ELL409   
Assignment 2

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2019EE10143

**Appendix:**

* CVXOPT linear kernel derivation:

**Part 1A**

* **Binary Classification**:
* **Linear Kernel**
* Note, here’s my understanding of the parameter C, based on [this](https://stats.stackexchange.com/questions/31066/what-is-the-influence-of-c-in-svms-with-linear-kernel): *The C parameter tells the SVM optimization how much you want to avoid misclassifying each training example. For large values of C, the optimization will choose a smaller-margin hyperplane if that hyperplane does a better job of getting all the training points classified correctly. Conversely, a very small value of C will cause the optimizer to look for a larger-margin separating hyperplane, even if that hyperplane misclassifies more points. For very tiny values of C, you should get misclassified examples, often even if your training data is linearly separable.* i.e., it kind of acts as a regularization constant

First, I take the linear kernel, for which, the only parameter is C (Because the degree is introduced in the separate poly kernel). Further, I first consider only 1st 10 features for this sub-part and then 25 features for each pair of target values. I have reported the combined results in table 1.

First, I take the first 10 features, split the dataset in 4:1 training:test set and run a 5-fold CV on the training set for the results. I took the best parameters returned by the grid search, and used them to train an SVM classifier but without the standard scaler. I again took these “best parameters” to train the model through CVXOPT and reported the score (accuracies) and support vectors for each of the cases.  
We know that a greater number of attributes/features would make the model more complex and increase the number of support vectors. It is also confirmed by the outputs.  
The plots are of 2 types. First is the score (mean accuracy) for different values of C, and the second is an error bar for the mean score for the 5-fold CV, spanning the standard deviation about mean. A similar approach is repeated while considering all of the 25 features.

Note: Most of the report below is directly copied from the output of a nice pipeline that I made

#################################################################################

Labels: 0, 1  
Number of features: 10

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Number of training examples: (484, 10) (484, 1)  
Number of test examples: (121, 10) (121, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 10.0}  
Training score for LIBSVM with best parameters: 1.0  
Test score for LIBSVM with best parameters: 0.9917355371900827

Support vectors as returned by LIBSVM: [array([-2.5672854 , 0.61358212, -0.18504852, -1.29098632, -1.10971372,

-1.92010159, 1.11095646, -0.26976221, 0.59437711, 1.33612076]), array([-2.5252242 , 0.1433732 , -1.00149657, 0.62202119, -1.33809398,

-1.70052622, 0.27725237, -0.66655132, -1.91520216, 1.33868618]), array([-2.19698028, 0.31159525, -1.41942432, -1.40785816, -1.61184166,

-1.56588107, 1.15550364, -2.03024934, -0.87517794, 0.70696161]), array([-1.62410951, 0.17525191, 0.78955537, -1.67133864, 0.97864023,

-0.49141539, 1.16826925, 0.60176822, -0.38505255, 0.74013041]), array([-1.54261417, 0.30739635, -1.59332713, 1.46957368, 0.03795295,

-1.31261301, -0.59115292, -0.43047483, -0.49556236, 0.14898264]), array([-1.00515896, -0.63373146, -0.86867173, 0.49808259, -1.0386103 ,

-1.67401918, 2.00609118, 0.22364069, -1.47484096, -0.13870134]), array([-0.87331614, -0.16715287, 0.02539877, -1.35126468, -0.30536666,

1.14538313, 2.31585465, 1.13378624, -0.26333482, -0.16841028]), array([-0.41825081, -1.67131418, 3.16556213, -3.61881864, 3.89569723,

1.30800603, 0.97929447, 1.19048336, 1.42255956, 0.9264488 ]), array([ 0.30583528, 0.30548217, -1.15368664, 2.69928582, -2.19587442,

1.37149925, 1.74760965, 0.61955023, 0.74977327, 0.95383963]), array([ 1.34038988, -1.24154295, -3.15608039, 1.47870173, -2.79963162,

1.65954014, 0.60293328, -0.48265476, 0.47713906, -0.49296996])]

--------------------------CVXOPT-----------------------------  
Test score for CVXOPT with best parameters: 99.17355371900827

Support vectors as returned by CVXOPT: [array([-2.5672854 , 0.61358212, -0.18504852, -1.29098632, -1.10971372,

-1.92010159, 1.11095646, -0.26976221, 0.59437711, 1.33612076]), array([-2.5252242 , 0.1433732 , -1.00149657, 0.62202119, -1.33809398,

-1.70052622, 0.27725237, -0.66655132, -1.91520216, 1.33868618]), array([-2.19698028, 0.31159525, -1.41942432, -1.40785816, -1.61184166,

-1.56588107, 1.15550364, -2.03024934, -0.87517794, 0.70696161]), array([-1.62410951, 0.17525191, 0.78955537, -1.67133864, 0.97864023,

-0.49141539, 1.16826925, 0.60176822, -0.38505255, 0.74013041]), array([-1.54261417, 0.30739635, -1.59332713, 1.46957368, 0.03795295,

-1.31261301, -0.59115292, -0.43047483, -0.49556236, 0.14898264]), array([-1.00515896, -0.63373146, -0.86867173, 0.49808259, -1.0386103 ,

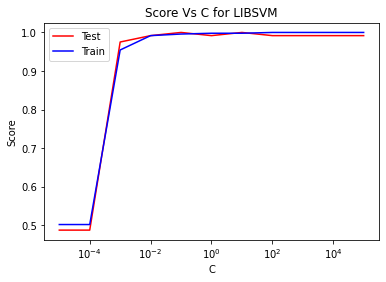
-1.67401918, 2.00609118, 0.22364069, -1.47484096, -0.13870134]), array([-0.87331614, -0.16715287, 0.02539877, -1.35126468, -0.30536666,

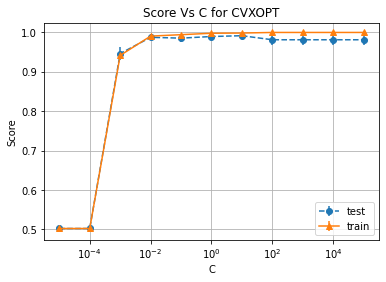
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1.30800603, 0.97929447, 1.19048336, 1.42255956, 0.9264488 ]), array([ 0.30583528, 0.30548217, -1.15368664, 2.69928582, -2.19587442,

1.37149925, 1.74760965, 0.61955023, 0.74977327, 0.95383963]), array([ 1.34038988, -1.24154295, -3.15608039, 1.47870173, -2.79963162,

1.65954014, 0.60293328, -0.48265476, 0.47713906, -0.49296996])]





#################################################################################

Labels: 0 , 1  
Number of features: 25

#################################################################################

Number of training examples: (484, 25) (484, 1)  
Number of test examples: (121, 25) (121, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 0.1}  
Training score for LIBSVM with best parameters: 1.0  
Test score for LIBSVM with best parameters: 0.9917355371900827

Support vectors as returned by LIBSVM: [array([-2.89254162e+00, -2.86503449e+00, 6.81144187e-03, 1.59270215e-01,

-1.34515154e+00, 3.45709596e-01, -7.95755352e-01, -3.15765760e-01,

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-1.20846820e-01, 2.88961691e-01, -2.21900639e+00, 5.40301541e-01,

7.54567897e-01, 3.22418185e-02, -4.74740708e-01, 7.99551279e-01,

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1.13961030e-01]), array([-2.5672854 , 0.61358212, -0.18504852, -1.29098632, -1.10971372,

-1.92010159, 1.11095646, -0.26976221, 0.59437711, 1.33612076,

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1.08666971, -1.29144801, 0.34684884, -0.44145979, 0.02832232]), array([-2.51772932, -1.45633484, 1.32322539, -0.48736174, -0.24050942,

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-0.0428089 , 1.14109959, 0.29981892, 0.04205963, 0.25630513]), array([-1.62410951, 0.17525191, 0.78955537, -1.67133864, 0.97864023,

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-0.55202231, -1.19512694, -1.00739896, -0.13193891, 0.73676494]), array([-1.55273591, -0.68410391, -0.76341679, -1.3259031 , -1.68824719,

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-0.1977592 , -0.07693047, -1.12648823, -0.5016521 , 0.8730506 ])]

--------------------------CVXOPT-----------------------------

Test score for CVXOPT with best parameters: 99.17355371900827

Support vectors as returned by CVXOPT: [array([-2.89254162e+00, -2.86503449e+00, 6.81144187e-03, 1.59270215e-01,

-1.34515154e+00, 3.45709596e-01, -7.95755352e-01, -3.15765760e-01,

8.73772760e-01, 5.05044794e-01, -5.24895362e-01, -7.45580779e-01,

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3.02467804e-01, 1.75551069e-01, -2.44406098e-04, -6.64032006e-01,

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-0.0428089 , 1.14109959, 0.29981892, 0.04205963, 0.25630513]), array([-1.62410951, 0.17525191, 0.78955537, -1.67133864, 0.97864023,

-0.49141539, 1.16826925, 0.60176822, -0.38505255, 0.74013041,

-0.58512278, -0.75063424, -0.68316951, -0.29320577, -0.1254242 ,

-0.00796613, 1.42061835, -0.12408011, 0.11795033, 0.37818441,

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-1.31261301, -0.59115292, -0.43047483, -0.49556236, 0.14898264,

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-0.37409136, -2.11202886, -0.1509801 , -1.28886141, -0.07662015,

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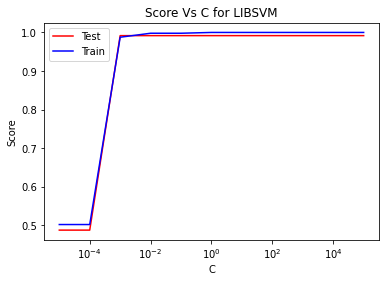
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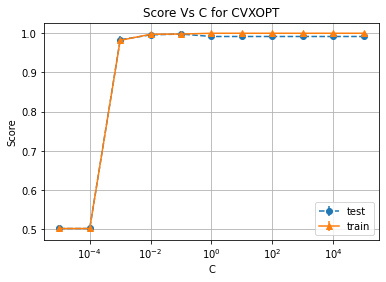
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Labels: 4 , 6  
Number of features: 10

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Number of training examples: (472, 10) (472, 1)  
Number of test examples: (119, 10) (119, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 0.01}  
Training score for LIBSVM with best parameters: 0.9766949152542372  
Test score for LIBSVM with best parameters: 1.0

Support vectors as returned by LIBSVM: [array([-2.81070165, 0.35744211, 0.63310309, 1.17685218, -0.96763593,

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--------------------------CVXOPT-----------------------------  
Test score for CVXOPT with best parameters: 100.0

Support vectors as returned by CVXOPT: [array([-2.81070165, 0.35744211, 0.63310309, 1.17685218, -0.96763593,

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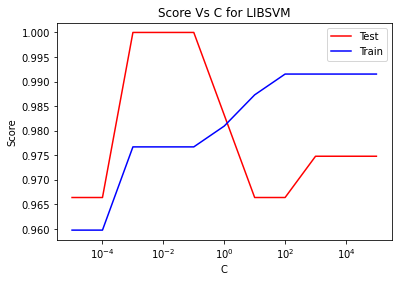
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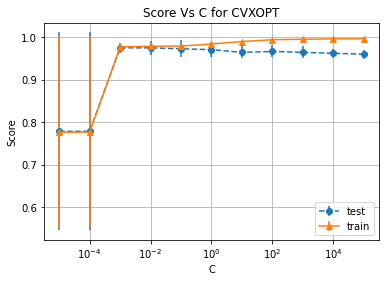
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Labels: 4 , 6  
Number of features: 25

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Number of training examples: (472, 25) (472, 1)  
Number of test examples: (119, 25) (119, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 0.1}  
Training score for LIBSVM with best parameters: 0.989406779661017  
Test score for LIBSVM with best parameters: 1.0

Support vectors as returned by LIBSVM: [array([-2.81070165, 0.35744211, 0.63310309, 1.17685218, -0.96763593,

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Test score for CVXOPT with best parameters: 100.0

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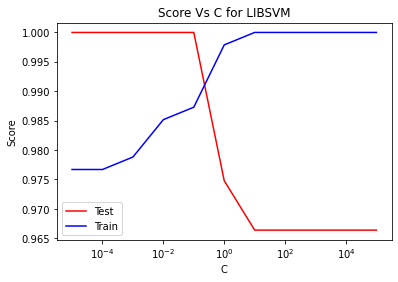
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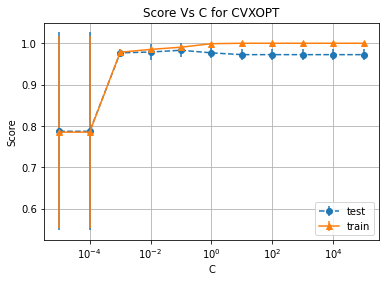
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Labels: 8 , 9  
Number of features: 10

#################################################################################

Number of training examples: (454, 10) (454, 1)  
Number of test examples: (114, 10) (114, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 0.01}  
Training score for LIBSVM with best parameters: 0.9295154185022027  
Test score for LIBSVM with best parameters: 0.9385964912280702

Support vectors as returned by LIBSVM: [array([-3.09693984, -0.29562341, 0.5956924 , -2.36047158, -0.26908291,

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--------------------------CVXOPT-----------------------------

Test score for CVXOPT with best parameters: 93.85964912280701

Support vectors as returned by CVXOPT: [array([-3.09693984, -0.29562341, 0.5956924 , -2.36047158, -0.26908291,

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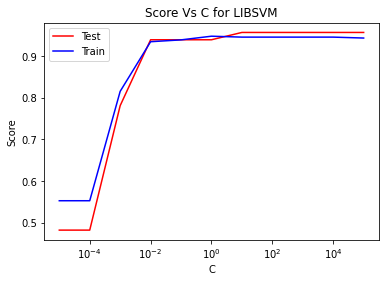
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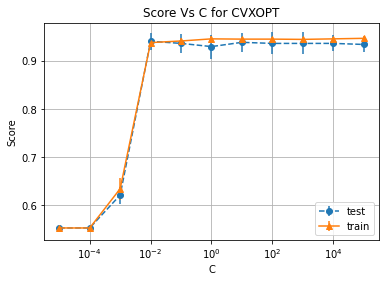
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Labels: 8 , 9  
Number of features: 25

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Number of training examples: (454, 25) (454, 1)  
Number of test examples: (114, 25) (114, 1)

--------------------------LIBSVM-----------------------------

The Best parameters according to grid search are: {'SVM\_\_C': 0.1}  
Training score for LIBSVM with best parameters: 0.9713656387665198  
Test score for LIBSVM with best parameters: 0.9736842105263158

Support vectors as returned by LIBSVM: [array([-3.0908651 , 0.39067619, -0.41124491, -1.42508018, -0.27529994,

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--------------------------CVXOPT-----------------------------

Test score for CVXOPT with best parameters: 97.36842105263158

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-1.64172608, -1.50971935, 0.77619553, 0.32253302, 0.37026349]), array([ 3.63855427, 1.91029455, -2.82010674, -0.36588816, -0.62496168,

1.34853275, -0.14790094, -1.92150705, 2.23723473, 0.18622984,

0.58355256, 0.48104089, -0.00481697, -0.23973943, -2.09299336,

-2.63689635, 1.40249279, 0.18671482, 0.49922222, -1.20634419,

-1.18859186, -1.04132291, 0.76586909, -0.51173099, -0.29709464]), array([ 4.29031403, 2.07833861, -2.06591132, 2.72135963, 0.85650927,

3.0527245 , 0.20289888, 0.05251563, 2.69285862, 0.94360347,

2.93019518, -1.72263005, -0.47701006, -0.04354398, -0.04800615,

-2.93385821, 0.4229547 , -0.26205017, 0.78550817, -0.98870041,

-0.926727 , -0.41793069, -0.26738633, -0.77005268, 0.99071905]), array([ 4.5220392 , -0.852378 , -3.17572321, -0.77090427, 0.84402989,

2.20200016, -1.10432379, -1.5463951 , 0.23114401, -1.89928828,

0.78490384, 1.01510816, 0.48149687, -0.25038959, -0.88990046,

-0.8050116 , 0.48841702, 0.69453659, -0.86338669, -0.28557348,

0.42646887, -1.15637183, 0.56414167, -0.48470149, -0.80558434])]

**Linear kernel**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Class A** | **Class B** | **Number of features** | **Best C** | **SVM training accuracy** | **SVM test accuracy** | **CVXOPT test accuracy** |
| 0 | 1 | 10 | 10 | 100% | 99.17% | 99.17% |
| 0 | 1 | 25 | 0.1 | 100% | 99.17% | 99.17% |
| 4 | 6 | 10 | 0.01 | 97.67% | 100% | 100% |
| 4 | 6 | 25 | 0.1 | 98.94% | 100% | 100% |
| 8 | 9 | 10 | 0.01 | 92.95% | 93.86% | 93.86% |
| 8 | 9 | 25 | 0.1 | 97.14% | 97.37% | 97.37% |

Table 1.

As we can see, the test accuracy is same for Libsvm and CVXOPT. Even the support vectors for both are same (Printed in sorted order, so that can also be confirmed by human inspection)

By the various graphs, one can see that smaller values of C lead to underfitting, while the higher value of C leads to overfitting. This is not *that* clearly visible because we have 25 features which makes the model complex enough to prevent overfitting.

* **Poly Kernel**
* For the poly kernel, we have 2 more parameters, gamma (kernel coefficient) and degree (of the polynomial). The default value of the *independent term* is 0 by default. Since it has little to no bearing on the result (since I am anyway using a standard scaler), I keep it as 0

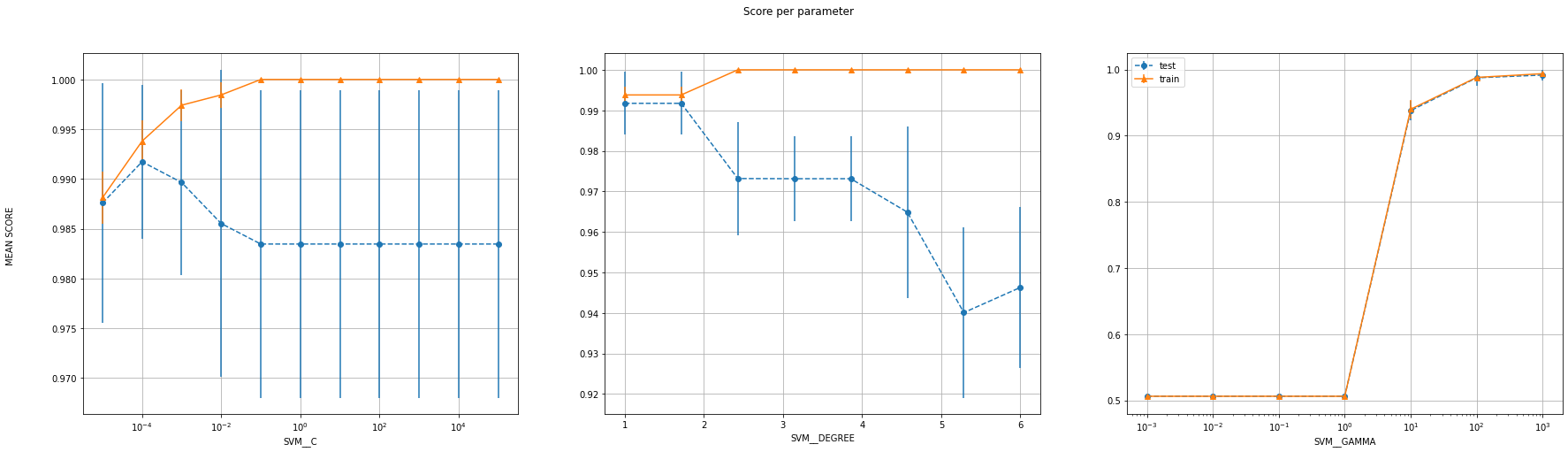
I first consider only 1st 10 features for this sub-part and report the results in the same table 1.

**10 features**:

I take the first 10 features, split the dataset in 4:1 training:test set and run a 5-fold CV on the training set for the results. Having 3 different parameters, there was no definite way to represent the scores on a graph (4D), therefore I only have single set of graphs for this, which are error bars for the mean score for the 5-fold CV, spanning the std dev about mean.  
Note: The graph has been split in 2 parts to fit in the screen

-----------------------------------------------------------------------------------------

Classes: 0 & 1  
Training size: 484 instances  
Test size: 121 instances  
Grid search returned: {'SVM\_\_C': 0.0001, 'SVM\_\_degree': 1.0, 'SVM\_\_gamma': 1000.0}  
Training Accuracy: 99.38%  
Test Accuracy: 100%



**References** (For Code)  
Note: It is possible that codes in some of these references are not present in my current version of the code. But they certainly influenced my code

* <https://stats.stackexchange.com/questions/31066/what-is-the-influence-of-c-in-svms-with-linear-kernel>
* <https://stackoverflow.com/questions/37161563/how-to-graph-grid-scores-from-gridsearchcv>
* <https://courses.csail.mit.edu/6.867/wiki/images/a/a7/Qp-cvxopt.pdf>
* <https://www.robots.ox.ac.uk/~az/lectures/ml/lect3.pdf>
* <https://scikit-learn.org/stable/modules/generated/sklearn.svm.SVC.html>
* <https://xavierbourretsicotte.github.io/SVM_implementation.html>