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Course: INF 552 Summer 2020
Assignment: HomeWork5 (Multi Layer Perceptron Neural Network)

**Multi Layer Perceptron Neural Network:**

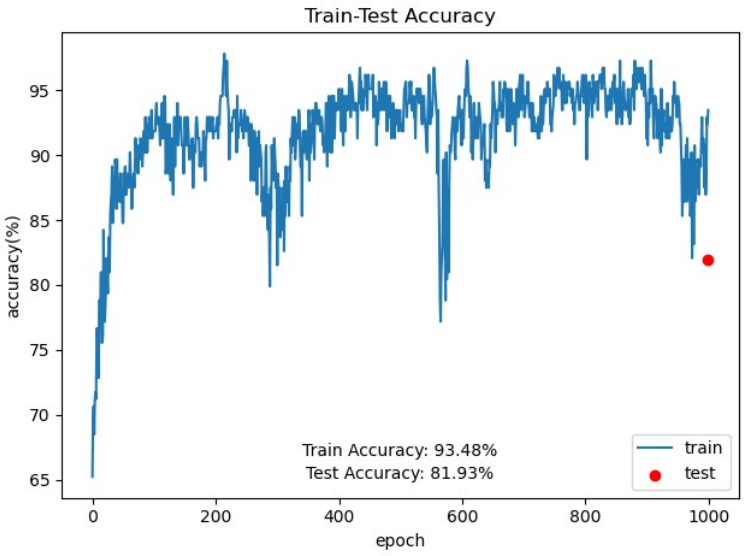
We are given the hand gestures image data-set in .pgm format with label given in the image name such as ‘down’ for thumbs down gesture and so for ‘up’, ‘hold’, ‘stop’ etc. We are asked to train the neural network on selected few images, just 184 out of 373 images in database. Testing is evaluated on 83 images. Architecture of the model is described as follows:-

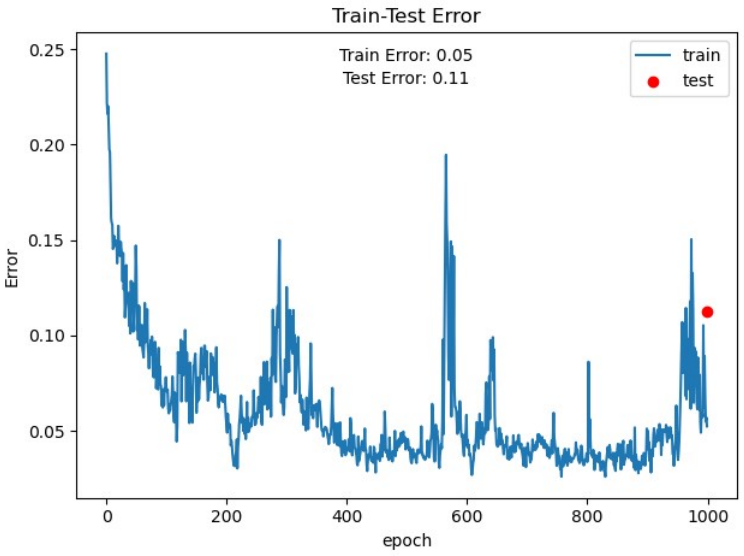
- Each image is 32x30 in grayscale with pixel value ranging from 0 to 255. We need to flatten the pixel array to form 960x1 column vector as an input sample, normalized to make pixel value ranging from 0 to 1.
- 1 hidden layer of size 100 is used which means weights_matrix is 961x100 (including bias term added with input, without which perceptron doesn’t work)
- Final layer is of size 1. Every perceptron/neuron has sigmoid output including the final one.
- Square error is used to evaluate and optimized the model by updating the weights subtracting derivative of squared error in Back propagation.
- Accuracy and Error plots for Train as well as Test run is plotted.

Hyper-parameters:

| | |
|---|---|
| Number of hidden layers | 1 |
| Number of perceptron in hidden layer | 100 |
| Number of epochs | 1000 |
| Weights initialization in range | -0.01 to 0.01 |
| Learning rate | 0.1 |

Based on above hyper-parameters, 81.93% test accuracy is achieved with 15 miss-labeled test images.



Training mislabeled(final epoch): 12/184
Training Accuracy(final epoch): 93.47826086956522%
Training Error(final epoch): 0.05247878120399662
Training Prediction(final epoch): entries marked with * are mis-labeled
1. gestures/A/A_down_4.pgm => 0
2. gestures/A/A_down_6.pgm => 0
3. gestures/A/A_down_7.pgm => 0
4. gestures/A/A_down_8.pgm => 0
5. gestures/A/A_down_9.pgm => 0
6. gestures/A/A_hold_3.pgm => 1
7. gestures/A/A_hold_4.pgm => 1
8. gestures/A/A_hold_5.pgm => 0
9. gestures/A/A_hold_8.pgm => 1 *
10. gestures/A/A_hold_9.pgm => 1 *
11. gestures/A/A_stop_5.pgm => 0
12. gestures/A/A_stop_6.pgm => 0
13. gestures/A/A_stop_9.pgm => 0
14. gestures/A/A_up_12.pgm => 0
15. gestures/A/A_up_3.pgm => 0
16. gestures/A/A_up_4.pgm => 0
17. gestures/A/A_up_5.pgm => 0
18. gestures/A/A_up_6.pgm => 0
19. gestures/A/A_up_7.pgm => 0
20. gestures/A/A_up_8.pgm => 1
21. gestures/A/A_up_9.pgm => 0
22. gestures/B/B_down_5.pgm => 0
23. gestures/B/B_down_6.pgm => 1 *
24. gestures/B/B_down_7.pgm => 0
25. gestures/B/B_hold_3.pgm => 1
26. gestures/B/B_hold_4.pgm => 1
27. gestures/B/B_hold_5.pgm => 0
28. gestures/B/B_hold_6.pgm => 0
29. gestures/B/B_stop_3.pgm => 1
30. gestures/B/B_stop_4.pgm => 0
31. gestures/B/B_up_5.pgm => 0
32. gestures/B/B_up_6.pgm => 1
33. gestures/B/B_up_7.pgm => 0
34. gestures/C/C_down_5.pgm => 0
35. gestures/C/C_down_6.pgm => 0
36. gestures/C/C_hold_3.pgm => 1
37. gestures/C/C_stop_4.pgm => 1
38. gestures/C/C_stop_5.pgm => 0
39. gestures/C/C_stop_6.pgm => 1
40. gestures/C/C_up_5.pgm => 0
41. gestures/C/C_up_6.pgm => 0
42. gestures/D/D_down_3.pgm => 1
43. gestures/D/D_down_6.pgm => 0
44. gestures/D/D_hold_3.pgm => 1
45. gestures/D/D_hold_4.pgm => 0
46. gestures/D/D_hold_5.pgm => 1
47. gestures/D/D_hold_7.pgm => 0
48. gestures/D/D_stop_3.pgm => 0
49. gestures/D/D_stop_4.pgm => 0
50. gestures/D/D_stop_6.pgm => 1
51. gestures/D/D_up_4.pgm => 0
52. gestures/D/D_up_5.pgm => 0
53. gestures/D/D_up_6.pgm => 0
54. gestures/E/E_down_2.pgm => 1 *

55. gestures/E/E_down_6.pgm => 0
56. gestures/E/E_down_7.pgm => 0
57. gestures/E/E_hold_6.pgm => 1
58. gestures/E/E_stop_3.pgm => 0
59. gestures/E/E_stop_6.pgm => 0
60. gestures/E/E_up_3.pgm => 0
61. gestures/E/E_up_4.pgm => 0
62. gestures/E/E_up_5.pgm => 0
63. gestures/E/E_up_8.pgm => 0
64. gestures/E/E_up_9.pgm => 0
65. gestures/F/F_down_5.pgm => 1
66. gestures/F/F_down_6.pgm => 1
67. gestures/F/F_down_7.pgm => 0
68. gestures/F/F_down_8.pgm => 0
69. gestures/F/F_hold_3.pgm => 1 *
70. gestures/F/F_hold_4.pgm => 0
71. gestures/F/F_hold_7.pgm => 0
72. gestures/F/F_stop_1.pgm => 0
73. gestures/F/F_stop_6.pgm => 1
74. gestures/F/F_stop_7.pgm => 0
75. gestures/F/F_up_1.pgm => 0
76. gestures/F/F_up_2.pgm => 1
77. gestures/F/F_up_5.pgm => 0
78. gestures/G/G_down_1.pgm => 0 *
79. gestures/G/G_down_4.pgm => 0
80. gestures/G/G_down_5.pgm => 0
81. gestures/G/G_down_6.pgm => 0
82. gestures/G/G_hold_1.pgm => 0
83. gestures/G/G_hold_5.pgm => 0
84. gestures/G/G_hold_6.pgm => 0
85. gestures/G/G_stop_1.pgm => 0
86. gestures/G/G_stop_6.pgm => 0
87. gestures/G/G_stop_7.pgm => 0
88. gestures/G/G_up_1.pgm => 0
89. gestures/G/G_up_6.pgm => 0
90. gestures/G/G_up_7.pgm => 0
91. gestures/H/H_down_1.pgm => 0
92. gestures/H/H_down_5.pgm => 1
93. gestures/H/H_down_6.pgm => 0
94. gestures/H/H_down_7.pgm => 0
95. gestures/H/H_hold_1.pgm => 0
96. gestures/H/H_hold_6.pgm => 0
97. gestures/H/H_hold_7.pgm => 0
98. gestures/H/H_hold_8.pgm => 1
99. gestures/H/H_hold_9.pgm => 0
100. gestures/H/H_stop_1.pgm => 0
101. gestures/H/H_stop_7.pgm => 1
102. gestures/H/H_up_1.pgm => 1
103. gestures/H/H_up_4.pgm => 0
104. gestures/H/H_up_6.pgm => 0
105. gestures/I/I_down_1.pgm => 1 *
106. gestures/I/I_down_2.pgm => 0
107. gestures/I/I_down_6.pgm => 0
108. gestures/I/I_down_7.pgm => 0
109. gestures/I/I_hold_1.pgm => 1
110. gestures/I/I_hold_6.pgm => 1
111. gestures/I/I_hold_7.pgm => 1
112. gestures/I/I_stop_1.pgm => 0

113. gestures/I/I_stop_7.pgm => 1
114. gestures/I/I_up_1.pgm => 0
115. gestures/I/I_up_6.pgm => 1
116. gestures/I/I_up_7.pgm => 1
117. gestures/J/J_down_1.pgm => 1
118. gestures/J/J_down_2.pgm => 0
119. gestures/J/J_down_7.pgm => 1 *
120. gestures/J/J_down_8.pgm => 1
121. gestures/J/J_hold_1.pgm => 0
122. gestures/J/J_hold_6.pgm => 0
123. gestures/J/J_stop_1.pgm => 0
124. gestures/J/J_stop_2.pgm => 0
125. gestures/J/J_stop_3.pgm => 1
126. gestures/J/J_stop_6.pgm => 1 *
127. gestures/J/J_stop_9.pgm => 0
128. gestures/J/J_up_3.pgm => 0
129. gestures/J/J_up_6.pgm => 0
130. gestures/J/J_up_7.pgm => 0
131. gestures/K/K_down_1.pgm => 0
132. gestures/K/K_down_5.pgm => 1
133. gestures/K/K_down_8.pgm => 1
134. gestures/K/K_hold_4.pgm => 1
135. gestures/K/K_hold_7.pgm => 0
136. gestures/K/K_hold_8.pgm => 0
137. gestures/K/K_hold_9.pgm => 0
138. gestures/K/K_stop_3.pgm => 0
139. gestures/K/K_stop_6.pgm => 0
140. gestures/K/K_stop_7.pgm => 0
141. gestures/K/K_stop_8.pgm => 1
142. gestures/K/K_up_1.pgm => 1
143. gestures/K/K_up_2.pgm => 1 *
144. gestures/K/K_up_3.pgm => 1
145. gestures/K/K_up_6.pgm => 0
146. gestures/K/K_up_7.pgm => 0
147. gestures/L/L_down_1.pgm => 0
148. gestures/L/L_down_2.pgm => 0
149. gestures/L/L_down_3.pgm => 0
150. gestures/L/L_down_6.pgm => 0
151. gestures/L/L_down_8.pgm => 1 *
152. gestures/L/L_hold_1.pgm => 1
153. gestures/L/L_hold_2.pgm => 1
154. gestures/L/L_hold_5.pgm => 0
155. gestures/L/L_hold_6.pgm => 0
156. gestures/L/L_stop_1.pgm => 1
157. gestures/L/L_stop_2.pgm => 0
158. gestures/L/L_stop_3.pgm => 0
159. gestures/L/L_stop_4.pgm => 0
160. gestures/L/L_up_2.pgm => 0
161. gestures/L/L_up_3.pgm => 1
162. gestures/L/L_up_4.pgm => 1
163. gestures/L/L_up_6.pgm => 0
164. gestures/M/M_down_1.pgm => 0
165. gestures/M/M_down_2.pgm => 0
166. gestures/M/M_down_3.pgm => 0
167. gestures/M/M_down_4.pgm => 0
168. gestures/M/M_down_7.pgm => 0
169. gestures/M/M_down_8.pgm => 0
170. gestures/M/M_hold_1.pgm => 0

171. gestures/M/M_hold_2.pgm => 1
172. gestures/M/M_hold_5.pgm => 0
173. gestures/M/M_hold_6.pgm => 0
174. gestures/M/M_stop_1.pgm => 0
175. gestures/M/M_stop_2.pgm => 1
176. gestures/M/M_stop_3.pgm => 0
177. gestures/M/M_stop_4.pgm => 1
178. gestures/M/M_stop_5.pgm => 1 *
179. gestures/M/M_stop_8.pgm => 1
180. gestures/M/M_stop_9.pgm => 0
181. gestures/M/M_up_1.pgm => 0
182. gestures/M/M_up_2.pgm => 0
183. gestures/M/M_up_3.pgm => 0
184. gestures/M/M_up_6.pgm => 1
==========

Test mislabeled: 15/83
Test Accuracy: 81.92771084337349%
Test Error: 0.1128745277960157
Test Prediction: entries marked with * are mis-labeled
1. gestures/A/A_down_1.pgm => 1
2. gestures/A/A_down_2.pgm => 1
3. gestures/A/A_hold_1.pgm => 0
4. gestures/A/A_hold_10.pgm => 1 *
5. gestures/A/A_stop_1.pgm => 0
6. gestures/A/A_stop_4.pgm => 0
7. gestures/A/A_up_1.pgm => 0
8. gestures/A/A_up_10.pgm => 0
9. gestures/B/B_down_1.pgm => 1
10. gestures/B/B_down_2.pgm => 1
11. gestures/B/B_hold_1.pgm => 0
12. gestures/B/B_hold_2.pgm => 0
13. gestures/B/B_stop_1.pgm => 0
14. gestures/B/B_stop_2.pgm => 1 *
15. gestures/B/B_up_1.pgm => 0
16. gestures/B/B_up_4.pgm => 0
17. gestures/C/C_down_1.pgm => 0 *
18. gestures/C/C_down_2.pgm => 1
19. gestures/C/C_hold_1.pgm => 0
20. gestures/C/C_hold_2.pgm => 0
21. gestures/C/C_stop_2.pgm => 1 *
22. gestures/C/C_stop_3.pgm => 0
23. gestures/C/C_up_1.pgm => 0
24. gestures/D/D_down_1.pgm => 1
25. gestures/D/D_down_2.pgm => 1
26. gestures/D/D_hold_1.pgm => 0
27. gestures/D/D_hold_2.pgm => 0
28. gestures/D/D_hold_6.pgm => 0
29. gestures/D/D_stop_1.pgm => 0
30. gestures/D/D_stop_2.pgm => 0
31. gestures/D/D_up_1.pgm => 1 *
32. gestures/D/D_up_3.pgm => 0
33. gestures/E/E_down_1.pgm => 1
34. gestures/E/E_hold_1.pgm => 1 *
35. gestures/E/E_hold_5.pgm => 1 *
36. gestures/E/E_stop_1.pgm => 0
37. gestures/E/E_stop_2.pgm => 0
38. gestures/E/E_up_1.pgm => 0

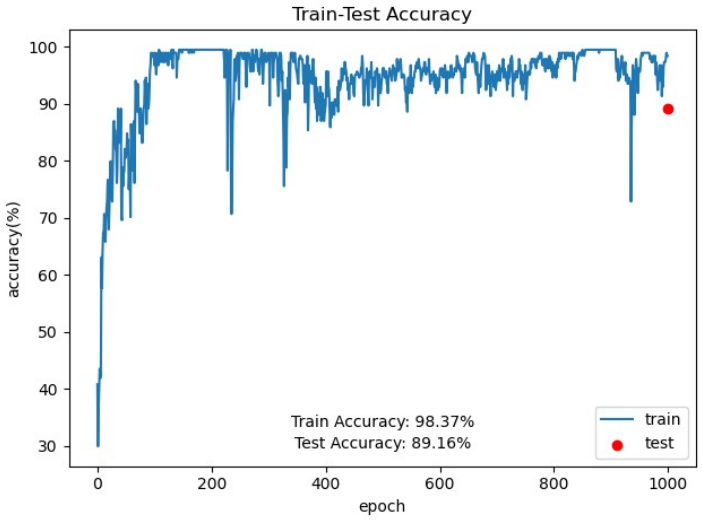
39. gestures/E/E_up_2.pgm => 1 *
40. gestures/F/F_down_1.pgm => 1
41. gestures/F/F_down_4.pgm => 1
42. gestures/F/F_hold_1.pgm => 0
43. gestures/F/F_hold_2.pgm => 1 *
44. gestures/F/F_stop_2.pgm => 1 *
45. gestures/F/F_stop_5.pgm => 1 *
46. gestures/G/G_down_2.pgm => 1
47. gestures/G/G_down_3.pgm => 1
48. gestures/G/G_hold_4.pgm => 0
49. gestures/G/G_stop_2.pgm => 0
50. gestures/G/G_stop_5.pgm => 0
51. gestures/G/G_up_2.pgm => 1 *
52. gestures/G/G_up_5.pgm => 0
53. gestures/H/H_down_2.pgm => 1
54. gestures/H/H_hold_10.pgm => 1 *
55. gestures/H/H_hold_2.pgm => 0
56. gestures/H/H_hold_5.pgm => 0
57. gestures/H/H_stop_5.pgm => 1 *
58. gestures/H/H_stop_6.pgm => 1 *
59. gestures/H/H_up_5.pgm => 0
60. gestures/I/I_hold_2.pgm => 0
61. gestures/I/I_hold_5.pgm => 0
62. gestures/I/I_down_3.pgm => 1
63. gestures/I/I_stop_5.pgm => 0
64. gestures/I/I_stop_6.pgm => 0
65. gestures/I/I_up_2.pgm => 0
66. gestures/I/I_up_3.pgm => 0
67. gestures/J/J_down_5.pgm => 1
68. gestures/J/J_down_6.pgm => 1
69. gestures/J/J_hold_2.pgm => 0
70. gestures/J/J_hold_3.pgm => 0
71. gestures/J/J_stop_7.pgm => 0
72. gestures/J/J_stop_8.pgm => 0
73. gestures/J/J_up_1.pgm => 0
74. gestures/J/J_up_2.pgm => 0
75. gestures/K/K_down_2.pgm => 1
76. gestures/K/K_down_3.pgm => 1
77. gestures/K/K_hold_1.pgm => 0
78. gestures/K/K_hold_2.pgm => 0
79. gestures/K/K_hold_3.pgm => 0
80. gestures/K/K_stop_1.pgm => 0
81. gestures/K/K_stop_2.pgm => 0
82. gestures/K/K_stop_1.pgm => 0
83. gestures/K/K_stop_2.pgm => 0
==========

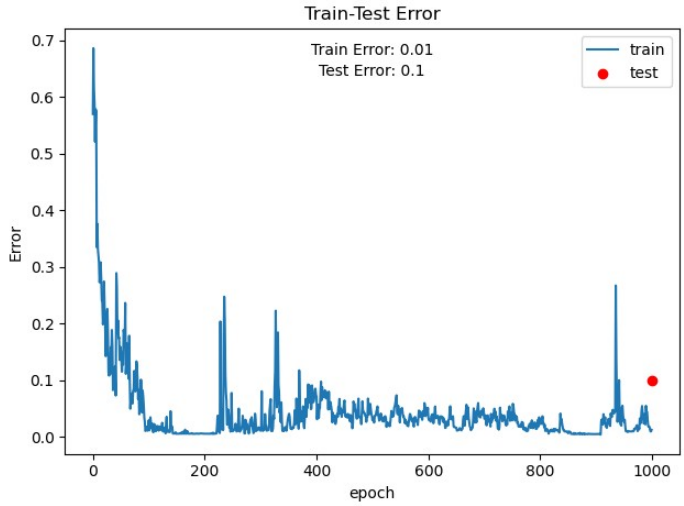
With change in weights hyper-parameter to be randomly initialized in range of -1 and 1, close to 90% test accuracy is achieved. Thus different hyper-parameters can be tuned to achieve best results.

| | |
|---|---|
| Weights initialization in range | -1 to 1 |

Training mislabeled(final epoch): 3 / 184
Training Accuracy(final epoch): 98.3695652173913 %
Training Squared Error(final epoch): 0.012565016841141396

Test mislabeled: 9 / 83
Test Accuracy: 89.1566265060241 %
Test Squared Error: 0.09873986943015811




**Data Structure:**

- Numpy array to apply mathematical operations on input, weights and output values.
- List to append the results after every epoch which was later used to plot and report the results.

**Code-Level Optimization:**

- Numpy is used instead of iterations to calculate high dimensional array which improved computation speed a lot faster.
- Input is shuffled before every epoch run to randomly select the order in which training samples will be processed using Stochastic Gradient Descent.

**Challenges:**

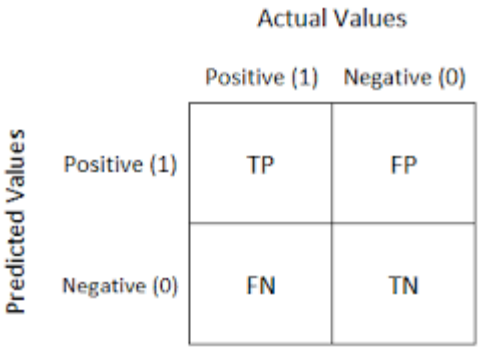
- Computing derivation of terms in back propagation was tricky especially delta value for which weights for bias terms ($W_0$) was not supposed to consider.

**Part – 2 Software Familiarization:**

We can use sklearn.neural_network to import MLPClassifier library to train and predict from our neural network. We have achieved better accuracy which is because of inherent optimization technique in sklearn libraries.

```
MLPClassifier(hidden_layer_sizes=100, learning_rate_init=0.1, max_iter=1000,
solver='sgd')
```

Accuracy upto 97% is achieved through sklearn libraries. We can also get confusion matrix and classification report.




```
[[64                0]
[ 3                16]]
```

TP = True positive
FP = False positive
FN = False negative
TN = True negative

Classification report is also available which provides great insight about precision, recall and F1-score.

| | precision | recall | f1-score | support |
|---|---|---|---|---|
| 0 | 0.96 | 1.00 | 0.98 | 64 |
| 1 | 1.00 | 0.84 | 0.91 | 19 |
| accuracy | | | 0.96 | 83 |
| macro avg | 0.98 | 0.92 | 0.95 | 83 |
| weighted avg | 0.97 | 0.96 | 0.96 | 83 |

Sklearn mislabeled: 3
Sklearn Accuracy: 96.3855421686747 %
Sklearn Prediction: entries marked with * are mis-labeled

**Part 3 – Application:**

- Banking: Credit card attrition, credit and loan application evaluation, fraud and risk evaluation, and loan delinquencies.
- Business Analytics: Customer behavior modeling, customer segmentation, fraud propensity, market research, market mix, market structure, and models for attrition, default, purchase, and renewals
- Defense: Counterterrorism, facial recognition, feature extraction, noise suppression, object discrimination, sensors, sonar, radar and image signal processing, signal/image identification, target tracking, and weapon steering
- Education: Adaptive learning software, dynamic forecasting, education system analysis and forecasting, student performance modeling, and personality profiling
- Financial: Corporate bond ratings, corporate financial analysis, credit line use analysis, currency price prediction, loan advising, mortgage screening, real estate appraisal, and portfolio trading
- Medical: Cancer cell analysis, ECG and EEG analysis, emergency room test advisement, expense reduction and quality improvement for hospital systems, transplant process optimization, and prosthesis design
- Securities: Automatic bond rating, market analysis, and stock trading advisory systems
- Transportation: Routing systems, truck brake diagnosis systems, and vehicle scheduling