1 and \
                e_feat_2 < e_feat_3 and \
                self.train_y[count] != 2:
                    self.error_best += 1

                elif e_feat_3 < e_feat_1 and \
                e_feat_3 < e_feat_2 and \
                self.train_y[count] != 3:
                    self.error_best += 1

            best_feats[idx] = self.error_best / len(self.train_x) # store error␣
↪rate for each combo of features
            print(f" For features {x1 + 1} and {x2 + 1}, the error rate on the␣
↪train set \
                    is {round(best_feats[idx], 3)}"
                    )
        return best_feats


    def _test_error_diff_feats(self, means):
        """ Test the error rate of the classifier with different features. """
        print("Obtaining error rates on the test set w/ the trained classifier..
↪..")
        feats_combos = list(itertools.combinations(range(13), 2)) # pairs of␣
↪combinations of features
        for idx in feats_combos:
            x1, x2 = idx[0], idx[1]
            self.error_test = 0.0
            for count, jdx in enumerate(self.test_x[:,[x1,x2]]):
                e_feat_1 = self.L2distance(jdx,
                                    means[0][[x1, x2]]
                                      ) # label 1 error
                e_feat_2 = self.L2distance(jdx,
                                     means[1][[x1, x2]]
                                      ) # label 2 error
                e_feat_3 = self.L2distance(jdx,
                                    means[2][[x1, x2]]
                                      ) # label 3 erro
                if e_feat_1 < e_feat_2 and \
                e_feat_1 < e_feat_3 and \
                self.test_y[count] != 1:
                    self.error_test += 1

                elif e_feat_2 < e_feat_1 and \
                e_feat_2 < e_feat_3 and \
                self.test_y[count] != 2:
                    self.error_test += 1

                elif e_feat_3 < e_feat_1 and \
                e_feat_3 < e_feat_2 and \
                self.test_y[count] != 3:
                    self.error_test += 1

            print(f" For features {x1 + 1} and {x2 + 1}, the error rate on test␣
↪set is \
            {round(self.error_test / len(self.test_x), 3)}"
            )


    def _main(self):
        """ Main function that attends each test case. """
        self.train_x, self.train_y, self.test_x, self.test_y = self._load() #␣
↪load train and test data

        # to solve 1(c) for the wine dataset.
        if self.q_no == 'c':
            print("You've chosen option (c)")
            x_train, x_test = self.train_x[:, :2], self.test_x[:, :2] # choose␣
↪only the first two features
            means = self._sample_mean(x_train, self.train_y) # compute sample␣
↪means for each class
            print("Plot of training data is....")
            plotDecBoundaries(x_train, self.train_y, means) # plot decision␣
↪boundaries on train set
            print("Plot of test data is....")
            plotDecBoundaries(x_train, self.train_y, means) # plot decision␣
↪boundaries on test set
            error = self._3class_error_rate(x_test, self.test_y, means) if self.
↪mode == 'test' \
            else self._3class_error_rate(x_train, self.train_y, means) #␣
↪compute error rate
            print(f"The error on the {self.mode} set is {error}.")

        # to solve 1(d) and 1(e) for the wine dataset.
        elif self.q_no == 'd':
            print("You've chosen option (d)")
            means = self._sample_mean(self.train_x, self.train_y) # compute sample means for each class
            feats_errors = self._best_features(means) # return the features and their errors
            min_error_feats = min(feats_errors.items(), key = lambda x: x[1]) # choose the feature with the minimum error
            x1_best, x2_best = min_error_feats[0][0], \
                               min_error_feats[0][1] # features with min error
            x_train, x_test = self.train_x[:, [x1_best, x2_best]], \
                                        self.test_x[:, [x1_best, x2_best]] # choose only the data of the best features
            best_mean = self._sample_mean(x_train, self.train_y) # compute mean of the best features
            print("Plot of training data (best two features) is....")
            plotDecBoundaries(x_train, self.test_y, best_mean) # plot decision boundaries on the best features
            print("Plot of test data (best two features) is....")
            plotDecBoundaries(x_test, self.test_y, best_mean) # plot decision boundaries on the best features
            error = self._3class_error_rate(x_test, self.test_y, best_mean) if self.mode == 'test' \
            else self._3class_error_rate(x_train, self.train_y, best_mean) # compute error rate on train/test based on the best features.
            print(f"The least error on the {self.mode} set is {error}, \
            computed on the best features {x1_best + 1} and {x2_best + 1}.")
            print(self._test_error_diff_feats(means))
            # print error rates on the test set w the trained classifier (for diff pair of features)

        else:
            raise ValueError('Invalid question number.\
                Please choose either (c) or (d)'
                )


if __name__ == '__main__':
    """
    Configure the object hw2 of Homework1_ce accordingly.

    Available "q_no" options: c, d [c (Performs 1(c)) and d performs 1(d) and 1(e)]
    Available "mode" options: train, test [default: train]

    If q_no = c and mode = 'train', use features x1 and x2 and report the error on the training data.
    If q_no = c and mode = 'test', use features x1 and x2 and report the error␣
↪on the test data.

    If q_no = d and mode = 'train', compute the best features and report the␣
↪error on the training data.
    If q_no = d and mode = 'test', compute the best features and report the␣
↪error on the test data.

    """
    hw2 = Homework1_ce(train_file, test_file, q_no = 'd', mode = 'train')
    hw2._main()
```

```
You've chosen option (d)
Finding best features w/ their errors…
 For features 1 and 2, the error rate on the train set                     is
0.202
 For features 1 and 3, the error rate on the train set                     is
0.315
 For features 1 and 4, the error rate on the train set                     is
0.449
 For features 1 and 5, the error rate on the train set                     is
0.562
 For features 1 and 6, the error rate on the train set                     is
0.146
 For features 1 and 7, the error rate on the train set                     is
0.09
 For features 1 and 8, the error rate on the train set                     is
0.337
 For features 1 and 9, the error rate on the train set                     is
0.169
 For features 1 and 10, the error rate on the train set                     is
0.258
 For features 1 and 11, the error rate on the train set                     is
0.258
 For features 1 and 12, the error rate on the train set                     is
0.079
 For features 1 and 13, the error rate on the train set                     is
0.247
 For features 2 and 3, the error rate on the train set                     is
0.393
 For features 2 and 4, the error rate on the train set                     is
0.393
 For features 2 and 5, the error rate on the train set                     is
0.573
 For features 2 and 6, the error rate on the train set                     is
0.292
 For features 2 and 7, the error rate on the train set                     is
```

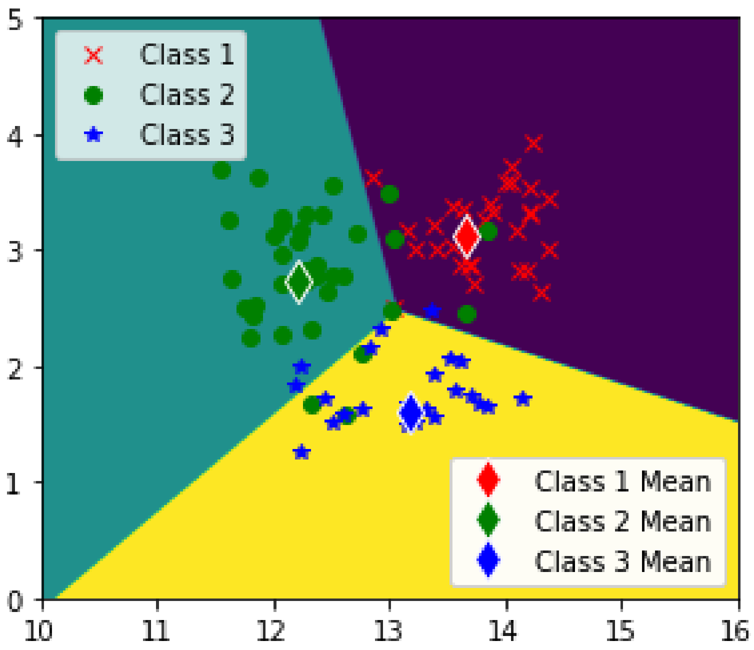
```
0.202
 For features 2 and 8, the error rate on the train set                     is
0.326
 For features 2 and 9, the error rate on the train set                     is
0.404
 For features 2 and 10, the error rate on the train set                     is
0.247
 For features 2 and 11, the error rate on the train set                     is
0.382
 For features 2 and 12, the error rate on the train set                     is
0.427
 For features 2 and 13, the error rate on the train set                     is
0.247
 For features 3 and 4, the error rate on the train set                     is
0.472
 For features 3 and 5, the error rate on the train set                     is
0.573
 For features 3 and 6, the error rate on the train set                     is
0.326
 For features 3 and 7, the error rate on the train set                     is
0.146
 For features 3 and 8, the error rate on the train set                     is
0.517
 For features 3 and 9, the error rate on the train set                     is
0.382
 For features 3 and 10, the error rate on the train set                     is
0.303
 For features 3 and 11, the error rate on the train set                     is
0.303
 For features 3 and 12, the error rate on the train set                     is
0.292
 For features 3 and 13, the error rate on the train set                     is
0.247
 For features 4 and 5, the error rate on the train set                     is
0.427
 For features 4 and 6, the error rate on the train set                     is
0.472
 For features 4 and 7, the error rate on the train set                     is
0.427
 For features 4 and 8, the error rate on the train set                     is
0.472
 For features 4 and 9, the error rate on the train set                     is
0.449
 For features 4 and 10, the error rate on the train set                     is
0.213
 For features 4 and 11, the error rate on the train set                     is
0.472
 For features 4 and 12, the error rate on the train set                     is
```

```
0.438
 For features 4 and 13, the error rate on the train set                     is
0.247
 For features 5 and 6, the error rate on the train set                     is
0.562
 For features 5 and 7, the error rate on the train set                     is
0.562
 For features 5 and 8, the error rate on the train set                     is
0.573
 For features 5 and 9, the error rate on the train set                     is
0.562
 For features 5 and 10, the error rate on the train set                     is
0.494
 For features 5 and 11, the error rate on the train set                     is
0.573
 For features 5 and 12, the error rate on the train set                     is
0.562
 For features 5 and 13, the error rate on the train set                     is
0.247
 For features 6 and 7, the error rate on the train set                     is
0.225
 For features 6 and 8, the error rate on the train set                     is
0.348
 For features 6 and 9, the error rate on the train set                     is
0.404
 For features 6 and 10, the error rate on the train set                     is
0.281
 For features 6 and 11, the error rate on the train set                     is
0.326
 For features 6 and 12, the error rate on the train set                     is
0.247
 For features 6 and 13, the error rate on the train set                     is
0.247
 For features 7 and 8, the error rate on the train set                     is
0.169
 For features 7 and 9, the error rate on the train set                     is
0.169
 For features 7 and 10, the error rate on the train set                     is
0.213
 For features 7 and 11, the error rate on the train set                     is
0.157
 For features 7 and 12, the error rate on the train set                     is
0.135
 For features 7 and 13, the error rate on the train set                     is
0.247
 For features 8 and 9, the error rate on the train set                     is
0.427
 For features 8 and 10, the error rate on the train set                     is
```

```
0.303
 For features 8 and 11, the error rate on the train set                     is
0.337
 For features 8 and 12, the error rate on the train set                     is
0.404
 For features 8 and 13, the error rate on the train set                     is
0.247
 For features 9 and 10, the error rate on the train set                     is
0.303
 For features 9 and 11, the error rate on the train set                     is
0.371
 For features 9 and 12, the error rate on the train set                     is
0.348
 For features 9 and 13, the error rate on the train set                     is
0.247
 For features 10 and 11, the error rate on the train set                     is
0.303
 For features 10 and 12, the error rate on the train set                     is
0.27
 For features 10 and 13, the error rate on the train set                     is
0.247
 For features 11 and 12, the error rate on the train set                     is
0.404
 For features 11 and 13, the error rate on the train set                     is
0.247
 For features 12 and 13, the error rate on the train set                     is
0.247
Plot of training data (best two features) is…
```



```
Plot of test data (best two features) is…
```



```
The least error on the train set is 0.079,             computed on the best
features 1 and 12.
Obtaining error rates on the test set w/ the trained classifier…
 For features 1 and 2, the error rate on test set is             0.225
 For features 1 and 3, the error rate on test set is             0.281
 For features 1 and 4, the error rate on test set is             0.404
 For features 1 and 5, the error rate on test set is             0.449
 For features 1 and 6, the error rate on test set is             0.157
 For features 1 and 7, the error rate on test set is             0.112
 For features 1 and 8, the error rate on test set is             0.281
 For features 1 and 9, the error rate on test set is             0.247
 For features 1 and 10, the error rate on test set is             0.225
 For features 1 and 11, the error rate on test set is             0.27
 For features 1 and 12, the error rate on test set is             0.124
 For features 1 and 13, the error rate on test set is             0.303
 For features 2 and 3, the error rate on test set is             0.382
 For features 2 and 4, the error rate on test set is             0.427
 For features 2 and 5, the error rate on test set is             0.438
 For features 2 and 6, the error rate on test set is             0.292
 For features 2 and 7, the error rate on test set is             0.236
 For features 2 and 8, the error rate on test set is             0.393
 For features 2 and 9, the error rate on test set is             0.371
 For features 2 and 10, the error rate on test set is             0.225
 For features 2 and 11, the error rate on test set is             0.449
 For features 2 and 12, the error rate on test set is             0.371
 For features 2 and 13, the error rate on test set is             0.303
 For features 3 and 4, the error rate on test set is             0.506
 For features 3 and 5, the error rate on test set is             0.461
 For features 3 and 6, the error rate on test set is             0.281
 For features 3 and 7, the error rate on test set is             0.225
 For features 3 and 8, the error rate on test set is             0.326
 For features 3 and 9, the error rate on test set is             0.404
 For features 3 and 10, the error rate on test set is             0.236
 For features 3 and 11, the error rate on test set is             0.27
 For features 3 and 12, the error rate on test set is             0.281
 For features 3 and 13, the error rate on test set is             0.303
 For features 4 and 5, the error rate on test set is             0.382
 For features 4 and 6, the error rate on test set is             0.472
 For features 4 and 7, the error rate on test set is             0.416
 For features 4 and 8, the error rate on test set is             0.506
 For features 4 and 9, the error rate on test set is             0.483
 For features 4 and 10, the error rate on test set is             0.292
 For features 4 and 11, the error rate on test set is             0.506
 For features 4 and 12, the error rate on test set is             0.449
 For features 4 and 13, the error rate on test set is             0.303
 For features 5 and 6, the error rate on test set is             0.449
 For features 5 and 7, the error rate on test set is             0.416
 For features 5 and 8, the error rate on test set is             0.461
 For features 5 and 9, the error rate on test set is             0.449
 For features 5 and 10, the error rate on test set is             0.438
 For features 5 and 11, the error rate on test set is             0.461
 For features 5 and 12, the error rate on test set is             0.438
 For features 5 and 13, the error rate on test set is             0.303
 For features 6 and 7, the error rate on test set is             0.247
 For features 6 and 8, the error rate on test set is             0.36
 For features 6 and 9, the error rate on test set is             0.326
 For features 6 and 10, the error rate on test set is             0.225
 For features 6 and 11, the error rate on test set is             0.281
 For features 6 and 12, the error rate on test set is             0.258
 For features 6 and 13, the error rate on test set is             0.303
 For features 7 and 8, the error rate on test set is             0.247
 For features 7 and 9, the error rate on test set is             0.27
 For features 7 and 10, the error rate on test set is             0.157
 For features 7 and 11, the error rate on test set is             0.247
 For features 7 and 12, the error rate on test set is             0.18
 For features 7 and 13, the error rate on test set is             0.303
 For features 8 and 9, the error rate on test set is             0.472
 For features 8 and 10, the error rate on test set is             0.236
 For features 8 and 11, the error rate on test set is             0.348
 For features 8 and 12, the error rate on test set is             0.326
```

```
 For features 8 and 13, the error rate on test set is             0.303
 For features 9 and 10, the error rate on test set is             0.247
 For features 9 and 11, the error rate on test set is             0.393
 For features 9 and 12, the error rate on test set is             0.315
 For features 9 and 13, the error rate on test set is             0.303
 For features 10 and 11, the error rate on test set is             0.236
 For features 10 and 12, the error rate on test set is             0.225
 For features 10 and 13, the error rate on test set is             0.303
 For features 11 and 12, the error rate on test set is             0.326
 For features 11 and 13, the error rate on test set is             0.303
 For features 12 and 13, the error rate on test set is             0.303
None
```

```
[ ]:
```

```
[ ]:
```