Vincent Purcell

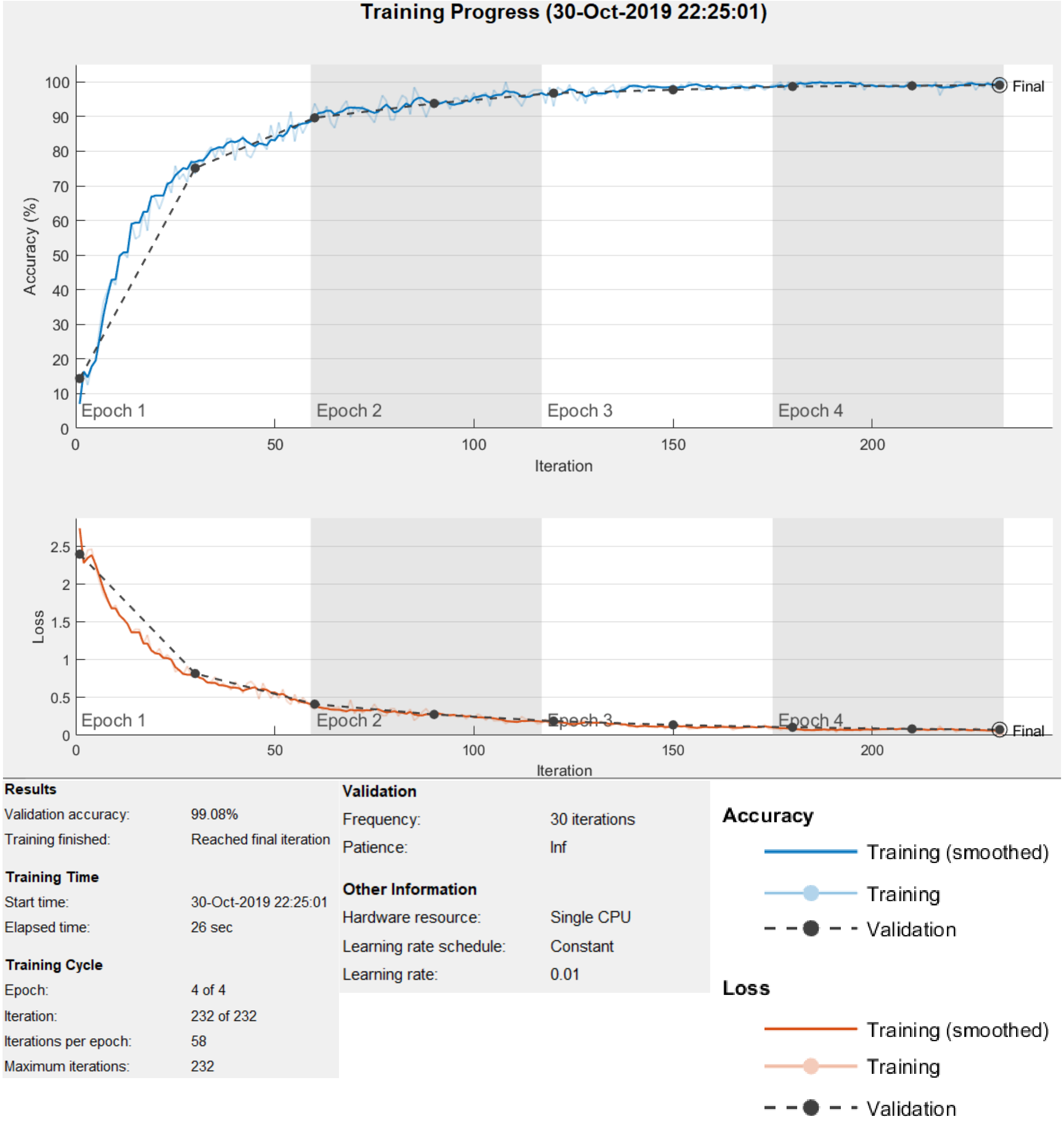
ECE487 – Pattern Recognition

Professor Cohen

28 October 2019

HW5 – SVMs and Decision Trees

Part 0-Create Simple Deep Learning Network for Classification



Results

Validation accuracy: 99.08%

Training finished: Reached final iteration

Training Time

Start time: 30-Oct-2019 22:25:01

Elapsed time: 26 sec

Training Cycle

Epoch: 4 of 4

Iteration: 232 of 232

Iterations per epoch: 58

Maximum iterations: 232

Validation

Frequency: 30 iterations

Patience: Inf

Other Information

Hardware resource: Single CPU

Learning rate schedule: Constant

Learning rate: 0.01

I ran the sample code for the MATLAB topic “Create Simple Deep Learning Network for Classification”. Above you can see the results from that. It shows the classifier had an accuracy of 99.08%.

The SVM had overall the best accuracy as long as the kernel scale had a value of 1 or greater. I believe that is due to underfitting though. I feel as though if the classes were distributed closer together the accuracy would differ. The graphs for the SVMs are seen below within the code. They show an accuracy of greater than 99.75%

Overall, for classification techniques, the most useful figure to understand the results is to display your classification plane and then mark the misclassified data points. I did that implementation below when I display the 12 models for the different SVM inputs.

Part 1-SVM and Decision Trees

All of the code can be seen below. There are twelve SVM plots due to the twelve possible combinations of three Box Constraint inputs and four Kernel Scale Inputs. Those twelve plots can be seen below within the code.

The Decision Trees can also be seen within the code below. When pruning is applied it decreases the number of branches that are within the decision tree. A higher level of pruning would certainly decrease the accuracy due to misclassification. This would be an example of underfitting.

Overall I would determine that the SVM is the best classifier as it is the most versatile when it comes to input parameters and it ultimately has the best accuracy.

Contents

Vincent Purcell - HW 4 - ECE487

```
clear; clc; close all;
```

Problem 4.6

Problem 4.6 from the Text on page 248.

```
% Data generation based on inputs from text book
rng('default')
rng(1)
m = [-5 5 5 -5; 5 -5 5 -5];
s = 2;
N = 100;
[x1,y1] = data_generator(m,s,N);
x1 = x1';
y1 = y1';
rng(10);
[x2,y2] = data_generator(m,s,N);
x2 = x2';
y2 = y2';

C_vec = [1,100,1000]';
sigma_vec = [0.5,1,2,4]';
tol = 0.001;

% Create 12 models and plot them based on all combinations of sigma and C
for i=1:size(C_vec)
    for j=1:size(sigma_vec)
        plotSVM(x1,y1,x2,y2,tol,C_vec(i),sigma_vec(j));
    end
end

% Call Decision Tree Function
decisionTree(x1,y1,x2,y2);
```

SVM Classification

Classification and Plot Function

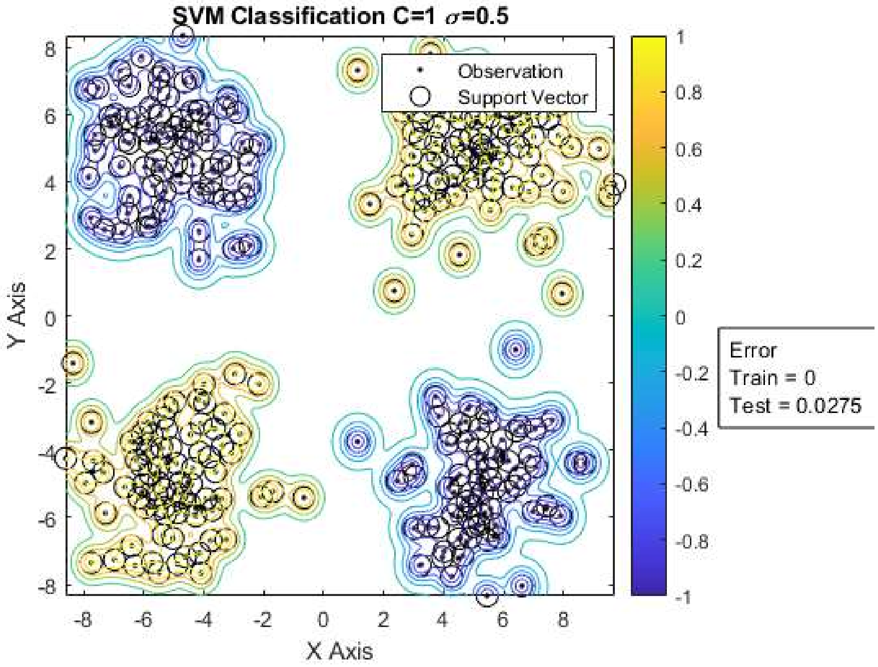
```
function plotSVM(x1,y1,x2,y2,tol,C,sigma)

    %Get classifier model and errors
    [model, test_err, train_err] = SVM_clas(x1,y1,x2,y2,tol,C,sigma);
    svInd = model.IsSupportVector;
    %Below plotting methods adapted from fitcsvm MATLAB documentation
    h = 0.02;
    [X1,X2] = meshgrid(min(x1(:,1)):h:max(x1(:,1)),...
        min(x1(:,2)):h:max(x1(:,2)));
    [~,score] = predict(model,[X1(:),X2(:)]);
    scoreGrid = reshape(score(:,1),835,916);

    figure
    plot(x1(:,1),x1(:,2),'k.')
    hold on
    plot(x1(svInd,1),x1(svInd,2),'ko','MarkerSize',10)
    contour(X1,X2,scoreGrid)
    colorbar;
    title_str = "SVM Classification C=" + num2str(C) + " \sigma=" + num2str(sigma);
    title(title_str)
    xlabel('X Axis')
    ylabel('Y Axis')
    legend('Observation','Support Vector')
    a = gca; % get the current axis;
    % set the width of the axis (the third value in Position)
    % to be 60% of the Figure's width
    a.Position(3) = 0.6;
    text1 = {"Error","Train = " + num2str(train_err) ...
        ,"Test = " + num2str(test_err)};
    annotation('textbox',[0.83 0 0 .5],'String',text1,'FitBoxToText','on')
    hold off
    snapnow
end
```

SVM Classifier

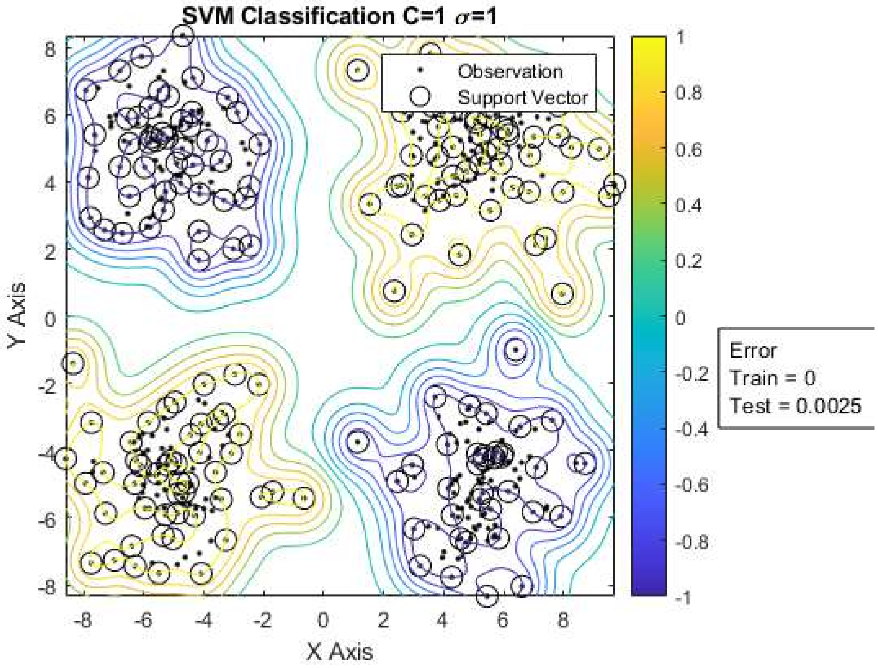
Function adapted from function on page 247 of the text

```
function [model,test_err,train_err]=SVM_clas(x1,y1,x2,y2,tol,C,sigma)

    % The following options are from the function in the textbook, it
    % required simple adaptation to the new function fitcsvm:
    % DeltaGradientTolerance = tol
    % Solver = SMO
    % Verbose = 1
    % IterationLimit = 20000
    % CacheSize = 10000
    % KernelFunction = RBF
    % KernelScale = sigma
    % BoxConstraint = C
    model = fitcsvm(x1,y1, ...
        'DeltaGradientTolerance',tol,...
        'Solver','SMO',...
        'Verbose',1,...
        'IterationLimit',20000,...
        'CacheSize',10000,...
        'KernelFunction','RBF',...
        'KernelScale',sigma,...
        'BoxConstraint',C);

    %Computation of the error probability
    test_err = loss(model,x2,y2);
    train_err = loss(model,x1,y1);
end
```

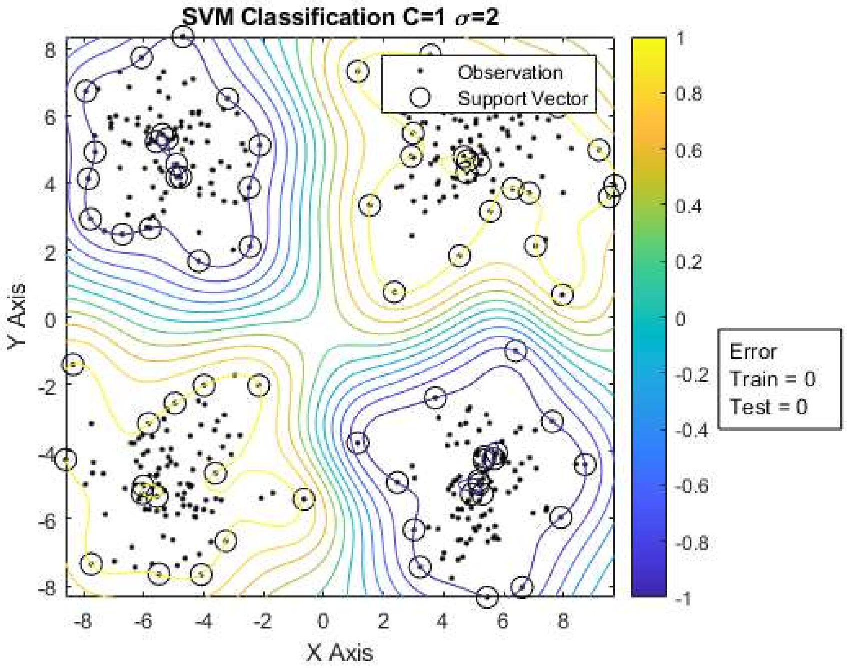
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility   |     Delta      |      KKT       |  Number of   |   Objective    |   Constraint   |
|              |      |              |      Gap       |    Gradient    |   Violation    |  Supp. Vec.  |                |   Violation    |
|===================================================================================================================================|
|            0 |active|          400 |  9.975062e-01  |  2.000000e+00  |  1.000000e+00  |            0 |  0.000000e+00  |  0.000000e+00  |
|         1000 |active|          400 |  8.407885e-04  |  1.983371e-03  |  1.018865e-03  |          297 | -7.239337e+01  |  3.339343e-16  |
|         1151 |active|          400 |  3.855007e-04  |  9.980384e-04  |  5.010877e-04  |          297 | -7.239356e+01  |  6.071532e-16  |

 Exiting Active Set upon convergence due to DeltaGradient.
```



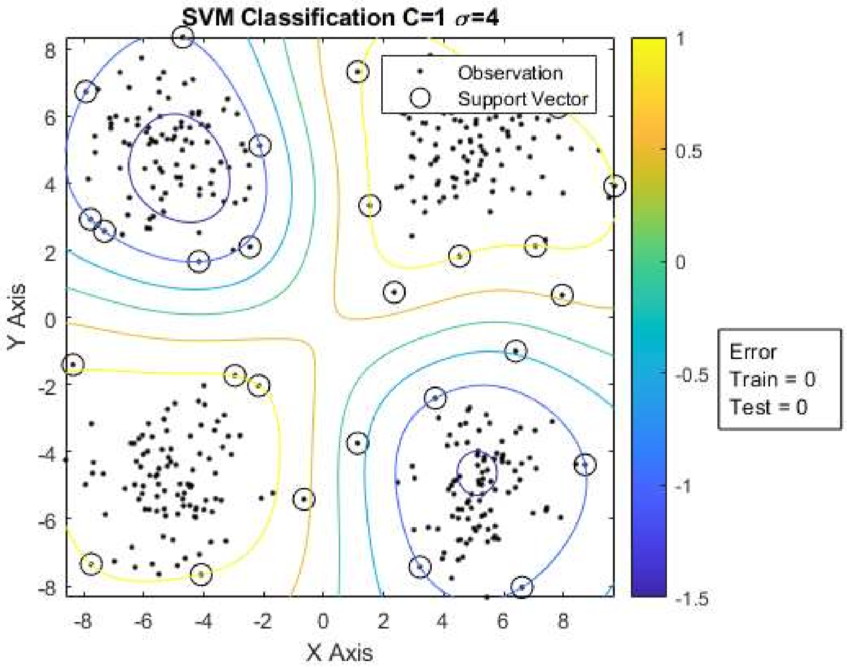
```
|===================================================================================================================================|
|   Iteration   | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |   Number of   |   Objective   |   Constraint  |
|               |      |              |      Gap      |    Gradient   |   Violation   |   Supp. Vec.  |               |   Violation   |
|===================================================================================================================================|
|             0 |active|          400 |  9.975062e-01 |  2.000000e+00 |  1.000000e+00 |             0 |  0.000000e+00 |  0.000000e+00 |
|          1000 |active|          400 |  1.165708e-03 |  2.337429e-03 |  1.254457e-03 |           188 | -3.195291e+01 |  8.413409e-17 |
|          1167 |active|          400 |  4.927793e-04 |  9.834192e-04 |  5.021250e-04 |           184 | -3.195314e+01 |  2.645453e-17 |

Exiting Active Set upon convergence due to DeltaGradient.
```



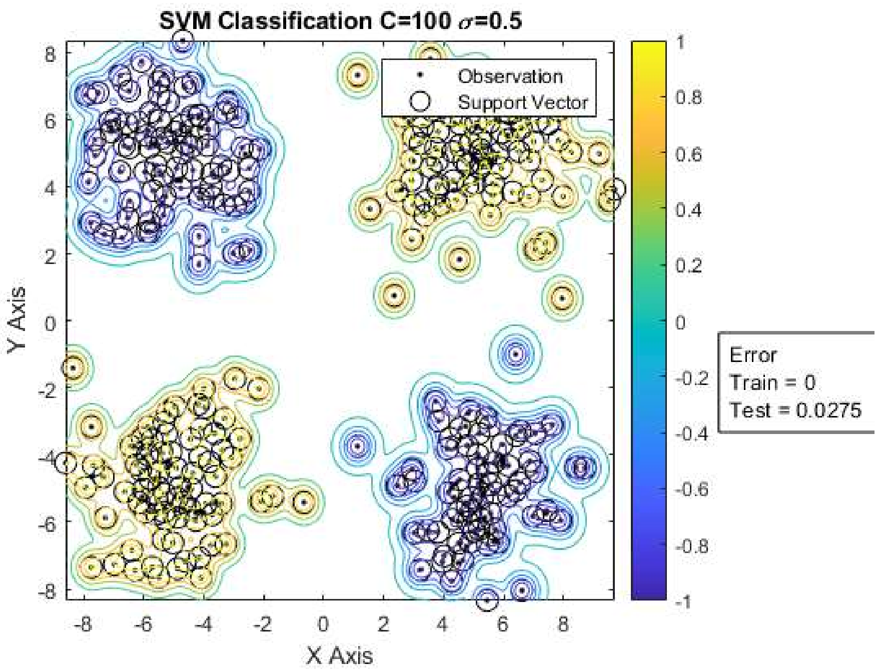
```
|===================================================================================================================================|
|   Iteration   | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |   Number of   |   Objective   |   Constraint  |
|               |      |              |      Gap      |    Gradient   |   Violation   |   Supp. Vec.  |               |   Violation   |
|===================================================================================================================================|
|             0 |active|          400 |  9.975062e-01 |  2.000000e+00 |  1.000000e+00 |             0 |  0.000000e+00 |  0.000000e+00 |
|           419 |active|          400 |  5.294154e-04 |  9.618164e-04 |  4.838165e-04 |            75 | -1.382540e+01 |  1.953732e-16 |

Exiting Active Set upon convergence due to DeltaGradient.
```



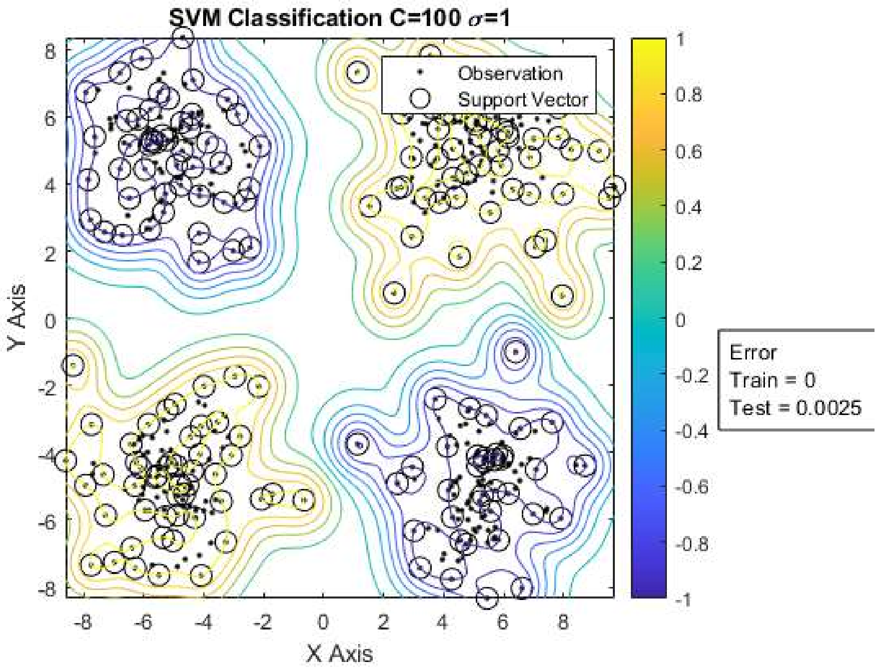
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint  |
|              |      |              |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation   |
|===================================================================================================================================|
|            0 |active|          400 |  9.975062e-01 |  2.000000e+00 |  1.000000e+00 |            0 |  0.000000e+00 |  0.000000e+00 |
|           88 |active|          400 |  1.282562e-04 |  6.374282e-04 |  3.575460e-04 |           28 | -9.747927e+00 |  2.775558e-17 |

Exiting Active Set upon convergence due to DeltaGradient.
```



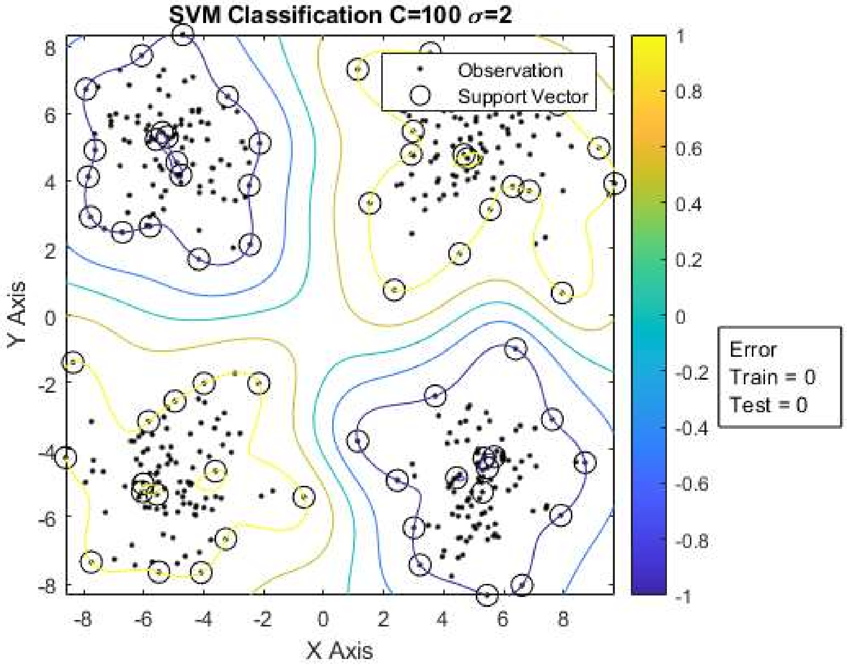
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint  |
|              |      |              |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation   |
|===================================================================================================================================|
|            0 |active|          400 |  9.999750e-01 |  2.000000e+00 |  1.000000e+00 |            0 |  0.000000e+00 |  0.000000e+00 |
|         1000 |active|          400 |  7.582241e-02 |  2.810799e-03 |  1.665751e-03 |          296 | -7.240008e+01 |  5.585810e-16 |
|         1160 |active|          400 |  4.109412e-02 |  9.976687e-04 |  5.177254e-04 |          297 | -7.240025e+01 |  7.754214e-16 |
Exiting Active Set upon convergence due to DeltaGradient.
```



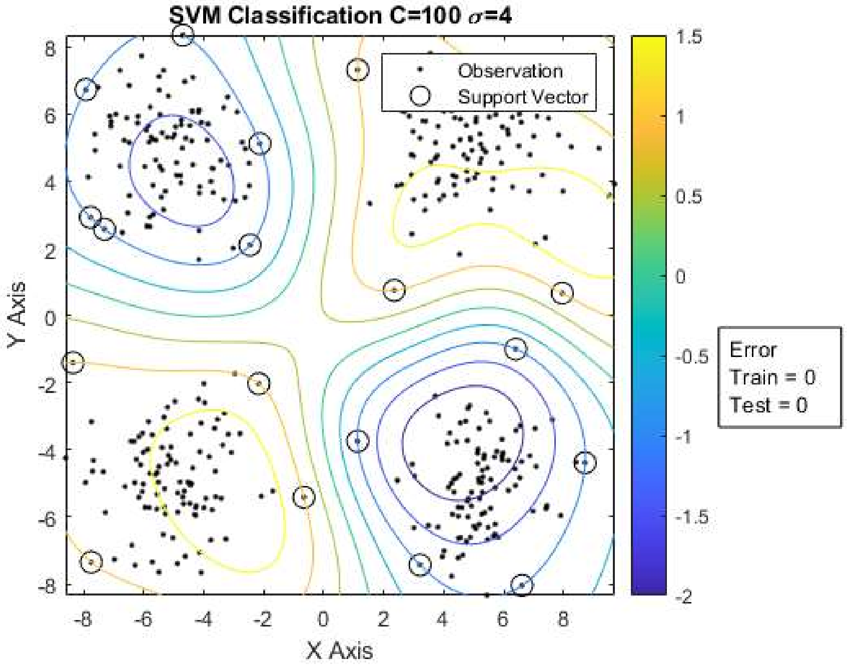
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size  |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint   |
|              |      |             |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation    |
|===================================================================================================================================|
|            0 |active|         400 |  9.999750e-01 |  2.000000e+00 |  1.000000e+00 |            0 |  0.000000e+00 |  0.000000e+00  |
|         1000 |active|         400 |  7.382879e-02 |  2.080937e-03 |  1.355332e-03 |          187 | -3.195580e+01 |  3.068292e-16  |
|         1063 |active|         400 |  5.763212e-02 |  9.999235e-04 |  5.191424e-04 |          186 | -3.195587e+01 |  1.040834e-16  |

Exiting Active Set upon convergence due to DeltaGradient.
```



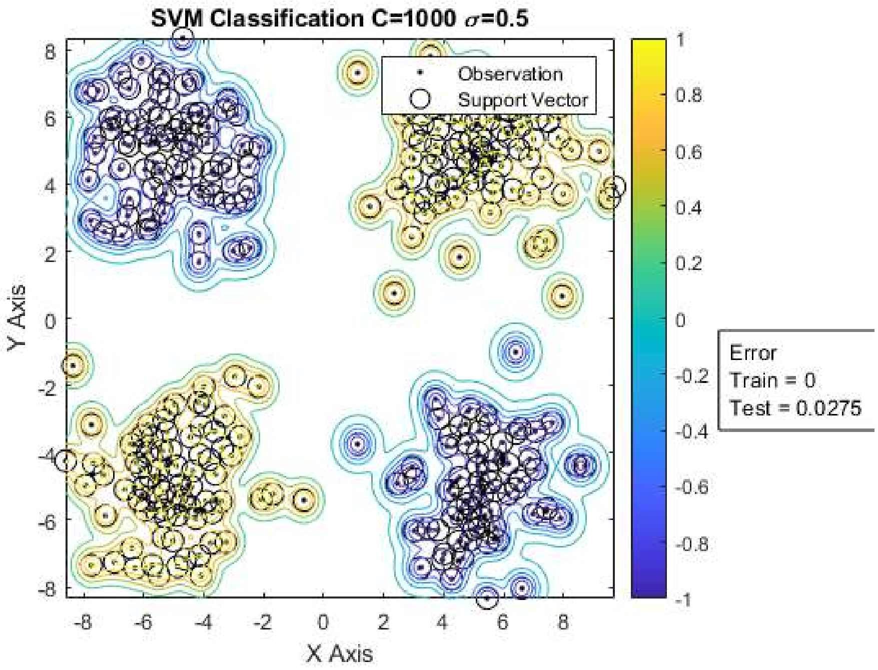
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size  |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint   |
|              |      |             |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation    |
|===================================================================================================================================|
|           0 |active|         400 |  9.999750e-01 |  2.000000e+00 |  1.000000e+00 |            0 |  0.000000e+00 |  0.000000e+00 |
|         386 |active|         400 |  3.377326e-02 |  8.624039e-04 |  4.503157e-04 |           68 | -1.387275e+01 |  6.982262e-17 |

Exiting Active Set upon convergence due to DeltaGradient.
```



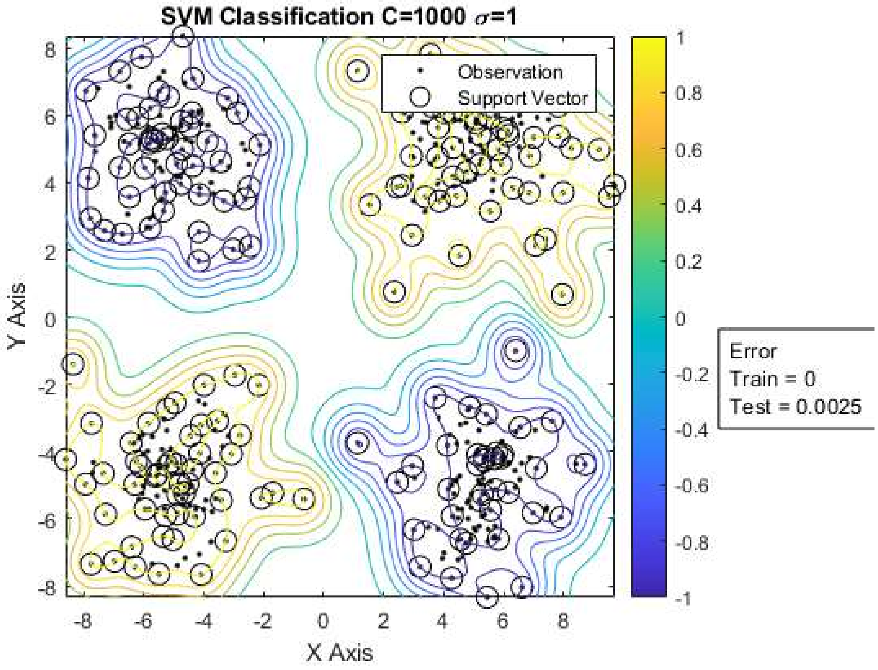
```
|====================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint  |
|              |      |              |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation   |
|====================================================================================================================================|
|           0 |active|         400 |  9.999750e-01 |  2.000000e+00 |  1.000000e+00 |            0 |  0.000000e+00 |  0.000000e+00 |
|          61 |active|         400 |  1.694130e-02 |  9.455347e-04 |  5.715393e-04 |           19 | -1.299826e+01 |  4.996004e-16 |

Exiting Active Set upon convergence due to DeltaGradient.
```



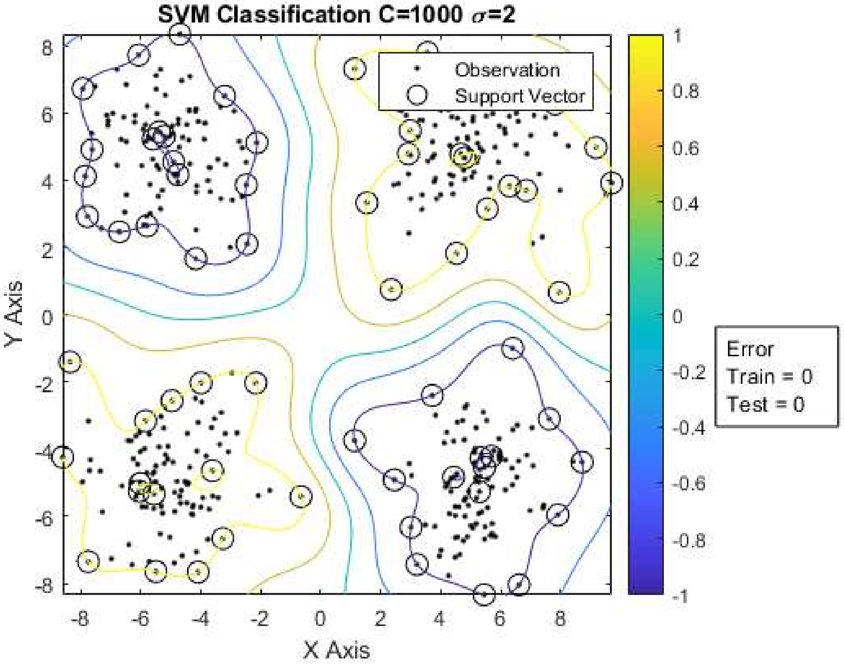
```
|====================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |  Number of   |   Objective   |   Constraint  |
|              |      |              |      Gap      |    Gradient   |   Violation   |  Supp. Vec.  |               |   Violation   |
|===================================================================================================================================|
|           0 |active|          400 |  9.999975e-01 |  2.000000e+00 |  1.000000e+00 |             0 |  0.000000e+00 |  0.000000e+00 |
|        1000 |active|          400 |  4.503944e-01 |  2.810799e-03 |  1.665751e-03 |           296 | -7.240008e+01 |  5.585810e-16 |
|        1160 |active|          400 |  2.999707e-01 |  9.976687e-04 |  5.177254e-04 |           297 | -7.240025e+01 |  7.754214e-16 |

Exiting Active Set upon convergence due to DeltaGradient.
```



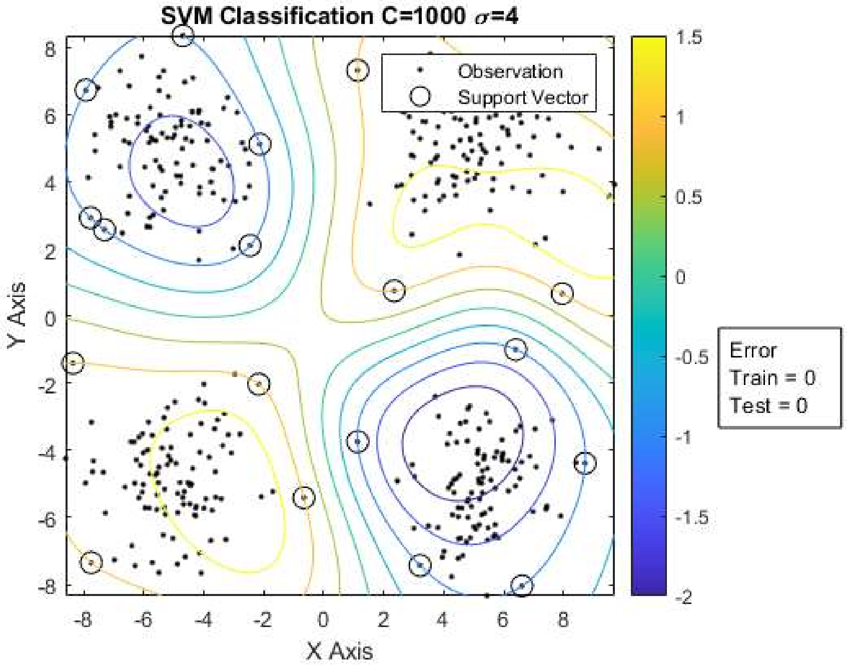
```
|===================================================================================================================================|
|   Iteration  | Set  |   Set Size   |  Feasibility  |     Delta     |      KKT      |  Number of    |   Objective   |   Constraint  |
|              |      |              |      Gap      |    Gradient   |   Violation   |  Supp. Vec.   |               |   Violation   |
|===================================================================================================================================|
|           0 |active|          400 |  9.999975e-01 |  2.000000e+00 |  1.000000e+00 |             0 |  0.000000e+00 |  0.000000e+00 |
|        1000 |active|          400 |  4.435076e-01 |  2.080937e-03 |  1.355332e-03 |           187 | -3.195580e+01 |  3.068292e-16 |
|        1063 |active|          400 |  3.794840e-01 |  9.999235e-04 |  5.191424e-04 |           186 | -3.195587e+01 |  1.040834e-16 |

Exiting Active Set upon convergence due to DeltaGradient.
```



```
|===================================================================================================================|
|   Iteration  | Set  |   Set Size  |  Feasibility |     Delta    |      KKT     |  Number of  |   Objective  |   Constraint  |
|              |      |             |      Gap     |    Gradient  |   Violation  |  Supp. Vec. |              |   Violation   |
|===================================================================================================================|
|            0 |active|         400 |  9.999975e-01 |  2.000000e+00 |  1.000000e+00 |           0 |  0.000000e+00 |  0.000000e+00 |
|          386 |active|         400 |  2.581275e-01 |  8.624039e-04 |  4.503157e-04 |          68 | -1.387275e+01 |  6.982262e-17 |

Exiting Active Set upon convergence due to DeltaGradient.
```



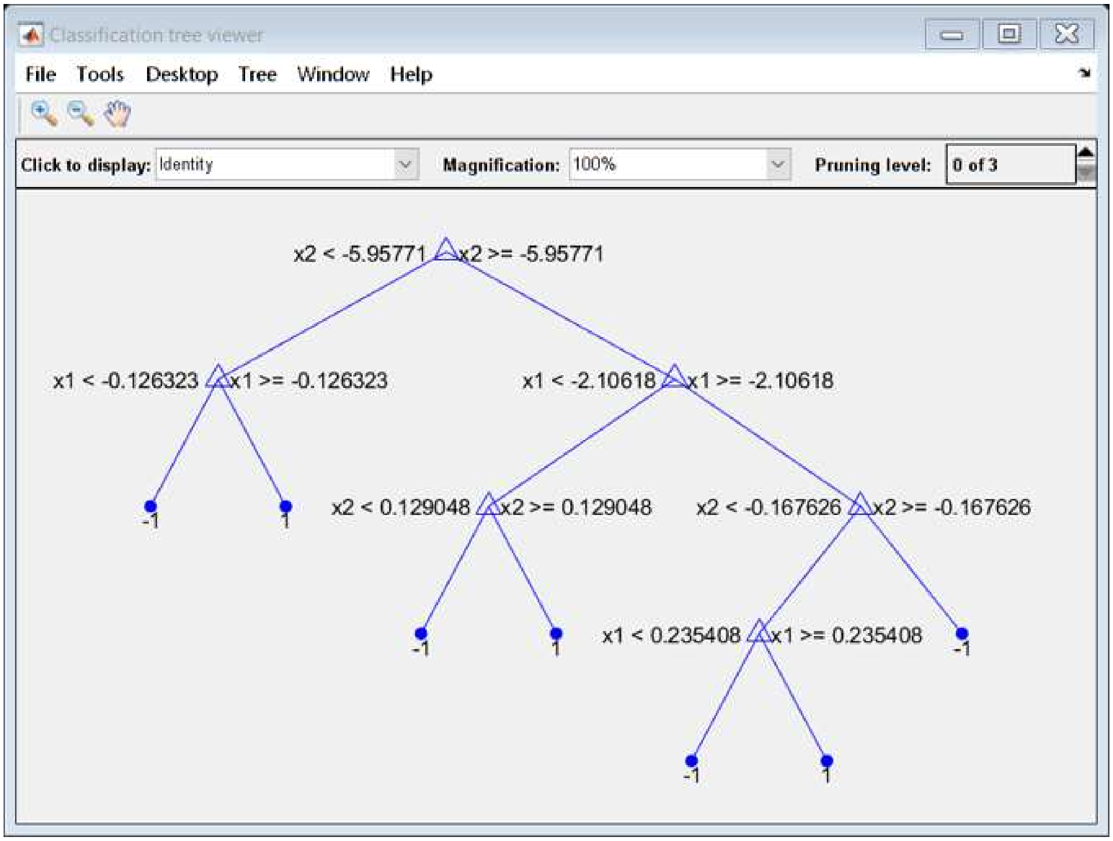
```
|===================================================================================================================|
|   Iteration  | Set  |   Set Size  |  Feasibility |     Delta    |      KKT     |  Number of  |   Objective  |   Constraint  |
|              |      |             |      Gap     |    Gradient  |   Violation  |  Supp. Vec. |              |   Violation   |
|===================================================================================================================|
|            0 |active|         400 |  9.999975e-01 |  2.000000e+00 |  1.000000e+00 |           0 |  0.000000e+00 |  0.000000e+00 |
|           61 |active|         400 |  1.475263e-01 |  9.455347e-04 |  5.715393e-04 |          19 | -1.299826e+01 |  4.996004e-16 |

Exiting Active Set upon convergence due to DeltaGradient.
```



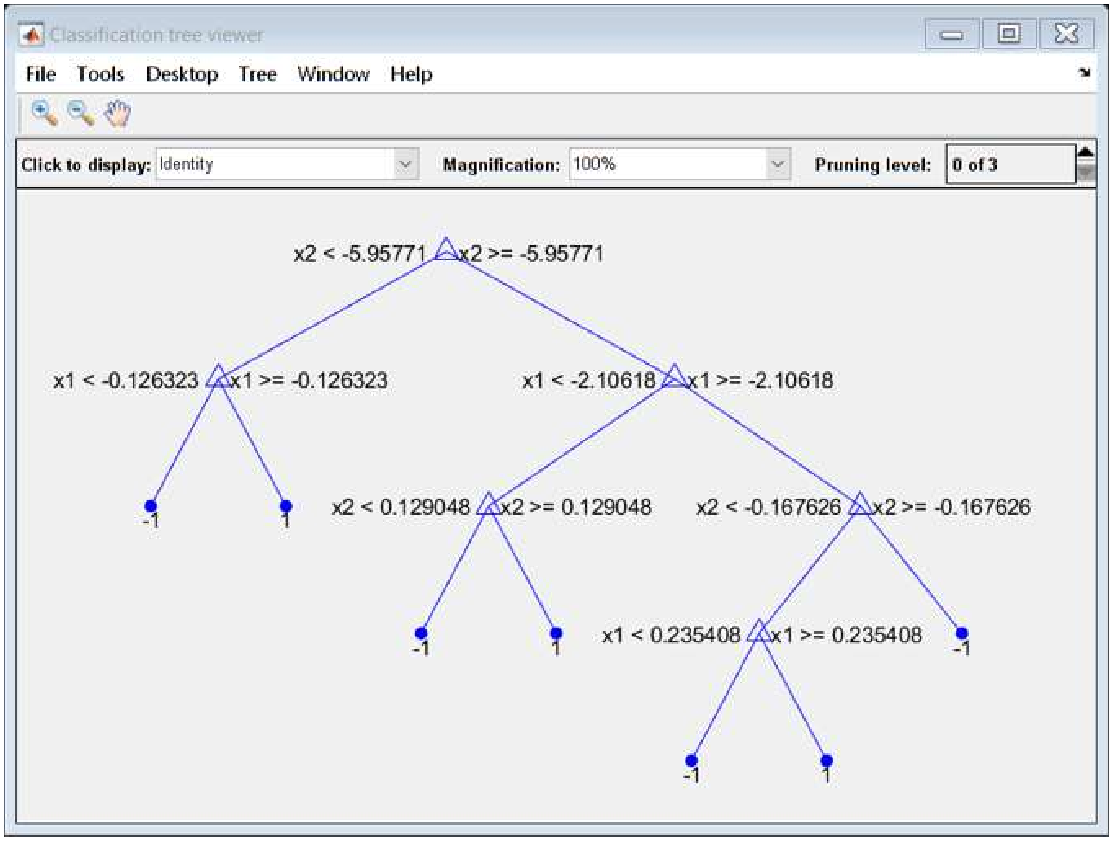
Decision Tree Classification

```
function decisionTree(x1,y1,x2,y2)
    rng(1);
    tree = fitctree(x1, y1, 'Prune', 'off','PruneCriterion','impurity');
    tree_pruned = prune(tree);

    view(tree,'Mode','graph');
    view(tree_pruned,'Mode','graph');

    test_err = loss(tree,x2,y2);
    train_err = loss(tree,x1,y1);

    test_err_p = loss(tree_pruned,x2,y2);
    train_err_p = loss(tree_pruned,x1,y1);

    fprintf('Testing Error without Pruning:  %f\n', test_err);
    fprintf('Training Error without Pruning: %f\n', train_err);
    fprintf('Testing Error with Pruning:     %f\n', test_err_p);
    fprintf('Training Error with Pruning:    %f\n', train_err_p);
end
```

```
Testing Error without Pruning:  0.005000
Training Error without Pruning: 0.000000
Testing Error with Pruning:     0.005000
Training Error with Pruning:    0.000000
```



Click to display: Identity Magnification: 100% Pruning level: 0 of 3



Click to display: Identity Magnification: 100% Pruning level: 0 of 3

Functions Received From Textbook

```
The following functions were received from the Textbook
Pattern Recognition - Theodoridis, Koutroumbas
```

Data Generation Class

Received from page 244 of the text

```
function [x,y]=data_generator(m,s,N)
    S = s*eye(2);
    [~,c] = size(m);
    x = []; % Creating the training set
    for i = 1:c
        x = [x mvnrnd(m(:,i)',S,N)'];
    end
    y=[ones(1,N) ones(1,N) -ones(1,N) -ones(1,N)];
end
```

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