Programming Assignment 2

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1 Backpropagation

- For the implementation of backpropagation, stochastic gradient descent version of algorithm is used. The structure of the graph implemented is described in Table 1.

  The graph of Sum Squared Error versus the number of iterations is given in Figure 1.

$$Confusion\ Matrix = \begin{bmatrix} 17 & 1 & 1 & 1 \\ 2 & 7 & 4 & 8 \\ 1 & 0 & 11 & 9 \\ 3 & 4 & 2 & 12 \end{bmatrix} \tag{1}$$

  Class 1:

$$Precision = 0.7391 \tag{2}$$

$$Recall = 0.85 \tag{3}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7907 \tag{4}$$

$$Accuracy = 0.8916 \tag{5}$$

  Class 2:

$$Precision = 0.5833 \tag{6}$$

Parameter	**Value**
Number of layers	3
Number of nodes in the input layer	97
Number of nodes in the hidden layer	50
Number of nodes in the output layer	4
Activation function for the hidden layer	Sigmoid function
Activation function for the output layer	Linear function
Learning rate	0.06

Table 1: Structure of the Neural Network

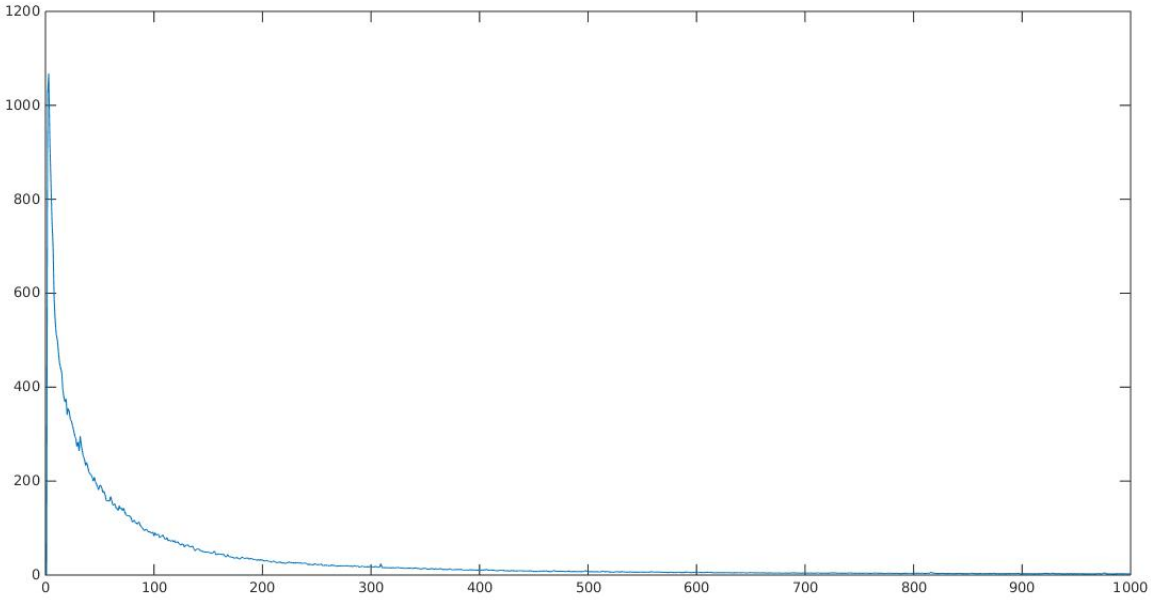

Figure 1: Sum squared error plot vs iterations

$$Recall = 0.3333 \tag{7}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.4242 \tag{8}$$

$$Accuracy = 0.7711 \tag{9}$$

Class 3:

$$Precision = 0.6111 \tag{10}$$

$$Recall = 0.5238 \tag{11}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.5641 \tag{12}$$

$$Accuracy = 0.7952 \tag{13}$$

Class 4:

$$Precision = 0.40 \tag{14}$$

$$Recall = 0.5714 \tag{15}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.4706 \tag{16}$$

$$Accuracy = 0.6747 \tag{17}$$

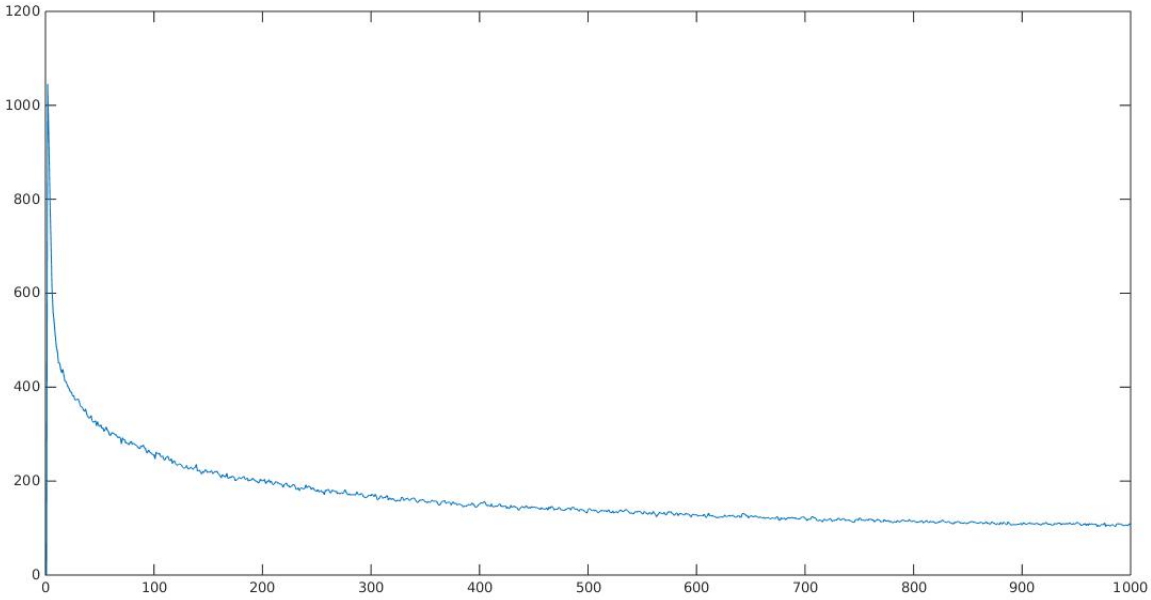

Figure 2: Sum squared error plot vs iterations

- With regularization, the gradient descent update rule changes as shown below.

$$w = w + \delta w - \nu * \lambda * w \tag{18}$$

where w = weights to be updated, ν = learning rate, λ = regularization factor.

The plot of Sum Squared error versus the iterations is given in the Figure 2.

$$Confusion\ Matrix = \begin{bmatrix} 17 & 1 & 2 & 0 \\ 0 & 11 & 5 & 5 \\ 2 & 0 & 19 & 0 \\ 2 & 6 & 5 & 8 \end{bmatrix} \tag{19}$$

Class 1:

$$Precision = 0.8095 \tag{20}$$

$$Recall = 0.8500 \tag{21}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.8293 \tag{22}$$

$$Accuracy = 0.9157 \tag{23}$$

Class 2:

$$Precision = 0.6111 \tag{24}$$

$$Recall = 0.5238 \tag{25}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.5641 \tag{26}$$

$$Accuracy = 0.7952 \tag{27}$$

Class 3:

$$Precision = 0.6129 \tag{28}$$

$$Recall = 0.9048 \tag{29}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7308 \tag{30}$$

$$Accuracy = 0.8313 \tag{31}$$

Class 4:

$$Precision = 0.6154 \tag{32}$$

$$Recall = 0.3810 \tag{33}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.4706 \tag{34}$$

$$Accuracy = 0.7831 \tag{35}$$

With regularization, there is an improvement in the classification accuracy, precision and recall. As λ (regularization factor increases) the classification is inaccurate as the weights are too constrained.

2 QDA & RDA

For the purpose of this problem, only petal length and petal width features are considered. The decision boundaries for LDA, QDA and RDA are shown in Figure 2, Figure 3 and Figure 4 respectively.

3 Logistic Regression

For the purpose of this problem a one vs all classifer procedure is used.

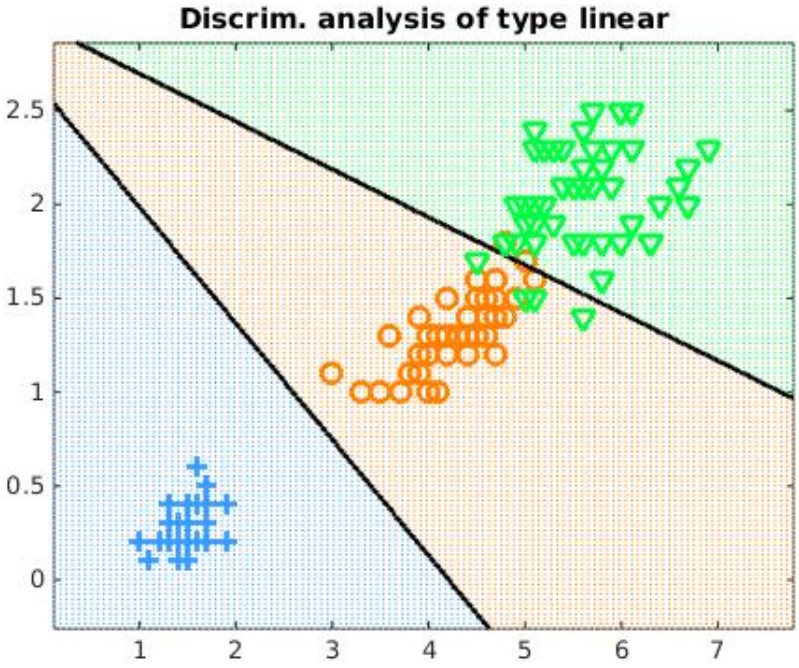

Figure 3: Decision boundaries for LDA

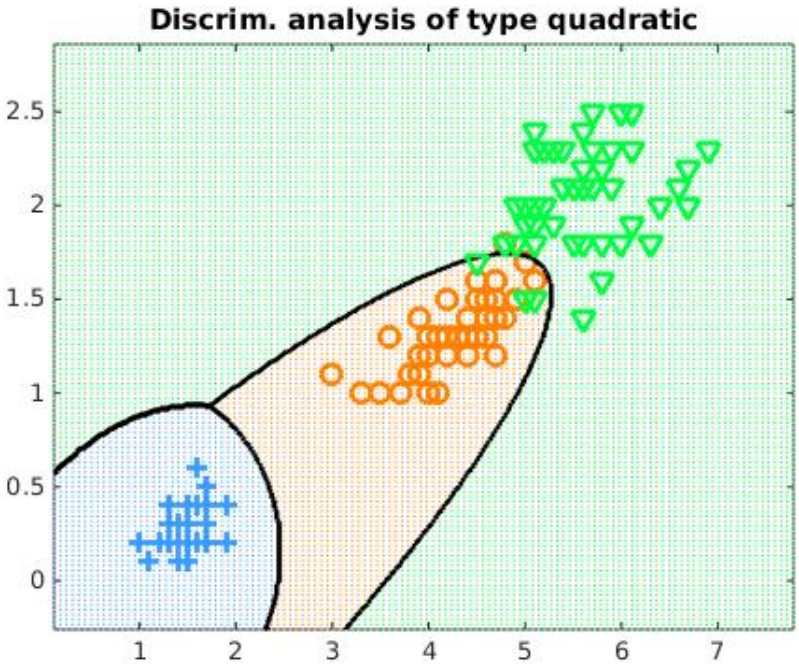

Figure 4: Decision boundaries for QDA

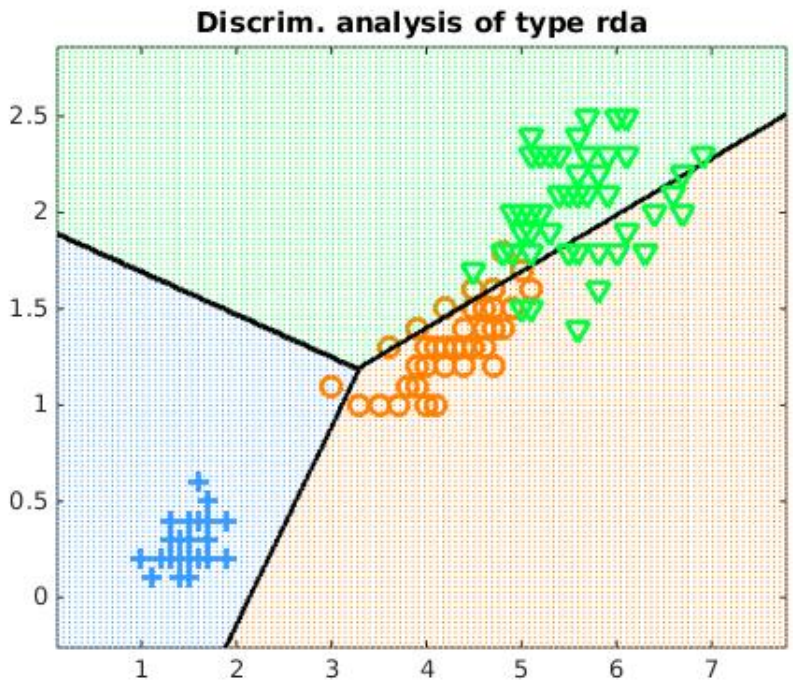

Figure 5: Decision boundaries for RDA

3.1 Logistic Regression

The confusion matrices, precision, recall, f- measure values are given below for logistic regression of classification of DS4.

Class 1:

$$Confusion\ Matrix = \begin{bmatrix} 8 & 12 \\ 4 & 59 \end{bmatrix} \tag{36}$$

$$Precision = 0.6667 \tag{37}$$

$$Recall = 0.40 \tag{38}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.8512 \tag{39}$$

Class 2:

$$Confusion\ Matrix = \begin{bmatrix} 11 & 10 \\ 5 & 57 \end{bmatrix} \tag{40}$$

$$Precision = 0.6875 \tag{41}$$

$$Recall = 0.5238 \tag{42}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.8054 \tag{43}$$

Class 3:

$$Confusion\ Matrix = \begin{bmatrix} 16 & 5 \\ 6 & 56 \end{bmatrix} \tag{44}$$

$$Precision = 0.7273 \tag{45}$$

$$Recall = 0.7619 \tag{46}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7336 \tag{47}$$

Class 4:

$$Confusion\ Matrix = \begin{bmatrix} 16 & 5 \\ 2 & 60 \end{bmatrix} \tag{48}$$

$$Precision = 0.8889 \tag{49}$$

$$Recall = 0.7619 \tag{50}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7059 \tag{51}$$

3.2 Regularized Logistic Regression

The confusion matrices, precision, recall, f- measure values are given below for one vs rest method of classification. The λ value chosen for the regularization is 0.1.

Class 1:

$$Confusion\ Matrix = \begin{bmatrix} 7 & 13 \\ 1 & 62 \end{bmatrix} \tag{52}$$

$$Precision = 0.8750 \tag{53}$$

$$Recall = 0.35 \tag{54}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7460 \tag{55}$$

Class 2:

$$Confusion\ Matrix = \begin{bmatrix} 16 & 5 \\ 0 & 62 \end{bmatrix} \tag{56}$$

$$Precision = 1 \tag{57}$$

$$Recall = 0.7619 \tag{58}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.7460 \tag{59}$$

Class 3:

$$Confusion\ Matrix = \begin{bmatrix} 20 & 1 \\ 2 & 60 \end{bmatrix} \tag{60}$$

$$Precision = 0.9091 \tag{61}$$

$$Recall = 0.9524 \tag{62}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.8251 \tag{63}$$

Class 4:

$$Confusion\ Matrix = \begin{bmatrix} 18 & 3 \\ 2 & 60 \end{bmatrix} \tag{64}$$

$$Precision = 0.90 \tag{65}$$

$$Recall = 0.8571 \tag{66}$$

$$f - measure = 2 * \frac{Precision * Recall}{Precision + Recall} = 0.8397 \tag{67}$$

With regularization, there is a huge improvement in the classification accuracy, precision and recall.