

# CMPE 462 Assignment 1 Report

## Part 1

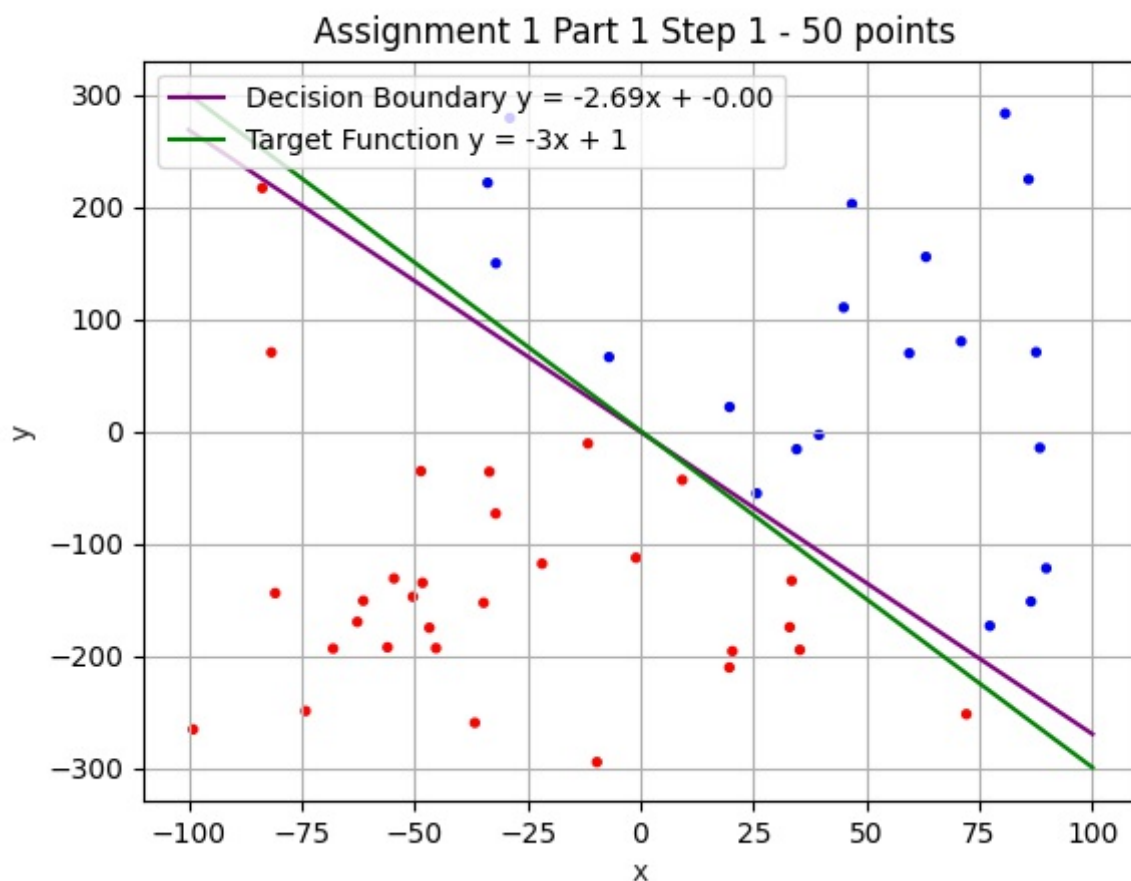
- Samples are randomly chosen from  $[-100, 100)$  range for  $x$  and  $[-300, 300)$  range for  $y$ . Range of  $y$  is 3 times that of  $x$ , in order to make sure the final plot looks full while the target function plot line is fully visible for that range.
- Random seed can be set by changing the global variable `RANDOM_SEED` By default it is kept as None (numpy requests a random seed from os)
- Below are the results and plots for each step with `RANDOM_SEED=12345`

### Step 1

Finished calculation in 25 iterations

Calculated weights are: [ 0. 531.02365676 197.25030511]

Decision Boundary is  $y = -2.69x + -0.00$

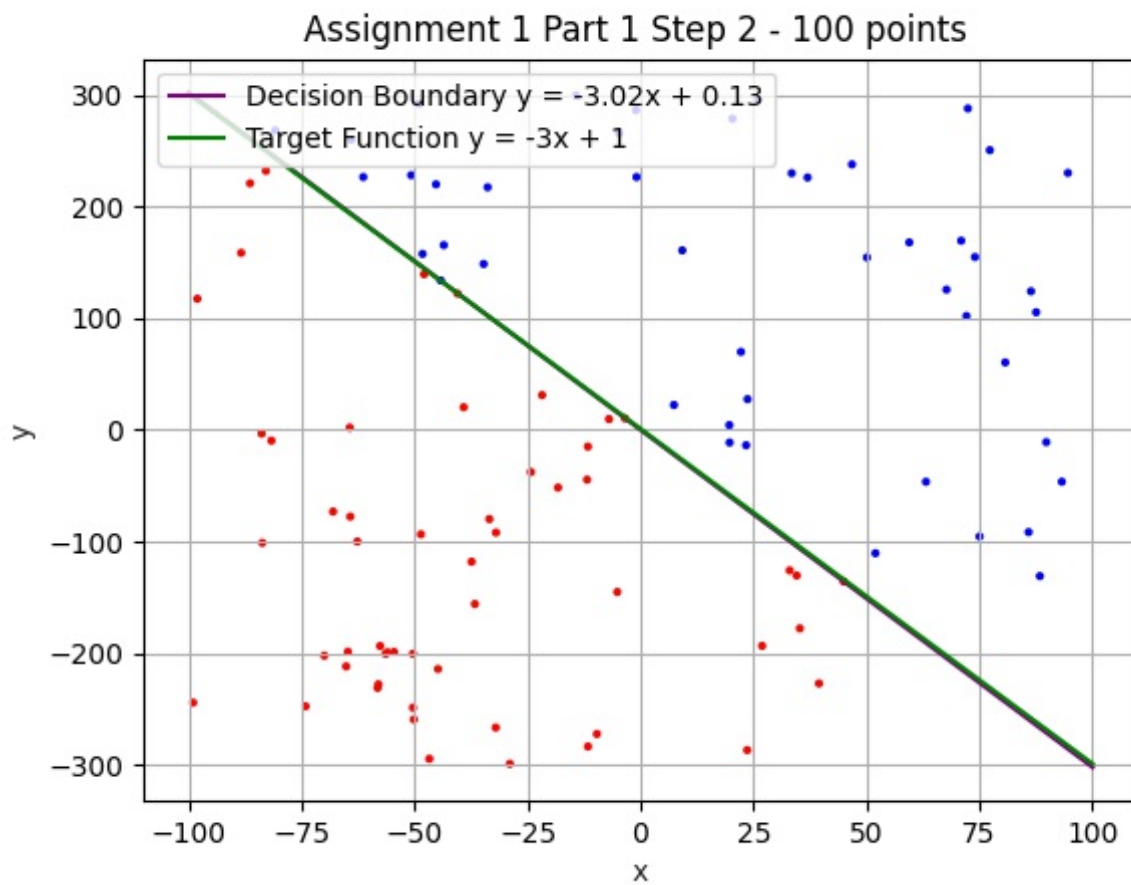


### Step 2

Finished calculation in 119 iterations

Calculated weights are: [ -50. 1122.35262344 371.32963463]

Decision Boundary is  $y = -3.02x + 0.13$

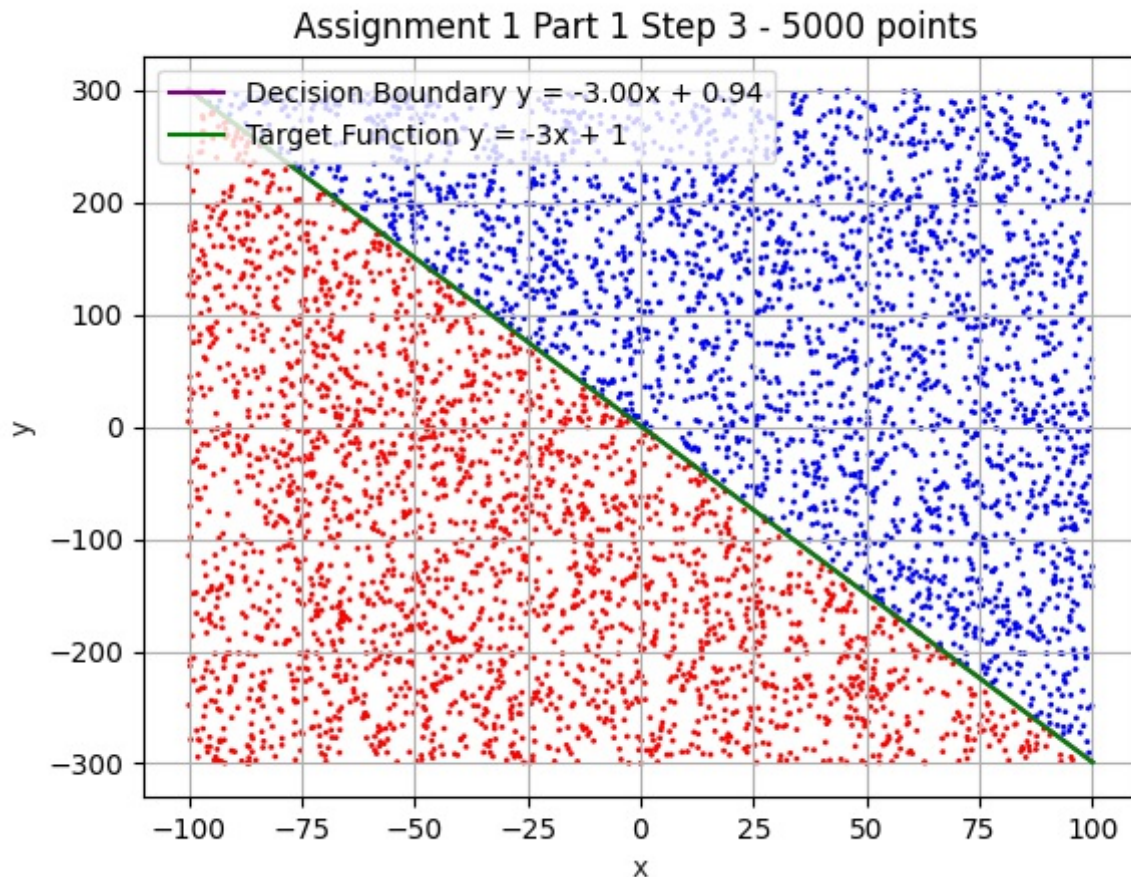


### Step 3

Finished calculation in 23867 iterations

Calculated weights are: [ -6418. 20547.05277251 6856.03386458]

Decision Boundary is  $y = -3.00x + 0.94$



## Part 1 Overview

When we check out above results, we can see that the decision boundary gets closer to the original target function as the number of sampled points are increased.

Also, as the number of sampled points are increased, PLA needs to make much more iterations to fully converge.

See below table for comparing above results.

Step	Samples	Iterations	$y = -3x + 1$
1	50	25	$y = -2.69x + -0.00$
2	100	119	$y = -3.02x + 0.13$
3	5000	23867	$y = -3.00x + 0.94$

## Part 2

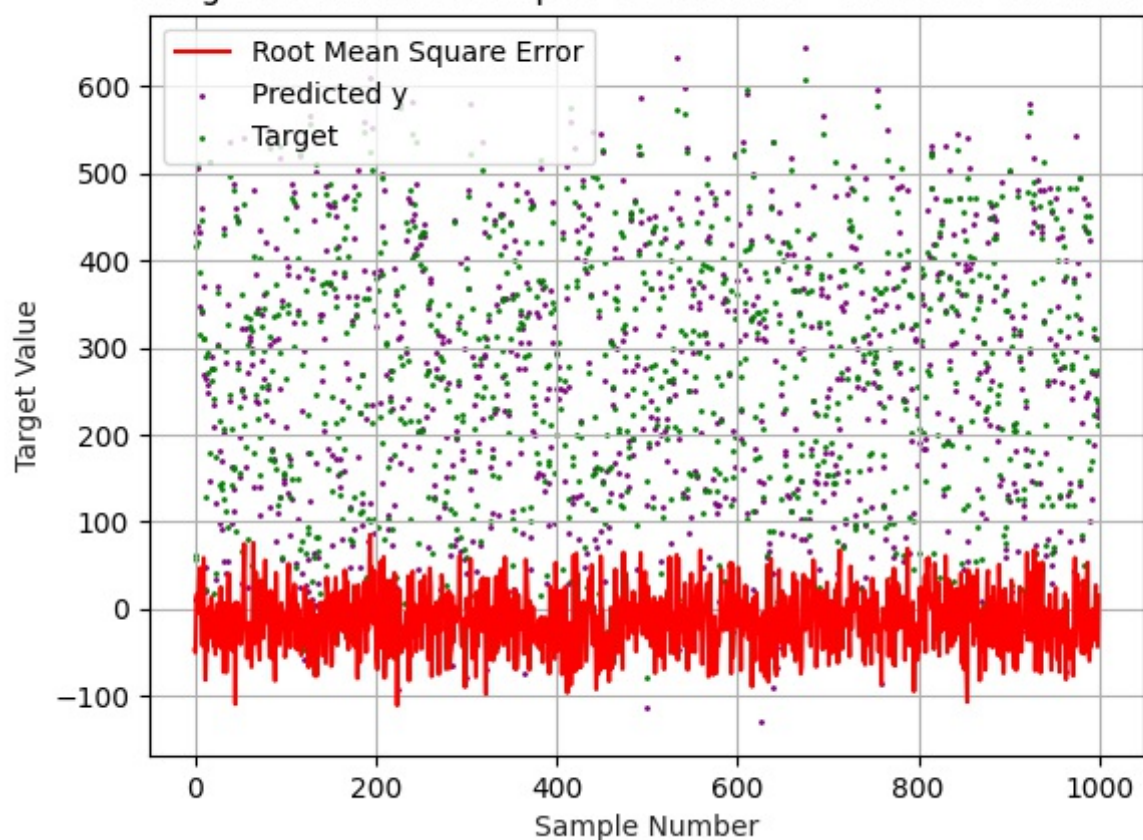
- Implemented closed form solution, so there will not be any loss over iterations graphs.
- Chose to apply 5-fold cross validation, this can be changed via the global variable, `PART2_S_FOLD_S_VALUE`
- Created a few supplementary graphs in order to get a better grasp of how well it predicts, and which lambda value to choose.
- Timing includes cross validation, but none of the extra-supplementary graph generations.

- Set PART2\_PLOT\_PREDICTIONS=True to create part2\_stepN\_predictions.png which shows predictions vs actual target values for each sample.
- Set PART2\_PLOT\_LAMBDA\_VALUES=True to create part2\_stepN\_regularization.png a graph of training & testing results (root mean square errors) over varying ln-lambda value. This will be same for step2 and step3 as expected, because they are only varied by regularization.
- Chosen the lambda value for regularization as  $e^{-10}$  yet it is neither beneficial nor harmful, as it seems.
- When we choose to do 2-fold cross validation instead, regularization becomes useful because of tolerating the lack of many training values causing over-fitting. But such analysis is out of this report's scope. If interested, one can set PART2\_S\_FOLD\_S\_VALUE=2 and PART2\_PLOT\_LAMBDA\_VALUES=True and run the program on part2, and check out the generated graph, part2\_stepN\_regularization.png.

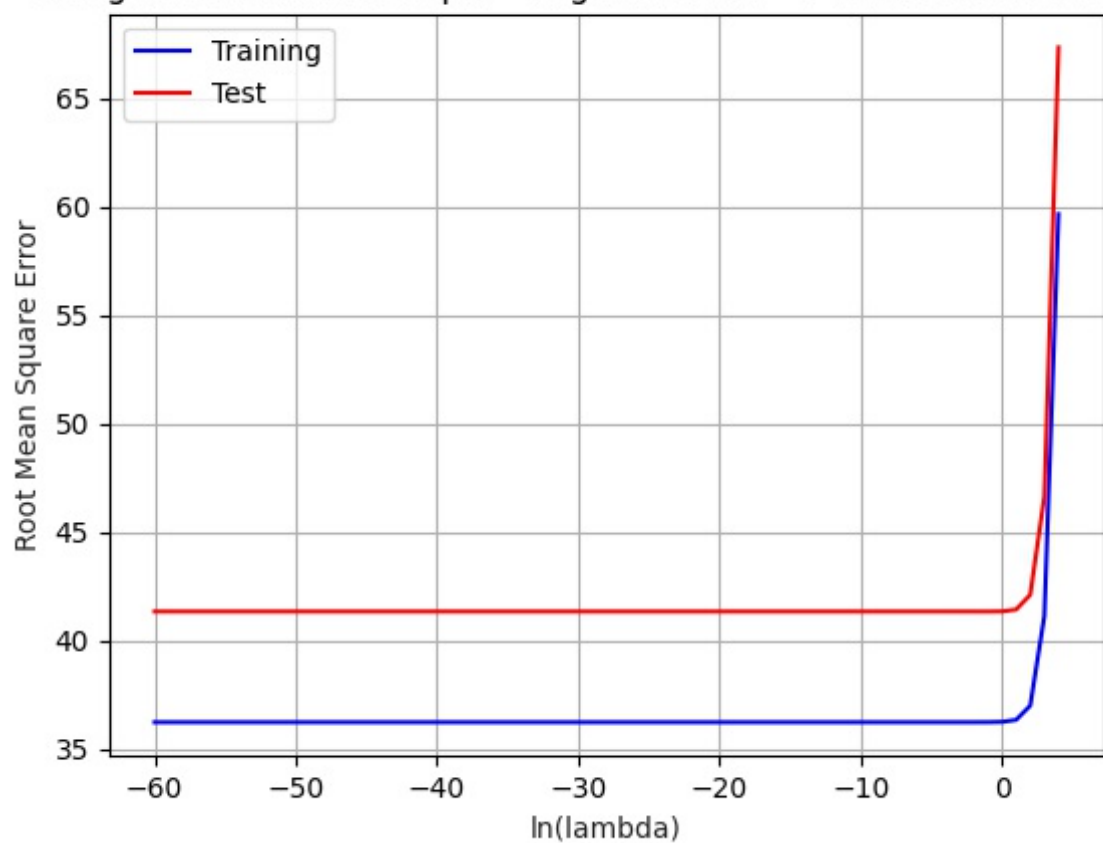
## Step 1

Applying 5-fold cross validation  
 There were 100 independent variables and 1 dependent variables  
 There were 1000 samples in total  
 Completed in 3.160 milliseconds  
 Average Erms\_train = 36.257771814312136  
 Average Erms\_test = 41.3584787667631

Assignment 1 Part 2 Step 1 - Predictions - No Cross-Validation



Assignment 1 Part 2 Step 1 - Regularization - 5-Fold Cross-Validation



## Step 2

Applying 5-fold cross validation

There were 500 independent variables and 1 dependent variables

There were 1000 samples in total

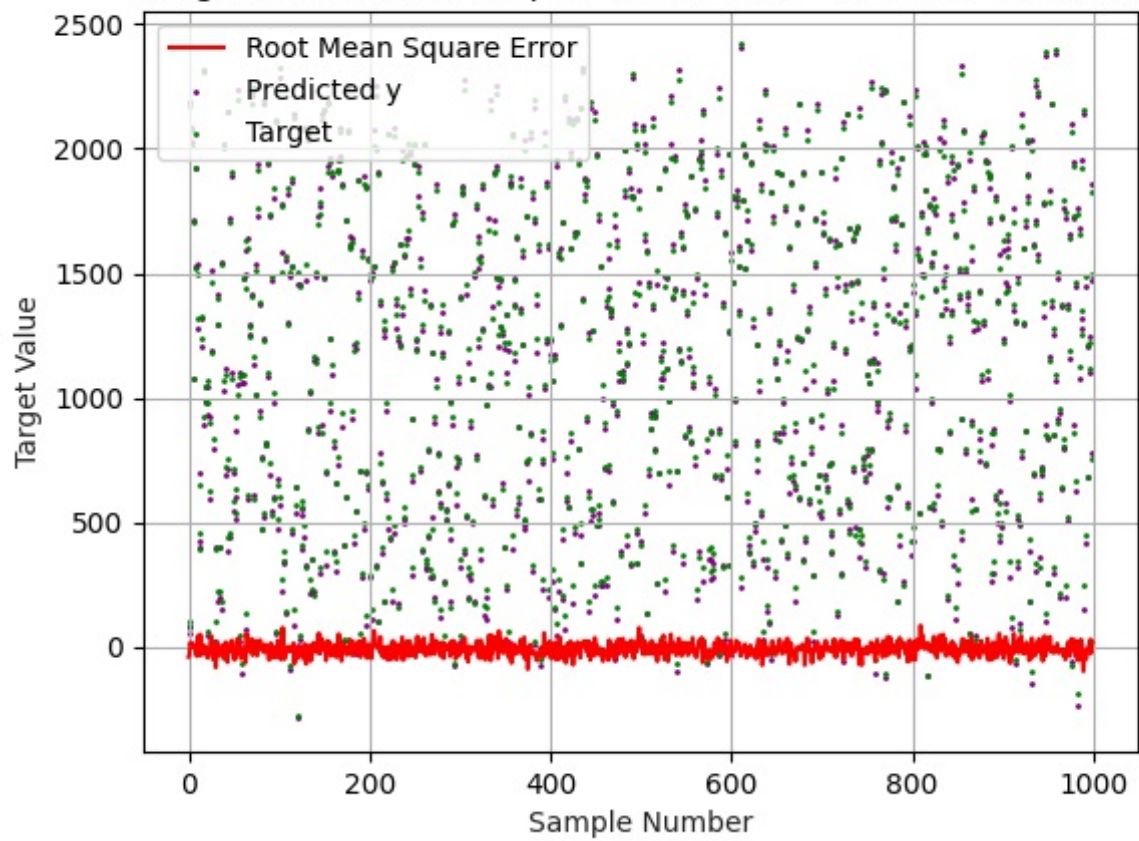
Completed in 48.580 milliseconds

Average Erms\_train = 23.6657974544233

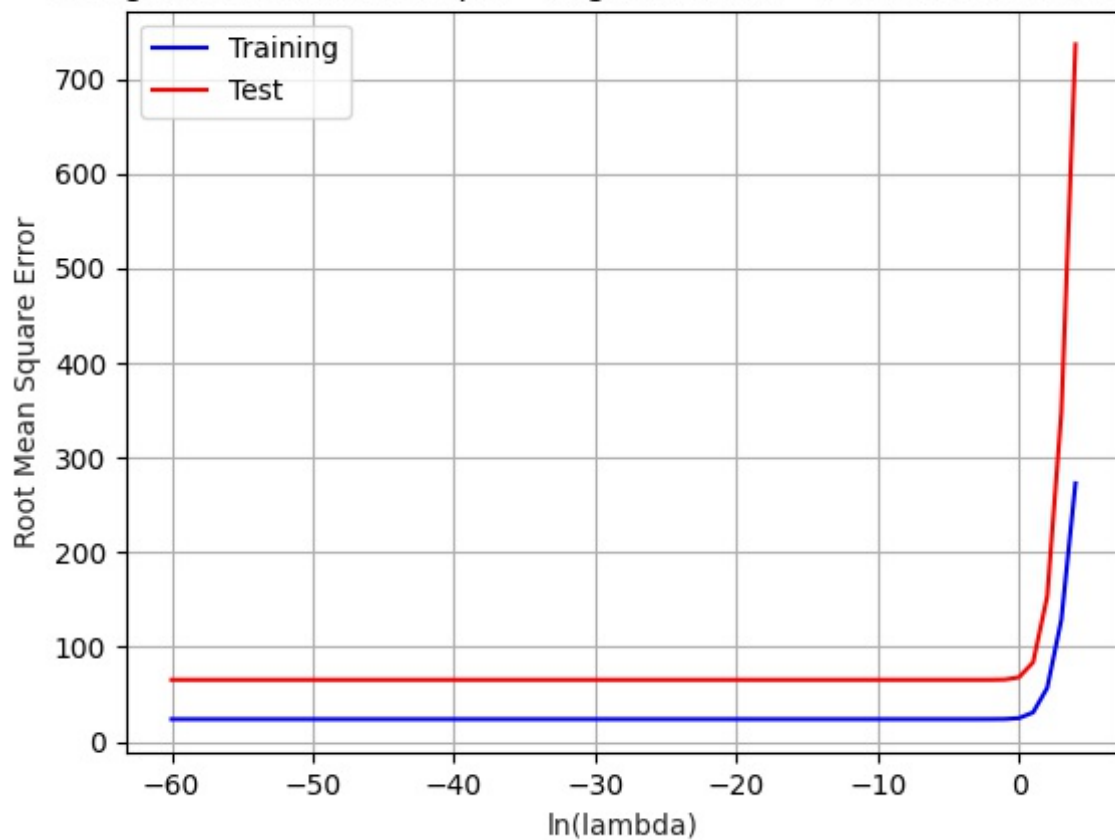
Average Erms\_test = 65.28337321386573



Assignment 1 Part 2 Step 2 - Predictions - No Cross-Validation



Assignment 1 Part 2 Step 2 - Regularization - 5-Fold Cross-Validation



### Step 3

Applying 5-fold cross validation

There were 500 independent variables and 1 dependent variables

There were 1000 samples in total

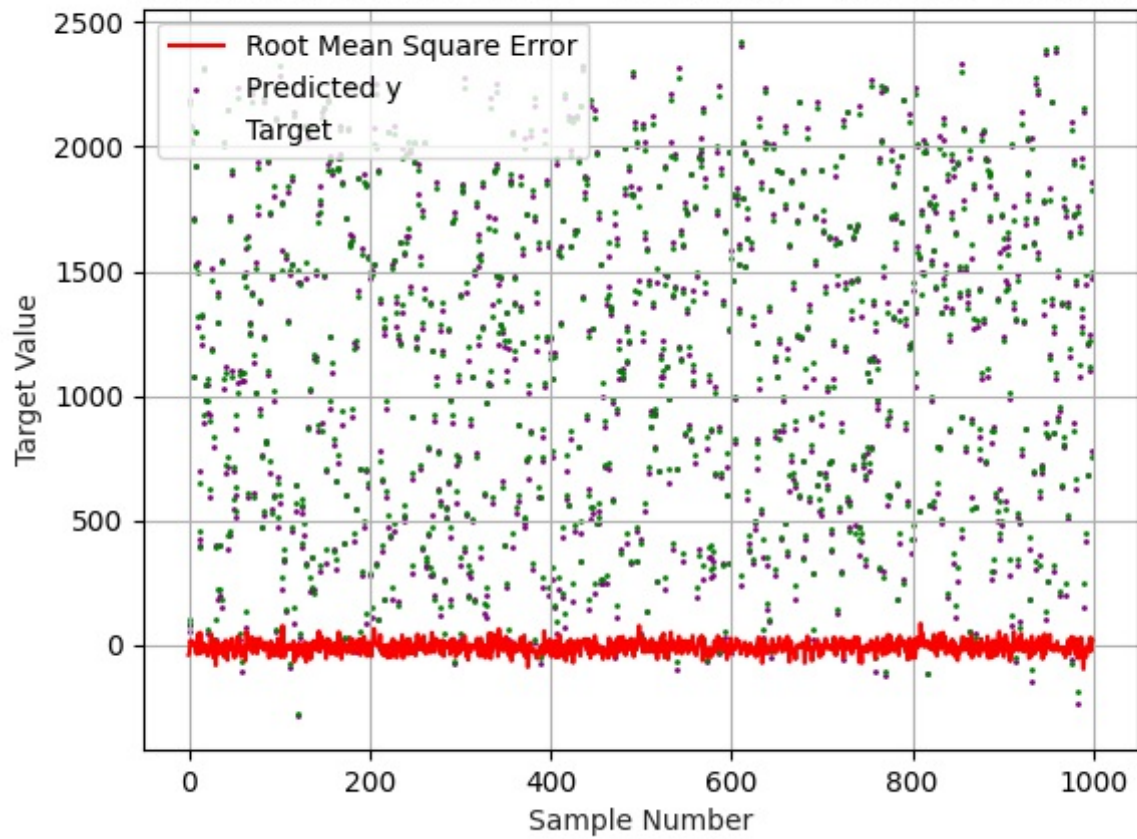
Completed in 52.595 milliseconds

Average Erms\_train = 23.665797456855017

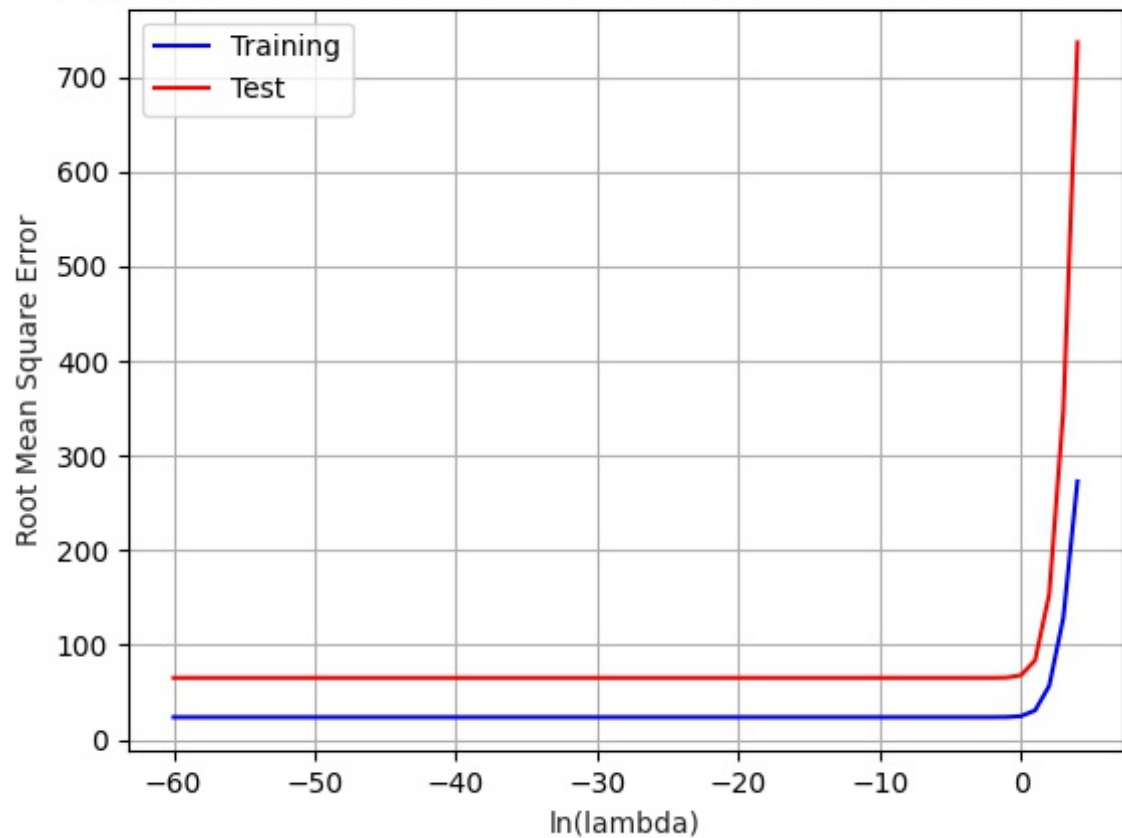
Average Erms\_test = 65.28335649367837



Assignment 1 Part 2 Step 3 - Predictions - No Cross-Validation



Assignment 1 Part 2 Step 3 - Regularization - 5-Fold Cross-Validation



## Part 2 Overview

Since I implemented the close form solution, the time it takes mostly depends on the matrix multiplication operations applied to the input. Thus, time spent depends on the input size and how long constant number of matrix multiplication operations on that input takes. Matrix multiplication can be considered  $O(N^2)$  where  $N$  resembles the size of the whole input (not one dimension) Input size is  $100 * 1000 = 100k$  for step 1, and  $500 * 1000 = 500k$  for step 2-3. Since,  $500k/100k = 5$  and  $5^2 = 25$ , I would expect step 2/3 to take 25 times that of step 1. We can see in the below table a similar fashion can be observed. (The time spent varies across different runs but the ratio of time spent on step 1 vs 2/3 is around 25 as expected)

When we check out the Erms values of step 2 and 3, we can see that the regularization did not do any change. Can check out the regularization graphs above and deduce that choosing a higher lambda value doesn't perform better, and if chosen too big, causes under-fitting.

When we check out the Erms values of step 1 vs 2/3, we can see that step 1 performs worse on training result. That is probably related to the ratio of the number of independent variables to sample sizes. That's because unless there was a clear linear generation method for data, fitting a linear regression line gets harder to cover for samples as the sample size gets higher than the number of independent variables. So maybe, applying a polynomial/logistic regression to step 1 might have performed better.

When we check out the test Erms values however, step 1 actually does perform better. That's probably again because of the same ratio. Since the number of independent variables and samples are close in step 2/3, it has a higher chance of over-fitting, and that's why they're performing worse on test Erms.

See below tables for comparing above results.

Step	IV	Samples	L2 Lamda	Time (ms)	Train Erms	Test Erms
1	100	1000	-	3.160	36.258	41.358
2	500	1000	-	48.580	23.666	65.283
3	500	1000	$\lambda = e^{-10}$	52.595	23.665	65.283

IV: Independent Variables Erms values are average of each run of s-fold cross-validation Time is the time spent for calculating weights including cross-validation Samples are the total number of samples before separating them for training and testing. L2 Lambda is the lambda value used for L2 Regularization if applied, -, otherwise.