Homework 2: Perceptron Learning

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The following is an analysis of the results of using a perceptron classifier written in google Dart on the optdigits dataset located at http://ftp.ics.uci.edu/pub/machine-learning-databases/optdigits/.

1 Setup

The source code for this program was written in Dart, and can be found on my github account at https://github.com/arik181/perceptron_classifier. In order to run this experiment, you will have to have the latest version of Google Dart installed (Release M4 or above). The simplest way to run the experiment is as follows:

- 1. Download and install the Dart Editor at http://www.dartlang.org/tools for Windows or Linux.
- 2. Retrieve the source code from https://github.com/arik181/perceptron_classifier
- 3. In the Dart Editor, go to file \rightarrow open existing folder (or type Ctrl-O)
- 4. Navigate to the source directory
- 5. Click the Run button (or type Ctrl-R)

The output from the classifier will appear in the console window.

2 Overview

Experiment 1

Training Statistics		Test Statistics	
Learning rate	0.2	Learning rate	0.2
Training runs	20	Training runs	20
Total successes	8520	Total successes	16387
Total failures	480	Total failures	1019
Precision	98%	Precision	97%
Recall	92%	Recall	92%
Accuracy	94%	Accuracy	94%

		\mathbf{T}	raini	ng	Conf	fusio	on M	Iatri	x	
	0	1	2	3	4	5	6	7	8	9
0	X	8	4	0	2	0	6	0	0	0
1	0	X	6	0	0	0	4	0	0	0
2	0	16	X	0	0	0	0	4	0	6
3	0	122	28	X	2	4	2	34	12	28
4	0	66	0	0	X	0	6	16	2	4
5	4	82	20	6	0	X	4	12	4	24
6	0	2	0	0	0	0	X	0	0	0
7	0	4	0	0	0	0	0	X	0	0
8	0	152	18	0	10	2	30	32	X	16
9	0	110	4	0	8	2	0	30	2	X

			Test	t Co	onfus	sion	Mat	trix		
	0	1	2	3	4	5	6	7	8	9
0	X	14	4	0	5	0	12	1	1	2
1	0	X	6	0	0	0	7	2	0	0
2	0	27	X	0	0	0	1	8	1	7
3	0	182	36	X	2	4	2	55	16	39
4	0	108	6	2	X	6	10	38	12	12
5	4	129	26	8	1	X	9	26	7	34
6	0	4	1	0	0	0	X	0	0	0
7	0	4	0	0	0	0	0	X	0	0
8	0	226	27	1	12	4	37	58	X	19
9	0	155	6	1	11	3	0	53	5	X

Experiment 2

Training Statistics		Test Statistics	
Learning rate	0.8	Learning rate	0.8
Training runs	20	Training runs	20
Total successes	8520	Total successes	16387
Total failures	480	Total failures	1019
Precision	98%	Precision	97%
Recall	92%	Recall	92%
Accuracy	94%	Accuracy	94%

		Training Confusion Matrix													
	0	1	2	3	4	5	6	7	8	9					
0	X	8	4	0	2	0	6	0	0	0					
1	0	X	6	0	0	0	4	0	0	0					
2	0	16	X	0	0	0	0	4	0	6					
3	0	122	28	X	2	4	2	34	12	28					
4	0	66	0	0	X	0	6	16	2	4					
5	4	82	20	6	0	X	4	12	4	24					
6	0	2	0	0	0	0	X	0	0	0					
7	0	4	0	0	0	0	0	X	0	0					
8	0	152	18	0	10	2	30	32	X	16					
9	0	110	4	0	8	2	0	30	2	X					

			Test	t Co	onfus	sion	Mat	trix		
	0	1	2	3	4	5	6	7	8	9
0	X	14	4	0	5	0	12	1	1	2
1	0	X	6	0	0	0	7	2	0	0
2	0	27	X	0	0	0	1	8	1	7
3	0	182	36	X	2	4	2	55	16	39
4	0	108	6	2	X	6	10	38	12	12
5	4	129	26	8	1	X	9	26	7	34
6	0	4	1	0	0	0	X	0	0	0
7	0	4	0	0	0	0	0	X	0	0
8	0	226	27	1	12	4	37	58	X	19
9	0	155	6	1	11	3	0	53	5	X

Experiment 3

Training Statistics		Test Statistics	
Learning rate	0.05	Learning rate	0.05
Training runs	20	Training runs	20
Total successes	8519	Total successes	16385
Total failures	481	Total failures	1021
Precision	98%	Precision	97%
Recall	92%	Recall	92%
Accuracy	94%	Accuracy	94%

		\mathbf{T}	raini	ing	Con	fusio	on N	Iatri	x					Tes	t Co	onfus	sion	Ma	trix		
	0	1	2	3	4	5	6	7	8	9		0	1	2	3	4	5	6	7	8	9
0	X	8	4	0	2	0	6	0	0	0	0	X	14	4	0	5	0	12	1	1	2
1	0	X	6	0	0	0	4	0	0	0	1	0	X	6	0	0	0	7	2	0	0
2	0	16	X	0	0	0	0	4	0	6	2	0	27	X	0	0	0	1	8	1	7
3	0	122	28	X	2	4	2	34	12	28	3	0	182	36	X	2	4	2	55	16	39
4	0	66	0	0	X	0	6	16	2	4	4	0	108	6	2	X	6	10	38	12	12
5	4	82	20	6	0	X	4	12	4	24	5	4	129	26	8	1	X	9	26	7	34
6	0	2	0	0	0	0	X	0	0	0	6	0	4	1	0	0	0	X	0	0	0
7	0	4	0	0	0	0	0	X	0	0	7	0	4	0	0	0	0	0	X	0	0
8	0	152	18	0	10	2	30	32	X	16	8	0	227	27	1	12	4	37	58	X	19
9	0	112	4	0	8	2	0	30	2	X	9	0	157	6	1	11	3	0	53	5	X

3 Summary

The three experiments produced very similar results. The first experiment produced identical results from the second experiment. I believe that this is due to the fact that I used the same number of training epochs across all perceptrons for all three experiments. It is possible that if I had allowed the experiments to run for much longer periods of time, there would be more of a divergence. There is some variation in the confusion matrix for the third experiment, with a slightly higher number of false classifications. There is also variation between the test runs and the training runs in each experiment, with the test runs containing a slightly higher failure rate overall, as expected.

The number 1 was the most commonly misclassified digit by a considerable margin, having the highest number of false negatives, but very few false positives, it seems to have been mistaken for other numbers quite regularly, and these errors accounted for 1075 of the 1377 false negatives over the test data in experiment two, or approximately 78%. The other experiments resulted in very similar classification errors on this digit.

4 Classifier Output - Experiment 1

start
reading files
creating perceptron classifiers
training classifiers
reporting training data

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 8520

 Total failures
 : 480

 Precision
 : 0.98%

 Recall
 : 0.92%

 Accuracy
 : 0.94%

	0	1	2	3	4	5	6	7	8	9
0	Х	8	4	0	2	0	6	0	0	0
1	0	X	6	0	0	0	4	0	0	0
2	0	16	X	0	0	0	0	4	0	6
3	0 1	22	28	Х	2	4	2	34	12	28
4 I	0	66	0	0	Х	0	6	16	2	4

```
4 82 20
              0 X 4 12
            6
                         4 24
6 I
      2
                    Х
                       0
         0
            0
              0
                 0
                           0
7 I
         0
            0
              0
                 0
                    0
                       Х
      4
                         0
                           0
    0 152 18
             10
                   30
                      32
                         X 16
9 I
    0 110
         4
            0
              8
                 2
                    0
                      30
                            Х
_____
running classifiers
_____
(0, 1)
          : 180
Successes
Failures
         : 6
False Positives : 6
False Negatives : 0
-----
           : 0.2
Learning rate
Training runs
              : 20
Total successes
              : 180
Total failures
              : 6
Precision
              : 0.94%
Recall
              : 1.0%
              : 0.97%
Accuracy
_____
_____
(0, 2)
Successes
         : 189
         : 0
Failures
False Positives : 0
False Negatives : 0
_____
Learning rate
              : 0.2
```

Learning rate : 0.2
Training runs : 20
Total successes : 189
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0, 3)

Failures : 0 False Positives : 0 False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 200
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0, 4)

Successes : 176
Failures : 3
False Positives : 3
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 176
Total failures : 3
Precision : 0.97%
Recall : 1.0%
Accuracy : 0.98%

(0, 5)

Successes : 183
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 183
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0, 6)

Failures : 6 False Positives : 6 False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 180
Total failures : 6
Precision : 0.94%
Recall : 1.0%
Accuracy : 0.97%

(0,7)

Successes : 188
Failures : 1
False Positives : 1
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 188
Total failures : 1
Precision : 0.99%
Recall : 1.0%
Accuracy : 0.99%

(0, 8)

Successes : 182
Failures : 1
False Positives : 1
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 182
Total failures : 1
Precision : 0.99%
Recall : 1.0%
Accuracy : 0.99%

(0, 9)

Failures : 2 False Positives : 2 False Negatives : 0

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 197

 Total failures
 : 2

 Precision
 : 0.98%

 Recall
 : 1.0%

 Accuracy
 : 0.99%

(1, 2)

Successes : 174
Failures : 11
False Positives : 0
False Negatives : 11

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 174

 Total failures
 : 11

 Precision
 : 1.0%

 Recall
 : 0.89%

 Accuracy
 : 0.94%

(1, 3)

Successes : 136
Failures : 60
False Positives : 0
False Negatives : 60

Learning rate : 0.2

Training runs : 20

Total successes : 136

Total failures : 60

Precision : 1.0%

Recall : 0.60%

Accuracy : 0.56%

(1, 4)

Failures : 42 False Positives : 0 False Negatives : 42

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 133

 Total failures
 : 42

 Precision
 : 1.0%

 Recall
 : 0.68%

 Accuracy
 : 0.68%

(1, 5)

Successes : 132
Failures : 47
False Positives : 0
False Negatives : 47

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 132

 Total failures
 : 47

 Precision
 : 1.0%

 Recall
 : 0.66%

 Accuracy
 : 0.64%

(1, 6)

Successes : 177
Failures : 5
False Positives : 3
False Negatives : 2

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 177

 Total failures
 : 5

 Precision
 : 0.97%

 Recall
 : 0.98%

 Accuracy
 : 0.97%

(1,7)

Failures : 2 False Positives : 2 False Negatives : 0

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 183

 Total failures
 : 2

 Precision
 : 0.98%

 Recall
 : 1.0%

 Accuracy
 : 0.99%

(1, 8)

Successes : 105 Failures : 74 False Positives : 0 False Negatives : 74

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 105

 Total failures
 : 74

 Precision
 : 1.0%

 Recall
 : 0.55%

 Accuracy
 : 0.30%

(1, 9)

Successes : 150
Failures : 45
False Positives : 0
False Negatives : 45

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 150

 Total failures
 : 45

 Precision
 : 1.0%

 Recall
 : 0.67%

 Accuracy
 : 0.70%

(2, 3)

Failures : 8 False Positives : 0 False Negatives : 8

Learning rate : 0.2
Training runs : 20
Total successes : 191
Total failures : 8
Precision : 1.0%
Recall : 0.92%
Accuracy : 0.96%

(2, 4)

Successes : 172
Failures : 6
False Positives : 0
False Negatives : 6

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 172

 Total failures
 : 6

 Precision
 : 1.0%

 Recall
 : 0.94%

 Accuracy
 : 0.97%

(2, 5)

Successes : 176
Failures : 6
False Positives : 0
False Negatives : 6

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 176

 Total failures
 : 6

 Precision
 : 1.0%

 Recall
 : 0.94%

 Accuracy
 : 0.97%

(2, 6)

Failures : 2 False Positives : 1 False Negatives : 1

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 183

 Total failures
 : 2

 Precision
 : 0.99%

 Recall
 : 0.99%

 Accuracy
 : 0.99%

(2, 7)

Successes : 184
Failures : 4
False Positives : 4
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 184
Total failures : 4
Precision : 0.96%
Recall : 1.0%
Accuracy : 0.98%

(2,8)

Successes : 172
Failures : 10
False Positives : 1
False Negatives : 9

Learning rate : 0.2
Training runs : 20
Total successes : 172
Total failures : 10
Precision : 0.99%
Recall : 0.91%
Accuracy : 0.94%

(2, 9)

Failures : 3 False Positives : 1 False Negatives : 2

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 195

 Total failures
 : 3

 Precision
 : 0.99%

 Recall
 : 0.98%

 Accuracy
 : 0.98%

(3, 4)

Successes : 187
Failures : 2
False Positives : 0
False Negatives : 2

Learning rate : 0.2
Training runs : 20
Total successes : 187
Total failures : 2
Precision : 1.0%
Recall : 0.98%
Accuracy : 0.99%

(3, 5)

Successes : 191
Failures : 2
False Positives : 0
False Negatives : 2

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 191

 Total failures
 : 2

 Precision
 : 1.0%

 Recall
 : 0.98%

 Accuracy
 : 0.99%

(3, 6)

Failures : 0 False Positives : 0 False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 196
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(3, 7)

Successes : 178
Failures : 21
False Positives : 21
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 178
Total failures : 21
Precision : 0.80%
Recall : 1.0%
Accuracy : 0.88%

(3, 8)

Successes : 188
Failures : 5
False Positives : 4
False Negatives : 1

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 188

 Total failures
 : 5

 Precision
 : 0.96%

 Recall
 : 0.99%

 Accuracy
 : 0.97%

(3, 9)

Failures : 12 False Positives : 11 False Negatives : 1

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 197

 Total failures
 : 12

 Precision
 : 0.90%

 Recall
 : 0.99%

 Accuracy
 : 0.94%

(4, 5)

Successes : 165
Failures : 7
False Positives : 6
False Negatives : 1

Learning rate : 0.2
Training runs : 20
Total successes : 165
Total failures : 7
Precision : 0.93%
Recall : 0.99%
Accuracy : 0.96%

(4, 6)

Successes : 171
Failures : 4
False Positives : 4
False Negatives : 0

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 171

 Total failures
 : 4

 Precision
 : 0.95%

 Recall
 : 1.0%

 Accuracy
 : 0.98%

(4,7)

Failures : 22 False Positives : 22 False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 156
Total failures : 22
Precision : 0.74%
Recall : 1.0%
Accuracy : 0.86%

(4, 8)

Successes : 160
Failures : 12
False Positives : 10
False Negatives : 2

Learning rate : 0.2
Training runs : 20
Total successes : 160
Total failures : 12
Precision : 0.88%
Recall : 0.97%
Accuracy : 0.93%

(4, 9)

Successes : 177
Failures : 11
False Positives : 8
False Negatives : 3

Learning rate : 0.2
Training runs : 20
Total successes : 177
Total failures : 11
Precision : 0.90%
Recall : 0.96%
Accuracy : 0.94%

(5, 6)

Failures : 5 False Positives : 5 False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 174
Total failures : 5
Precision : 0.94%
Recall : 1.0%
Accuracy : 0.97%

(5,7)

Successes : 168
Failures : 14
False Positives : 14
False Negatives : 0

Learning rate : 0.2
Training runs : 20
Total successes : 168
Total failures : 14
Precision : 0.84%
Recall : 1.0%
Accuracy : 0.92%

(5, 8)

Successes : 171
Failures : 5
False Positives : 3
False Negatives : 2

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 171

 Total failures
 : 5

 Precision
 : 0.97%

 Recall
 : 0.98%

 Accuracy
 : 0.97%

(5, 9)

Failures : 11 False Positives : 10 False Negatives : 1

Learning rate : 0.2
Training runs : 20
Total successes : 181
Total failures : 11
Precision : 0.89%
Recall : 0.99%
Accuracy : 0.94%

(6,7)

Successes : 185
Failures : 0
False Positives : 0
False Negatives : 0

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 185

 Total failures
 : 0

 Precision
 : 1.0%

 Recall
 : 1.0%

 Accuracy
 : 1.0%

(6, 8)

Successes : 172
Failures : 7
False Positives : 0
False Negatives : 7

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 172

 Total failures
 : 7

 Precision
 : 1.0%

 Recall
 : 0.93%

 Accuracy
 : 0.96%

(6, 9)

Failures : 0 False Positives : 0 False Negatives : 0

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 195

 Total failures
 : 0

 Precision
 : 1.0%

 Recall
 : 1.0%

 Accuracy
 : 1.0%

(7, 8)

Successes : 156
Failures : 26
False Positives : 0
False Negatives : 26

Learning rate : 0.2
Training runs : 20
Total successes : 156
Total failures : 26
Precision : 1.0%
Recall : 0.78%
Accuracy : 0.83%

(7, 9)

Successes : 175
Failures : 23
False Positives : 0
False Negatives : 23

Learning rate : 0.2
Training runs : 20
Total successes : 175
Total failures : 23
Precision : 1.0%
Recall : 0.80%
Accuracy : 0.87%

(8, 9)

Failures : 6 False Positives : 3 False Negatives : 3

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 186

 Total failures
 : 6

 Precision
 : 0.97%

 Recall
 : 0.97%

 Accuracy
 : 0.97%

reporting test data

 Learning rate
 : 0.2

 Training runs
 : 20

 Total successes
 : 16387

 Total failures
 : 1019

 Precision
 : 0.97%

 Recall
 : 0.92%

 Accuracy
 : 0.94%

4.1 Classifier Output - Experiment 2

start
reading files
creating perceptron classifiers
training classifiers
reporting training data

 Learning rate
 : 0.8

 Training runs
 : 20

 Total successes
 : 8520

 Total failures
 : 480

 Precision
 : 0.98%

 Recall
 : 0.92%

 Accuracy
 : 0.94%

		٠	•								
		0	1	2	3	4	5	6	7	8	9
0		X	8	4	0	2	0	6	0	0	0
1	1	0	Х	6	0	0	0	4	0	0	0
2	I	0	16	X	0	0	0	0	4	0	6
3	1	0	122	28	Х	2	4	2	34	12	28
4	1	0	66	0	0	X	0	6	16	2	4
5	1	4	82	20	6	0	X	4	12	4	24
6	1	0	2	0	0	0	0	Х	0	0	0
7	1	0	4	0	0	0	0	0	Х	0	0
8	1	0	152	18	0	10	2	30	32	Х	16
9	1	0	110	4	0	8	2	0	30	2	Х

running classifiers

(0, 1)

Successes : 180
Failures : 6
False Positives : 6
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 180
Total failures : 6
Precision : 0.94%
Recall : 1.0%
Accuracy : 0.97%

(0, 2)

Successes : 189
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 189
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0, 3)

Successes : 200
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 200
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0,4)

Successes : 176
Failures : 3
False Positives : 3
False Negatives : 0

Learning rate : 0.8 Training runs : 20 Total successes : 176 Total failures : 3 : 0.97% Precision Recall : 1.0% : 0.98% Accuracy

(0,5)

Successes : 183 Failures : 0 False Positives: 0 False Negatives : 0

Learning rate : 0.8 : 20 Training runs : 183 . 1 : 0 Total successes Total failures Precision : 1.0% : 1.0% Recall : 1.0% Accuracy

(0, 6)

Successes : 180 Failures : 6 False Positives : 6 False Negatives : 0

: 0.8 Learning rate : 20 Training runs Total successes : 180 Total failures : 6 : 0.94% Precision : 1.0% Recall Accuracy : 0.97%

(0,7)

Successes : 188 Failures : 1 False Positives: 1 False Negatives : 0

Learning rate : 0.8 Training runs : 20 Total successes : 188 Total failures : 1 : 0.99% Precision Recall : 1.0% : 0.99% Accuracy

(0,8)

Successes : 182 Failures : 1 False Positives : 1 False Negatives : 0

Learning rate : 0.8 : 20 Training runs : 182 Total successes . 1 : 1 Total failures Precision : 0.99% : 1.0% Recall : 0.99% Accuracy

(0, 9)

Successes : 197 Failures : 2 False Positives : 2 False Negatives : 0

: 0.8 Learning rate : 20 Training runs Total successes : 197
Total failures : 2 : 0.98% Precision : 1.0% Recall Accuracy : 0.99%

(1,2)

Successes : 174 Failures : 11 False Positives : 0 False Negatives : 11

Learning rate : 0.8 Training runs : 20 Total successes : 174 : 11 Total failures : 1.0% Precision Recall : 0.89% : 0.94% Accuracy

(1, 3)

Successes : 136 Failures : 60 False Positives : 0 False Negatives: 60

Learning rate : 0.8 : 20 Training runs : 136 Total successes : 60 Total failures : 1.0% Precision : 0.60% Recall : 0.56% Accuracy

(1, 4)

Successes : 133 Failures : 42 False Positives : 0 False Negatives : 42

: 0.8 Learning rate : 20 Training runs Total successes : 133 Total failures : 42 Total failures : 42 : 1.0% Precision : 0.68% Recall Accuracy : 0.68%

(1,5)

Successes : 132 Failures : 47 False Positives: 0 False Negatives: 47

Learning rate : 0.8 Training runs : 20 Total successes : 132 : 47 Total failures : 1.0% Precision Recall : 0.66% : 0.64% Accuracy

(1, 6)

Successes : 177 Failures : 5 False Positives : 3 False Negatives : 2

Learning rate : 0.8 : 20 Training runs : 177 Total successes : 5 Total failures Precision : 0.97% : 0.98% Recall : 0.97% Accuracy

(1, 7)

Successes : 183 Failures : 2 False Positives : 2 False Negatives : 0

: 0.8 Learning rate : 20 Training runs Total successes : 183
Total failures : 2 Total failures : 2 : 0.98% Precision : 1.0% Recall Accuracy : 0.99%

(1,8)

Successes : 105 Failures : 74 False Positives: 0 False Negatives: 74

Learning rate : 0.8
Training runs : 20
Total successes : 105
Total failures : 74
Precision : 1.0%
Recall : 0.55%
Accuracy : 0.30%

(1,9)

Successes : 150
Failures : 45
False Positives : 0
False Negatives : 45

 Learning rate
 : 0.8

 Training runs
 : 20

 Total successes
 : 150

 Total failures
 : 45

 Precision
 : 1.0%

 Recall
 : 0.67%

 Accuracy
 : 0.70%

(2, 3)

Successes : 191
Failures : 8
False Positives : 0
False Negatives : 8

Learning rate : 0.8
Training runs : 20
Total successes : 191
Total failures : 8
Precision : 1.0%
Recall : 0.92%
Accuracy : 0.96%

(2, 4)

Successes : 172
Failures : 6
False Positives : 0
False Negatives : 6

Learning rate : 0.8 Training runs : 20 Total successes : 172 Total failures : 6 : 1.0% Precision Recall : 0.94% : 0.97% Accuracy

(2, 5)

Successes : 176 Failures : 6 False Positives: 0 False Negatives : 6

Learning rate : 0.8 : 20 Training runs : 176 Total successes : 6 Total failures Precision : 1.0% : 0.94% Recall : 0.97% Accuracy

(2, 6)

Successes : 183 Failures : 2 False Positives : 1 False Negatives : 1

: 0.8 Learning rate : 20 Training runs Total successes : 183
Total failures : 2 : 0.99% Precision : 0.99% Recall Accuracy : 0.99%

(2, 7)

Successes : 184 Failures : 4 False Positives: 4 False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 184
Total failures : 4
Precision : 0.96%
Recall : 1.0%
Accuracy : 0.98%

(2, 8)

Successes : 172
Failures : 10
False Positives : 1
False Negatives : 9

 Learning rate
 : 0.8

 Training runs
 : 20

 Total successes
 : 172

 Total failures
 : 0.99%

 Recall
 : 0.91%

 Accuracy
 : 0.94%

(2, 9)

Successes : 195
Failures : 3
False Positives : 1
False Negatives : 2

 Learning rate
 : 0.8

 Training runs
 : 20

 Total successes
 : 195

 Total failures
 : 3

 Precision
 : 0.99%

 Recall
 : 0.98%

 Accuracy
 : 0.98%

(3, 4)

Successes : 187
Failures : 2
False Positives : 0
False Negatives : 2

Learning rate : 0.8
Training runs : 20
Total successes : 187
Total failures : 2
Precision : 1.0%
Recall : 0.98%
Accuracy : 0.99%

(3, 5)

Successes : 191
Failures : 2
False Positives : 0
False Negatives : 2

Learning rate : 0.8
Training runs : 20
Total successes : 191
Total failures : 2
Precision : 1.0%
Recall : 0.98%
Accuracy : 0.99%

(3, 6)

Successes : 196
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 196
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(3, 7)

Successes : 178
Failures : 21
False Positives : 21
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 178
Total failures : 21
Precision : 0.80%
Recall : 1.0%
Accuracy : 0.88%

(3, 8)

Successes : 188
Failures : 5
False Positives : 4
False Negatives : 1

Learning rate : 0.8
Training runs : 20
Total successes : 188
Total failures : 5
Precision : 0.96%
Recall : 0.99%
Accuracy : 0.97%

(3, 9)

Successes : 197
Failures : 12
False Positives : 11
False Negatives : 1

Learning rate : 0.8
Training runs : 20
Total successes : 197
Total failures : 12
Precision : 0.90%
Recall : 0.99%
Accuracy : 0.94%

(4,5)

Successes : 165
Failures : 7
False Positives : 6
False Negatives : 1

Learning rate : 0.8
Training runs : 20
Total successes : 165
Total failures : 7
Precision : 0.93%

 Precision
 : 0.93%

 Recall
 : 0.99%

 Accuracy
 : 0.96%

(4, 6)

Successes : 171
Failures : 4
False Positives : 4
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 171
Total failures : 4
Precision : 0.95%
Recall : 1.0%
Accuracy : 0.98%

(4,7)

Successes : 156
Failures : 22
False Positives : 22
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 156
Total failures : 22
Precision : 0.74%
Recall : 1.0%
Accuracy : 0.86%

(4,8)

Successes : 160 Failures : 12 False Positives : 10 False Negatives : 2

Learning rate : 0.8 Training runs : 20 Total successes : 160 : 12 Total failures : 0.88% Precision Recall : 0.97% : 0.93% Accuracy

(4, 9)

Successes : 177 Failures : 11 False Positives: 8 False Negatives : 3

Learning rate : 0.8 : 20 Training runs : 177 Total successes . 17 : 11 · Total failures Precision : 0.90% : 0.96% Recall : 0.94% Accuracy

(5, 6)

Successes : 174 Failures : 5 False Positives : 5 False Negatives : 0

: 0.8 Learning rate : 20 Training runs Total successes : 174
Total failures : 5 : 5 : 0.94% Precision : 1.0% Recall Accuracy : 0.97%

(5,7)

Successes : 168 Failures : 14 False Positives: 14 False Negatives : 0

Learning rate : 0.8 Training runs : 20 Total successes : 168 : 14 Total failures : 0.84% Precision Recall : 1.0% : 0.92% Accuracy

(5,8)

Successes : 171 Failures : 5 False Positives: 3 False Negatives : 2

Learning rate : 0.8 : 20 Training runs : 171 Total successes . 1 : 5 Total failures Precision : 0.97% : 0.98% Recall : 0.97% Accuracy

(5, 9)

Successes : 181 Failures : 11 False Positives: 10 False Negatives : 1

: 0.8 Learning rate : 20 Training runs Total successes : 181
Total failures : 11 : 0.89% Precision : 0.99% Recall Accuracy : 0.94%

(6,7)

Successes : 185 Failures : 0 False Positives: 0 False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 185
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(6,8)

Successes : 172
Failures : 7
False Positives : 0
False Negatives : 7

 Learning rate
 : 0.8

 Training runs
 : 20

 Total successes
 : 172

 Total failures
 : 7

 Precision
 : 1.0%

 Recall
 : 0.93%

 Accuracy
 : 0.96%

(6, 9)

Successes : 195
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.8
Training runs : 20
Total successes : 195
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(7, 8)

Successes : 156
Failures : 26
False Positives : 0
False Negatives : 26

Learning rate : 0.8 Training runs : 20 Total successes : 156 : 26 Total failures : 1.0% Precision Recall : 0.78% : 0.83% Accuracy

-----_____

(7, 9)

Successes : 175 Failures : 23 False Positives : 0 False Negatives: 23

Learning rate : 0.8 : 20 Training runs : 175 Total successes : 23 Total failures Precision : 1.0% : 0.80% Recall : 0.87% Accuracy

-----_____

(8, 9)

Successes : 186 Failures : 6 False Positives : 3 False Negatives : 3

: 0.8 Learning rate : 20 Training runs Total successes : 186
Total failures : 6 : 0.97% Precision : 0.97% : 0.97% Recall

Accuracy _____

reporting test data

Learning rate : 0.8
Training runs : 20
Total successes : 16387
Total failures : 1019

Precision : 0.97% Recall : 0.92% Accuracy : 0.94%

4.2 Classifier Output - Experiment 3

start reading files creating perceptron classifiers training classifiers reporting training data

_____ Learning rate : 0.05

Training runs : 20 Total successes : 8519 Total failures : 481 Precision : 0.98% Recall : 0.92% Accuracy : 0.94%

0 1 2 3 4 5 6 7 8 9

running classifiers

(0,1)

Successes : 180
Failures : 6
False Positives : 6
False Negatives : 0

 Learning rate
 : 0.05

 Training runs
 : 20

 Total successes
 : 180

 Total failures
 : 6

 Precision
 : 0.94%

 Recall
 : 1.0%

 Accuracy
 : 0.97%

(0, 2)

Successes : 189
Failures : 0
False Positives : 0
False Negatives : 0

Training runs : 20 : 189 : 0 : 1.0% Total successes Total failures Precision : 1.0% Recall : 1.0% Accuracy

-----_____

(0, 3)

Successes : 200 Failures : 0 False Positives : 0 False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 200
Total failures : 0 : 1.0% Precision Recall : 1.0% : 1.0% Accuracy

(0, 4)

Successes : 176 Failures : 3 False Positives : 3 False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 176
Total failures : 3 Total failures : 3 : 0.97% Precision Recall : 1.0% Accuracy : 0.98%

(0, 5)

Successes : 183 Failures : 0 False Positives : 0 False Negatives : 0

Training runs : 20
Total successes : 183
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(0, 6)

Successes : 180
Failures : 6
False Positives : 6
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 180
Total failures : 6

Total failures : 6
Precision : 0.94%
Recall : 1.0%
Accuracy : 0.97%

Accuracy : 0.97%

(0,7)

Successes : 188
Failures : 1
False Positives : 1
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 188
Total failures : 1
Precision : 0.99%
Recall : 1.0%
Accuracy : 0.99%

(0, 8)

Successes : 182
Failures : 1
False Positives : 1
False Negatives : 0

Training runs : 20
Total successes : 182
Total failures : 1
Precision : 0.99%
Recall : 1.0%
Accuracy : 0.99%

(0, 9)

Successes : 197
Failures : 2
False Positives : 2
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 197
Total failures : 2
Precision : 0.98%
Recall : 1.0%
Accuracy : 0.99%

(1, 2)

Successes : 174
Failures : 11
False Positives : 0
False Negatives : 11

Learning rate : 0.05
Training runs : 20
Total successes : 174
Total failures : 11
Precision : 1.0%
Recall : 0.89%
Accuracy : 0.94%

(1, 3)

Successes : 136
Failures : 60
False Positives : 0
False Negatives : 60

. 20 : 136 : 60 Training runs : 20Total successes Total failures Precision : 1.0% : 0.60% Recall : 0.56% Accuracy

-----_____

(1, 4)

Successes : 133 Failures : 42 False Positives : 0 False Negatives : 42

Learning rate : 0.05
Training runs : 20
Total successes : 133
Total failures : 42 Precision : 1.0% : 0.68% : 0.68% Recall Accuracy

(1, 5)

Successes : 132 Failures : 47 False Positives : 0 False Negatives : 47

_____ Learning rate : 0.05 Training runs : 20 : 132 : 47 Total successes Total failures

: 1.0% Precision Recall : 0.66% Accuracy : 0.64%

(1, 6)

Successes : 177 Failures : 5 False Positives : 3 False Negatives : 2

-----Learning rate : 0.05

Training runs : 20
Total successes : 177
Total failures : 5
Precision : 0.97%
Recall : 0.98%
Accuracy : 0.97%

(1, 7)

Successes : 183
Failures : 2
False Positives : 2
False Negatives : 0

 Learning rate
 : 0.05

 Training runs
 : 20

 Total successes
 : 183

 Total failures
 : 2

 Precision
 : 0.98%

 Recall
 : 1.0%

 Accuracy
 : 0.99%

Accuracy : 0.99%

(1, 8)

Successes : 104
Failures : 75
False Positives : 0
False Negatives : 75

Learning rate : 0.05
Training runs : 20
Total successes : 104
Total failures : 75
Precision : 1.0%
Recall : 0.55%
Accuracy : 0.28%

(1, 9)

Successes : 150
Failures : 45
False Positives : 0
False Negatives : 45

Training runs : 20
Total successes : 150
Total failures : 45
Precision : 1.0%
Recall : 0.67%
Accuracy : 0.70%

(2,3)

Successes : 191
Failures : 8
False Positives : 0
False Negatives : 8

Learning rate : 0.05
Training runs : 20
Total successes : 191
Total failures : 8
Precision : 1.0%
Recall : 0.92%
Accuracy : 0.96%

(2, 4)

Successes : 172
Failures : 6
False Positives : 0
False Negatives : 6

Learning rate : 0.05
Training runs : 20
Total successes : 172
Total failures : 6
Precision : 1.0%
Recall : 0.94%
Accuracy : 0.97%

(2, 5)

Successes : 176
Failures : 6
False Positives : 0
False Negatives : 6

Training runs : 20
Total successes : 176
Total failures : 6
Precision : 1.0%
Recall : 0.94%
Accuracy : 0.97%

-----_____

(2, 6)

Successes : 183 Failures : 2 False Positives : 1 False Negatives : 1

Learning rate : 0.05
Training runs : 20
Total successes : 183
Total failures : 2 Precision : 0.99% : 0.99% : 0.99% Recall

(2, 7)

Accuracy

Successes : 184 Failures : 4 False Positives : 4 False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 184
Total failures : 4 Total failures : 4 : 0.96% Precision Recall : 1.0% Accuracy : 0.98%

(2, 8)

Successes : 172 Failures : 10 False Positives : 1 False Negatives : 9

Training runs : 20 : 172 Total successes : 10 Total failures Precision : 0.99% : 0.91% : 0.94% Recall Accuracy

-----_____

(2, 9)

Successes : 195 Failures : 3 False Positives : 1 False Negatives : 2

Learning rate : 0.05
Training runs : 20
Total successes : 195
Total failures : 3

Precision : 0.99% : 0.98% : 0.98% Recall Accuracy

(3, 4)

Successes : 187 Failures : 2 False Positives : 0 False Negatives : 2

_____ Learning rate : 0.05 Training runs : 20 : 187 : 2 Total successes Total failures : 1.0% Precision : 0.98% Recall Accuracy

: 0.99%

(3, 5)

Successes : 191 Failures : 2 False Positives : 0 False Negatives : 2

Training runs : 20
Total successes : 191
Total failures : 2
Precision : 1.0%
Recall : 0.98%
Accuracy : 0.99%

(3, 6)

Successes : 196
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 196
Total failures : 0
Precision : 1.0%
Recall : 1.0%
Accuracy : 1.0%

(3,7)

Successes : 178
Failures : 21
False Positives : 21
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 178
Total failures : 21
Precision : 0.80%
Recall : 1.0%
Accuracy : 0.88%

(3, 8)

Successes : 188
Failures : 5
False Positives : 4
False Negatives : 1

Training runs : 20 Total successes : 188 ses : 188 es : 5 : 0.96% : 0.99% : 0.97% Total failures Precision Recall Accuracy

-----_____

(3, 9)

Successes : 197 Failures : 12 False Positives : 11 False Negatives : 1

Learning rate : 0.05
Training runs : 20
Total successes : 197
Total failures : 12 Precision : 0.90% : 0.99% Recall : 0.94% Accuracy

(4, 5)

Successes : 165 Failures : 7 False Positives : 6 False Negatives : 1

Learning rate : 0.05
Training runs : 20
Total successes : 165
Total failures : 7 : 0.93% Precision : 0.99% Recall Accuracy : 0.96%

(4, 6)

Successes : 171 Failures : 4 False Positives : 4 False Negatives : 0

Training runs : 20
Total successes : 171
Total failures : 4
Precision : 0.95%
Recall : 1.0%
Accuracy : 0.98%

(4,7)

Successes : 156
Failures : 22
False Positives : 22
False Negatives : 0

 Learning rate
 : 0.05

 Training runs
 : 20

 Total successes
 : 156

 Total failures
 : 22

 Precision
 : 0.74%

 Recall
 : 1.0%

 Accuracy
 : 0.86%

(4, 8)

Successes : 160 Failures : 12 False Positives : 10 False Negatives : 2

Learning rate : 0.05
Training runs : 20

Training runs : 20
Total successes : 160
Total failures : 12
Precision : 0.88%
Recall : 0.97%
Accuracy : 0.93%

(4, 9)

Successes : 177
Failures : 11
False Positives : 8
False Negatives : 3

Training runs : 20 ses : 177 es : 11 : 0.90% : 0.96% : 0.94% Total successes Total failures Precision Recall Accuracy

-----_____

(5, 6)

Successes : 174 Failures : 5 False Positives : 5 False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 174
Total failures : 5 Precision : 0.94% : 1.0% : 0.97% Recall Accuracy

(5,7)

Successes : 168 Failures : 14 False Positives: 14 False Negatives : 0

Learning rate : 0.05 Training runs : 20 : 168 : 14 Total successes Total failures : 0.84% Precision Recall : 1.0% Accuracy : 0.92%

(5, 8)

Successes : 171 Failures : 5 False Positives : 3 False Negatives : 2

Training runs : 20
Total successes : 171
Total failures : 5
Precision : 0.97%
Recall : 0.98%
Accuracy : 0.97%

-----_____

(5, 9)

Successes : 181 Failures : 11 False Positives: 10 False Negatives : 1

Learning rate : 0.05
Training runs : 20
Total successes : 181
Total failures : 11 Precision : 0.89% Recall : 0.99% : 0.94% Accuracy

(6,7)

Successes : 185 Failures : 0 False Positives : 0 False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 185
Total failures : 0 Total failures : 0 : 1.0% Precision Recall : 1.0% Accuracy : 1.0%

(6, 8)

Successes : 172 Failures : 7 False Positives : 0 False Negatives : 7

Training runs : 20
Total successes : 172
Total failures : 7
Precision : 1.0%
Recall : 0.93%
Accuracy : 0.96%

(6, 9)

Successes : 195
Failures : 0
False Positives : 0
False Negatives : 0

Learning rate : 0.05
Training runs : 20
Total successes : 195
Total failures : 0
Precision : 1.0%
Recall : 1.0%

Accuracy : 1.0%

(7, 8)

Successes : 156
Failures : 26
False Positives : 0
False Negatives : 26

Learning rate : 0.05
Training runs : 20
Total successes : 156
Total failures : 26
Precision : 1.0%
Recall : 0.78%
Accuracy : 0.83%

(7, 9)

Successes : 175
Failures : 23
False Positives : 0
False Negatives : 23

Training runs : 20
Total successes : 175
Total failures : 23
Precision : 1.0%
Recall : 0.80%
Accuracy : 0.87%

(8, 9)

Successes : 186
Failures : 6
False Positives : 3
False Negatives : 3

Learning rate : 0.05
Training runs : 20
Total successes : 186
Total failures : 6
Precision : 0.97%

Recall : 0.97%
Accuracy : 0.97%

reporting test data

 Learning rate
 : 0.05

 Training runs
 : 20

 Total successes
 : 16385

 Total failures
 : 1021

 Precision
 : 0.97%

 Recall
 : 0.92%

 Accuracy
 : 0.94%

0 1 2 3 4 5 6 7 8 9

0 | X 14 4 0 5 0 12 1 1 2

1 | 0 X 6 0 0 0 7 2 0 0

2 | 0 27 X 0 0 0 1 8 1 7

3 | 0 182 36 X 2 4 2 55 16 39

4 | 0 108 6 2 X 6 10 38 12 12

5 | 4 129 26 8 1 X 9 26 7 34
