Report SVM and Bias/Variance

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1   SVM

Linear SVM in LIBSVM.
   a) linear kernel

```
for c = 0.000244140625
Cross Validation Accuracy = 55.75%
Average time: 0.374700625738


for c = 0.0009765625
Cross Validation Accuracy = 55.75%
Average time: 0.369784673055


for c = 0.00390625
Cross Validation Accuracy = 55.75%
Average time: 0.375274976095


for c = 0.015625
Cross Validation Accuracy = 71.2%
Average time: 0.362869262695


for c = 0.0625
Cross Validation Accuracy = 91.25%
Average time: 0.274736642838


for c = 0.25
Cross Validation Accuracy = 91.6%
Average time: 0.165066639582


for c = 1
Cross Validation Accuracy = 94.4%
Average time: 0.112902641296


for c = 4
```

```
Cross Validation Accuracy = 94.4%
Average time: 0.0861463546753


for c = 16
Cross Validation Accuracy = 95.9%
Average time: 0.0804420312246
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b) Polynomial kernel

for c,d =  0.015625 1
Cross Validation Accuracy = 55.75%
Average time: 0.356227397919


for c,d =  0.015625 2
Cross Validation Accuracy = 55.75%
Average time: 0.368517319361


for c,d =  0.015625 3
Cross Validation Accuracy = 55.75%
Average time: 0.362882932027


for c,d =  0.0625 1
Cross Validation Accuracy = 89.6%
Average time: 0.298223654429


for c,d =  0.0625 2
Cross Validation Accuracy = 88.65%
Average time: 0.338028033574


for c,d =  0.0625 3
Cross Validation Accuracy = 72.1%
Average time: 0.350508371989


for c,d =  0.25 1
Cross Validation Accuracy = 91.3%
Average time: 0.186383326848


for c,d =  0.25 2
Cross Validation Accuracy = 92%
Average time: 0.219321330388


for c,d =  0.25 3
Cross Validation Accuracy = 91.6%
Average time: 0.270109335581
```

```
for c,d =  1 1
Cross Validation Accuracy = 93.6%
Average time: 0.1266552739

for c,d =  1 2
Cross Validation Accuracy = 92.65%
Average time: 0.139814376831

for c,d =  1 3
Cross Validation Accuracy = 93.35%
Average time: 0.179284016291

for c,d =  4 1
Cross Validation Accuracy = 94.55%
Average time: 0.0938669840495

for c,d =  4 2
Cross Validation Accuracy = 94.7%
Average time: 0.0998153686523

for c,d =  4 3
Cross Validation Accuracy = 94.95%
Average time: 0.117389281591

for c,d =  16 1
Cross Validation Accuracy = 94.65%
Average time: 0.0816299915314

for c,d =  16 2
Cross Validation Accuracy = 95.65%
Average time: 0.0807036558787

for c,d =  16 3
Cross Validation Accuracy = 96.2%
Average time: 0.0877663294474

for c,d =  64 1
Cross Validation Accuracy = 94%
Average time: 0.0846985975901

for c,d =  64 2
Cross Validation Accuracy = 96.6%
Average time: 0.0776766935984

for c,d =  64 3
Cross Validation Accuracy = 96.9%
```

```
Average time: 0.082767645518

for c,d =  256 1
Cross Validation Accuracy = 94.45%
Average time: 0.104080359141

for c,d =  256 2
Cross Validation Accuracy = 96.7%
Average time: 0.0745690663656

for c,d =  256 3
Cross Validation Accuracy = 96.25%
Average time: 0.0767703851064

for c,d =  1024 1
Cross Validation Accuracy = 94.55%
Average time: 0.227657318115

for c,d =  1024 2
Cross Validation Accuracy = 97.05%
Average time: 0.0891873041789

for c,d =  1024 3
Cross Validation Accuracy = 96.5%
Average time: 0.0778923034668

for c,d =  4096 1
Cross Validation Accuracy = 94.2%
Average time: 0.52498904864

for c,d =  4096 2
Cross Validation Accuracy = 96.35%
Average time: 0.0992469787598

for c,d =  4096 3
Cross Validation Accuracy = 96.35%
Average time: 0.0785965919495

for c,d =  16384 1
Cross Validation Accuracy = 93.65%
Average time: 4.88202468554

for c,d =  16384 2
Cross Validation Accuracy = 96.35%
Average time: 0.102289676666
```

```
for c,d =  16384 3
Cross Validation Accuracy = 95.8%
Average time: 0.0769366423289
```

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b) RBF kernel

```
for c,gamma =  0.015625 6.103515625e-05
Cross Validation Accuracy = 55.75%
Average time: 0.359410683314


for c,gamma =  0.015625 0.000244140625
Cross Validation Accuracy = 55.75%
Average time: 0.366421699524


for c,gamma =  0.015625 0.0009765625
Cross Validation Accuracy = 55.75%
Average time: 0.367117961248


for c,gamma =  0.015625 0.00390625
Cross Validation Accuracy = 55.75%
Average time: 0.368617693583


for c,gamma =  0.015625 0.015625
Cross Validation Accuracy = 56.1%
Average time: 0.360798358917


for c,gamma =  0.015625 0.0625
Cross Validation Accuracy = 87.7%
Average time: 0.358225663503


for c,gamma =  0.015625 0.25
Cross Validation Accuracy = 60.55%
Average time: 0.375350316366


for c,gamma =  0.0625 6.103515625e-05
Cross Validation Accuracy = 55.75%
Average time: 0.363487641017


for c,gamma =  0.0625 0.000244140625
Cross Validation Accuracy = 55.75%
Average time: 0.373608032862


for c,gamma =  0.0625 0.0009765625
Cross Validation Accuracy = 55.75%
Average time: 0.367438316345
```

```
for c,gamma =   0.0625 0.00390625
Cross Validation Accuracy = 64.3%
Average time: 0.362851381302

for c,gamma =   0.0625 0.015625
Cross Validation Accuracy = 90.4%
Average time: 0.301982005437

for c,gamma =   0.0625 0.0625
Cross Validation Accuracy = 91.9%
Average time: 0.230672995249

for c,gamma =   0.0625 0.25
Cross Validation Accuracy = 92.55%
Average time: 0.306898355484

for c,gamma =   0.25 6.103515625e-05
Cross Validation Accuracy = 55.75%
Average time: 0.36016535759

for c,gamma =   0.25 0.000244140625
Cross Validation Accuracy = 55.75%
Average time: 0.371179024378

for c,gamma =   0.25 0.0009765625
Cross Validation Accuracy = 66.8%
Average time: 0.368921995163

for c,gamma =   0.25 0.00390625
Cross Validation Accuracy = 90.6%
Average time: 0.278455336889

for c,gamma =   0.25 0.015625
Cross Validation Accuracy = 91.35%
Average time: 0.179018974304

for c,gamma =   0.25 0.0625
Cross Validation Accuracy = 93.65%
Average time: 0.1414706707

for c,gamma =   0.25 0.25
Cross Validation Accuracy = 96.1%
Average time: 0.208843628565

for c,gamma =   1 6.103515625e-05
```

```
Cross Validation Accuracy = 55.75%
Average time: 0.364450057348


for c,gamma =  1 0.000244140625
Cross Validation Accuracy = 67.4%
Average time: 0.368824720383


for c,gamma =  1 0.0009765625
Cross Validation Accuracy = 90.7%
Average time: 0.269176324209


for c,gamma =  1 0.00390625
Cross Validation Accuracy = 91.2%
Average time: 0.172989288966


for c,gamma =  1 0.015625
Cross Validation Accuracy = 93.45%
Average time: 0.125102043152


for c,gamma =  1 0.0625
Cross Validation Accuracy = 96.1%
Average time: 0.100438038508


for c,gamma =  1 0.25
Cross Validation Accuracy = 97.3%
Average time: 0.14359164238


for c,gamma =  4 6.103515625e-05
Cross Validation Accuracy = 67.35%
Average time: 0.357124646505


for c,gamma =  4 0.000244140625
Cross Validation Accuracy = 90.55%
Average time: 0.274480024974


for c,gamma =  4 0.0009765625
Cross Validation Accuracy = 91.3%
Average time: 0.172302722931


for c,gamma =  4 0.00390625
Cross Validation Accuracy = 93.4%
Average time: 0.115982294083


for c,gamma =  4 0.015625
Cross Validation Accuracy = 95%
Average time: 0.0887730121613
```

```
for c,gamma =   4 0.0625
Cross Validation Accuracy = 97%
Average time: 0.0814469655355

for c,gamma =   4 0.25
Cross Validation Accuracy = 97.15%
Average time: 0.130587339401

for c,gamma =   16 6.103515625e-05
Cross Validation Accuracy = 90.35%
Average time: 0.267911354701

for c,gamma =   16 0.000244140625
Cross Validation Accuracy = 91.55%
Average time: 0.169866959254

for c,gamma =   16 0.0009765625
Cross Validation Accuracy = 93.65%
Average time: 0.118268648783

for c,gamma =   16 0.00390625
Cross Validation Accuracy = 94.55%
Average time: 0.0873273213704

for c,gamma =   16 0.015625
Cross Validation Accuracy = 96.2%
Average time: 0.0782226721446

for c,gamma =   16 0.0625
Cross Validation Accuracy = 96.25%
Average time: 0.0739223162333

for c,gamma =   16 0.25
Cross Validation Accuracy = 97.1%
Average time: 0.125694990158

for c,gamma =   64 6.103515625e-05
Cross Validation Accuracy = 91.4%
Average time: 0.170482714971

for c,gamma =   64 0.000244140625
Cross Validation Accuracy = 93.65%
Average time: 0.116478363673

for c,gamma =   64 0.0009765625
```

```
Cross Validation Accuracy = 94.3%
Average time: 0.0962306658427


for c,gamma =   64 0.00390625
Cross Validation Accuracy = 94.6%
Average time: 0.0810159842173


for c,gamma =   64 0.015625
Cross Validation Accuracy = 96.75%
Average time: 0.077134291331


for c,gamma =   64 0.0625
Cross Validation Accuracy = 96.6%
Average time: 0.0726536909739


for c,gamma =   64 0.25
Cross Validation Accuracy = 96.7%
Average time: 0.124210039775


for c,gamma =   256 6.103515625e-05
Cross Validation Accuracy = 93.9%
Average time: 0.12159705162


for c,gamma =   256 0.000244140625
Cross Validation Accuracy = 94.25%
Average time: 0.0992126464844


for c,gamma =   256 0.0009765625
Cross Validation Accuracy = 94.3%
Average time: 0.0889236132304


for c,gamma =   256 0.00390625
Cross Validation Accuracy = 95.5%
Average time: 0.0807417233785


for c,gamma =   256 0.015625
Cross Validation Accuracy = 96.75%
Average time: 0.0820542971293


for c,gamma =   256 0.0625
Cross Validation Accuracy = 96.7%
Average time: 0.0745573043823


for c,gamma =   256 0.25
Cross Validation Accuracy = 97%
Average time: 0.129339694977
```

```
for c,gamma =   1024 6.103515625e-05
Cross Validation Accuracy = 94.3%
Average time: 0.0887923240662

for c,gamma =   1024 0.000244140625
Cross Validation Accuracy = 94.4%
Average time: 0.0862356821696

for c,gamma =   1024 0.0009765625
Cross Validation Accuracy = 94.6%
Average time: 0.0859529972076

for c,gamma =   1024 0.00390625
Cross Validation Accuracy = 96.6%
Average time: 0.0930480162303

for c,gamma =   1024 0.015625
Cross Validation Accuracy = 96.95%
Average time: 0.0868326822917

for c,gamma =   1024 0.0625
Cross Validation Accuracy = 97%
Average time: 0.0695406595866

for c,gamma =   1024 0.25
Cross Validation Accuracy = 96.85%
Average time: 0.126975615819

for c,gamma =   4096 6.103515625e-05
Cross Validation Accuracy = 94.55%
Average time: 0.0818753242493

for c,gamma =   4096 0.000244140625
Cross Validation Accuracy = 94.9%
Average time: 0.0879953702291

for c,gamma =   4096 0.0009765625
Cross Validation Accuracy = 95.5%
Average time: 0.108120997747

for c,gamma =   4096 0.00390625
Cross Validation Accuracy = 96.3%
Average time: 0.125629663467

for c,gamma =   4096 0.015625
```

```
Cross Validation Accuracy = 95.8%
Average time: 0.0906340281169

for c,gamma =  4096 0.0625
Cross Validation Accuracy = 96%
Average time: 0.0733679930369

for c,gamma =  4096 0.25
Cross Validation Accuracy = 97.1%
Average time: 0.129065672557

for c,gamma =  16384 6.103515625e-05
Cross Validation Accuracy = 94.75%
Average time: 0.088879664739

for c,gamma =  16384 0.000244140625
Cross Validation Accuracy = 93.95%
Average time: 0.109682321548

for c,gamma =  16384 0.0009765625
Cross Validation Accuracy = 96.6%
Average time: 0.157010316849

for c,gamma =  16384 0.00390625
Cross Validation Accuracy = 95.85%
Average time: 0.155296007792

for c,gamma =  16384 0.015625
Cross Validation Accuracy = 95.95%
Average time: 0.10554599762

for c,gamma =  16384 0.0625
Cross Validation Accuracy = 96.4%
Average time: 0.0709290504456

for c,gamma =  16384 0.25
Cross Validation Accuracy = 97.25%
Average time: 0.128865718842
```

When we compare RBF kernel to Polynomial kernel, we clearly see in our outputs that the accuracy of RBF is better than Polynomial almost at all points with very minute increase in time taken for execution. Therefore we will choose RBF kernel for our prediction on test set.The RBF kernel defines a function space that is a lot larger than that of the polynomial kernel.

```
Prediction using best modelAccuracy = 95.55%
```

```
(1911/2000) (classification)

We are using
for c,gamma =  1 0.25
Cross Validation Accuracy = 97.3%
Average time: 0.143314282099
As this c and gamma has the highest accuracy
```
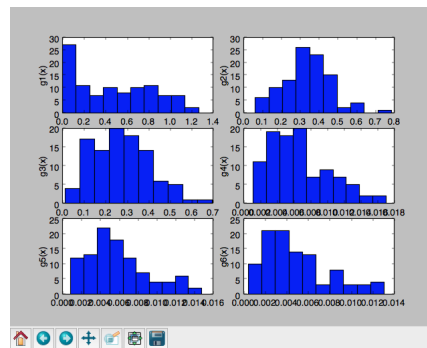
2   Bias Variance
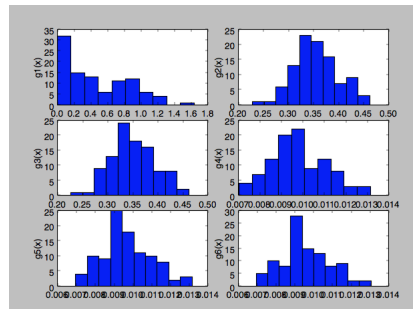

Figure 1: Histogram: 10 samples

Figure 2: Histogram: 100 samples

```
a)
Bias for samples =  10
g1 0.464670596393
g2 0.379695953737
g3 0.39136437327
```

```
g4 0.00962367677138
g5 0.0101603554496
g6 0.025474937751
Variance for sample =  10
g1 0.0
g2 0.0299487453329
g3 0.130365215736
g4 0.0063195307962
g5 0.0323198561665
g6 2.31193301787
------------------------
b)
Bias for samples =  100
g1 0.486957692703
g2 0.372980330185
g3 0.372968350489
g4 0.010098389952
g5 0.0101028785983
g6 0.0101007169824
Variance for sample =  100
g1 0.0
g2 0.0051331418099
g3 0.0110456350049
g4 0.000348751277908
g5 0.000475692578798
g6 0.000567528800048
--------------------------
```

c) As we increase the model complexity, the bias decreases and the variance increases. The bias decreases because now the hypothesis has a better chance of approximating the target function. The variance increases because increasing the model complexity increases the number of options of hypothesis to choose from. In our program we can see the bias coming down till g4 (where it is minimum) and then shoots up as we increase the model complexity. This is because the target function is a second order polynomial which is closest to g4(x) hypothesis

$$g_4(x) = w_0 + w_1 x + w_2 x^2 \, and f(x) = 2x^2 + \epsilon$$

In our program we can see that the variance increases with increase in model complexity but at one point it drops significantly [g4(x) again]. This is because the target function is a second order polynomial which is closest to g4(x) hypothesis

Increasing number of examples does not effect the bias. Bias is independent of the number of samples. Bias depends on the complexity of the model and is the difference between the best hypothesis in the set to the target function. The model complexity has nothing to do with the number of examples

The variance decreases with increase in number of samples as we can clearly see in our example with n=10 and n=100. More examples results in better training of the model and leads to lesser variance

```
---------------------------
d)
for lambda =  0.001
Bias for samples =  100
g4 0.0103461653869
Variance for sample =  100
g4 0.000340393228804


for lambda =  0.003
Bias for samples =  100
g4 0.0103767761257
Variance for sample =  100
g4 0.000336729514951


for lambda =  0.01
Bias for samples =  100
g4 0.0101632393831
Variance for sample =  100
g4 0.000324387108887


for lambda =  0.03
Bias for samples =  100
g4 0.0100026714771
Variance for sample =  100
g4 0.00027450332815


for lambda =  0.1
Bias for samples =  100
g4 0.00976641408505
Variance for sample =  100
g4 0.000304862312879


for lambda =  0.3
Bias for samples =  100
g4 0.010335812114
Variance for sample =  100
g4 0.000293737173654
```

```
for lambda =  1.0
Bias for samples =  100
g4 0.0146627874671
Variance for sample =  100
g4 0.000417604404035
```

In the above program we can clearly see that the bias is increasing as the lambda is becoming large except at the phase where it is coming down to a low value (lowest at lambda=0.1. This is because this lambda is suitable as it is decreasing the bias . We can see the variance decreases with with increase in lambda until lambda reaches optimal value and then starts increasing again