CS440 : Introduction to Artificial Intelligence **Spring 2014**

Problem Set 2 - Part 1

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1. **Solution to problem 1**

   (a) **Training on data set 1**

   a) The final weights

   $StartingThreshhold = 0.0$
   $CalculatedThreshhold = -53.5$

   Weights:
   $w_1 \rightarrow -752.0$
   $w_2 \rightarrow 4771.0$
   $w_3 \rightarrow 17714.0$
   $w_4 \rightarrow 762.0$
   $w_5 \rightarrow 6.0$
   $w_6 \rightarrow 676.0$
   $w_7 \rightarrow 3060.0$
   $w_8 \rightarrow -2004.0$
   $w_9 \rightarrow 5459.0$
   $w_{10} \rightarrow 9591.2999999989$
   $w_{11} \rightarrow 3832.0$
   $w_{12} \rightarrow 14963.0$
   $w_{13} \rightarrow 20912.0$

   b) The number of training epochs required
   The training took 1979 epochs.

   c) The margin
   $\gamma \rightarrow 0.1521547389026288$

   (b) **Test on data set 1**

   a) A confusion matrix

54	0
0	63

   b) Two lists of example indices
   No errors were found with this dataset since the weight vectors were calculated from this dataset.

c) The total loss summed over the misclassified examples
The loss for this dataset is 0.0 since it is the training data set.

(c) **Test on data set 2**

a) A confusion matrix

12	1
0	20

b) Two lists of example indices
False Negatives:
Index: 22
Inputs: $(60.0, 1.0, 4.0, 140.0, 293.0, 0.0, 2.0, 170.0, 0.0, 1.2, 2.0, 2.0, 7.0)$

False Positives:
There were no false positives

c) The total loss summed over the misclassified examples
Total loss: 77.440000001312

(d) **Application to data set 3**
Classifications:
$1 \rightarrow 0.0$
$2 \rightarrow 1.0$
$3 \rightarrow 0.0$
$4 \rightarrow 1.0$
$5 \rightarrow 1.0$
$6 \rightarrow 0.0$
$7 \rightarrow 0.0$
$8 \rightarrow 0.0$
$9 \rightarrow 0.0$
$10 \rightarrow 1.0$
$11 \rightarrow 1.0$
$12 \rightarrow 0.0$
$13 \rightarrow 1.0$
$14 \rightarrow 0.0$
$15 \rightarrow 0.0$
$16 \rightarrow 0.0$
$17 \rightarrow 1.0$
$18 \rightarrow 0.0$
$19 \rightarrow 0.0$
$20 \rightarrow 0.0$
$21 \rightarrow 0.0$

Which feature is the most important?
In order to determine the most influential property I have used the correlation

coefficients to find the most correlation between each property and the classification. The source code to find this property is also within the project.

Label	CorrelationCoefficient
age	0.576399638726158
sex	0.15811388300841894
chest	0.4934637712198269
resting blood pressure	0.08008953852726183
serum cholestoral	−0.32382553481251514
fasting blood sugar	0.31622776601683766
resting electrocardiographic results	0.1386750490563073
maximum heart rate achieved	−0.5353426981014223
exercise induced angina	0.685994340570035
oldpeak	0.8086701966434094
slope	0.6123724356957945
number of major vessels	0.8152133857595864
thal	0.43905703995876144

Property With Maximum Correlation
Label: number of major vessels
Correlation Coefficient: 0.8152133857595864

1 Source Code

The following is the source code for the assignment. It consists of 5 classes to get all the required output.

- CorrelationCoefficient
  This class is used to calculate the correlation coefficient on the resultant classifications when running the learner in application mode to tell which is the most important input.

- Pair
  This is mainly a utility class used to group the weight and input together for clarity in traversal of the arrays.

- VectorUtils
  This is a collection of vector utilities that are used throughout the application such as: dot product, addition, scaling, finding the norm, and zipping two vectors into one array of Pairs. This is used to traverse the arrays in parallel.

- WidrowHoffLearner
  This class has the Widrow Hoff Learning specific code as defined in the assignment and lectures.

- Main
  This class simply runs all the classes and displays the output.

  I have excluded the source for DataSet for brevity.

1.1 Main.java

```
1  package hw2.widrowhoff;
2
3  import java.util.List;
4
5  public class Main {
6
7    @SuppressWarnings("unused")
8    public static void main(String[] args) {
9      final String dataSet1Csv = "DataSet1.csv";
10     final String dataSet2Csv = "DataSet2.csv";
11     final String dataSet3Csv = "DataSet3.csv";
12
13     DataSet dataSet1 = new DataSet(dataSet1Csv);
14     DataSet dataSet2 = new DataSet(dataSet2Csv);
15     DataSet dataSet3 = new DataSet(dataSet3Csv);
16
17     WidrowHoffLearner learner = new WidrowHoffLearner( dataSet1, 0.0 );
18     learner.trainWeightVector();
19
20     for( int i = 0; i < learner.getWeights().length; i++ ) {
21       System.out.println("\\( w_{" + (i+1) + "} \\rightarrow " + learner.
             getWeights()[i] + " \\)");
22     }
23
24     System.out.println("-----------------------------");
25     System.out.println("Data set 1 test");
26     System.out.println("-----------------------------");
27     learner.testWeightVector(dataSet1);
28     System.out.println("-----------------------------");
29     System.out.println("Data set 2 test");
30     System.out.println("-----------------------------");
31     learner.testWeightVector(dataSet2);
32
33     System.out.println("-----------------------------");
34     System.out.println("Data set 3 application");
35     System.out.println("-----------------------------");
36
37     final List<Double> classifications = learner.applyWeightVector(dataSet3);
38     for( int i = 0; i < classifications.size(); i++ ) {
39       System.out.println( "\\( " + (i+1) + " \\rightarrow " + classifications.
             get(i) + " \\) \\\\" );
40     }
41
42     final List<Pair<String,Double>> coefficients = CorrelationCoefficient.
         calculate(dataSet3, classifications);
```

```
43      System.out.println("-------------------------");
44      System.out.println("Correlation Coefficients");
45      System.out.println("-------------------------");
46      String maxProp = "";
47      Double maxCorrelation = Double.MIN_VALUE;
48      System.out.println("\\( \\begin{array}{l|l}");
49      System.out.println("\\bf{Label} & \\bf{Correlation Coefficient} \\\\");
50      System.out.println("\\hline");
51      for(final Pair<String, Double> coefficient : coefficients ) {
52        System.out.println("\\text{ " + coefficient.getLeft().trim().replaceAll(
              "[^A-Za-z0-9]", " ") + " } & " + coefficient.getRight() + " \\\\");
53        if( coefficient.getRight().compareTo(maxCorrelation) > 0 ) {
54          maxProp = coefficient.getLeft();
55          maxCorrelation = coefficient.getRight();
56        }
57      }
58      System.out.println("\\end{array} \\)");
59      System.out.println();
60
61
62      System.out.println("-------------------------");
63      System.out.println("Maximum Correlation Prop");
64      System.out.println("-------------------------");
65      System.out.println("\\bf{ Property With Maximum Correlation} \\\\ ");
66      System.out.println("Label: " + maxProp.replaceAll("[^A-Za-z0-9]", " ") + "
            \\\\");
67      System.out.println("Correlation Coefficient: \\(" + maxCorrelation + "\\)"
            );
68    }
69
70  }
```

1.2 Pair.java

```
1  package hw2.widrowhoff;
2
3  public class Pair<T1, T2> {
4    private final T1 left;
5    private final T2 right;
6
7    public Pair(T1 left, T2 right) {
8      this.left = left;
9      this.right = right;
10   }
11
12   public T1 getLeft() {
13     return left;
14   }
15   public T2 getRight() {
16     return right;
17   }
18 }
```

1.3 VectorUtils.java

```
1  package hw2.widrowhoff;
2
3  import java.util.ArrayList;
4  import java.util.List;
5
6  public class VectorUtils {
7
8    public static double dotProduct( final double[] x, final double[] y ) {
9      double sum = 0;
10     for( int i = 0; i < x.length && i < y.length; i++ ) {
11       sum += x[i] * y[i];
12     }
13
14     return sum;
15   }
16
17   public static double[] scale( final double[] x, final double scalar ) {
18     double[] xCopy = x.clone();
19     for( int i = 0; i < x.length; i++ ) {
20       xCopy[i] *= scalar;
21     }
22     return xCopy;
23   }
24
25   public static double[] add( double[] x, final double[] y ) {
26     double[] xCopy = x.clone();
27     double[] yCopy = y.clone();
28     for( int i = 0; i < xCopy.length && i < yCopy.length; i++ ) {
29       xCopy[i] += yCopy[i];
30     }
31
32     return xCopy;
33   }
34
35   public static List<Pair<Double, Double> > zip( double[] x, double[] y ) {
36     List<Pair<Double, Double> > zippedVector = new ArrayList<Pair<Double,
         Double>>();
37     for( int i = 0; i < x.length && i < y.length; i++ ) {
38       zippedVector.add( new Pair<Double,Double>(x[i], y[i]) );
39     }
40     return zippedVector;
41   }
42
43   public static double[] unitVector( double[] x ) {
44     double[] copy = x.clone();
45     double norm = norm(copy);
46     return scale(x, 1.0 / norm );
47   }
48
49   public static double norm( double[] x ) {
50     double sum = 0;
51     for( int i = 0; i < x.length; i++) {
```

```
52        sum += Math.pow(x[i], 2.0);
53      }
54      return Math.sqrt(sum);
55    }
56  }
```

1.4 CorrelationCoefficient.java

```
1  package hw2.widrowhoff;
2
3  import java.util.ArrayList;
4  import java.util.Arrays;
5  import java.util.List;
6
7  public class CorrelationCoefficient {
8
9    public static List<Pair<String,Double>> calculate(final DataSet dataSet,
         final List<Double> classifications ) {
10     final String[] labels = dataSet.fields;
11     List<Pair<String,Double>> coefficients = new ArrayList<Pair<String,Double
           >>();
12
13     final List<List<Double>> transformedArray = transform(dataSet.exData);
14     final double classificationMean = mean(classifications);
15
16     int i = 0;
17     for( final List<Double> array : transformedArray ) {
18       final double mean = mean(array);
19       final String label = labels[i];
20
21       double numeratorSum = 0.0;
22       double xDenominatorSum = 0.0;
23       double yDenominatorSum = 0.0;
24
25       int j = 0;
26       for( final Double x : array ) {
27         final double xDiff = x - mean;
28         final double yDiff = classifications.get(j) - classificationMean;
29
30         numeratorSum += xDiff * yDiff;
31         xDenominatorSum += xDiff * xDiff;
32         yDenominatorSum += yDiff * yDiff;
33
34         j++;
35       }
36
37       final Double correlationCoefficient = numeratorSum / Math.sqrt(
             xDenominatorSum * yDenominatorSum);
38       final Pair<String,Double> coefficientWithLabel = new Pair<String,Double
             >(label, correlationCoefficient);
39       coefficients.add(coefficientWithLabel);
40       i++;
```

```
41      }
42
43      return coefficients;
44    }
45
46    private static List< List<Double> > transform(double[][] data ) {
47      List<List<Double>> transformed = new ArrayList<List<Double>>();
48
49      for( int i = 0; i < data[0].length; i++ ) {
50        List<Double> column = new ArrayList<Double>();
51        for( int j = 0; j < data.length; j++ ) {
52          column.add(data[j][i]);
53        }
54        transformed.add(column);
55      }
56
57      return transformed;
58    }
59
60    private static double mean(final double[] array) {
61      double sum = 0.0;
62      for( int i = 0; i < array.length; i++ ) {
63        sum+= array[i];
64      }
65      return sum / (double) array.length;
66    }
67
68    private static double mean(final List<Double> array) {
69      double sum = 0.0;
70      for( int i = 0; i < array.size(); i++ ) {
71        sum+= array.get(i);
72      }
73      return sum / (double) array.size();
74    }
75  }
```

1.5 WidrowHoffLearner.java

```
1  package hw2.widrowhoff;
2
3  import java.util.ArrayList;
4  import java.util.List;
5
6  public class WidrowHoffLearner {
7
8    private double[] weights;
9    private double[] homogeneousWeights;
10   private double[][] x;
11   private double alpha = 1;
12   private double threshold;
13   private double[] labels;
14   private double margin;
```

```
15
16    public WidrowHoffLearner( final DataSet dataSet, final double[] weights,
          final double threshold ) {
17      this.x = dataSet.exData;
18      this.labels = dataSet.exLabels;
19      this.threshold = threshold;
20    }
21
22    public WidrowHoffLearner( final DataSet dataSet, final double threshold ) {
23      this.x = dataSet.exData;
24      this.labels = dataSet.exLabels;
25      final int inputLength = x[0].length; // get input vector length less the
            value of the class
26      double[] weightsVector = new double[inputLength];
27      for( int i = 0; i < inputLength; i++ ) {
28        weightsVector[i] = 0;
29      }
30      this.weights = weightsVector;
31
32      homogeneousWeights = new double[ weights.length + 1];
33      homogeneousWeights[0] = threshold;
34      for(int k = 1; k < weights.length; k++ ) {
35        homogeneousWeights[k] = weights[k - 1];
36      }
37
38      this.threshold = threshold;
39    }
40
41    public void trainWeightVector() {
42      int iterations = 0;
43      while( true ) {
44        int errors = 0;
45        for( int i = 0; i < x.length; i++ ) {
46          double[] heterogeneousInputs = x[i];
47          double[] inputs = new double[heterogeneousInputs.length + 1];
48          inputs[0] = -1;
49          for(int j = 1; j < inputs.length; j++) {
50            inputs[j] = heterogeneousInputs[j-1];
51          }
52
53          double err = labels[i] - percepW( inputs ); // use last value in array
                as label
54
55          // 0 - correct
56          // -1 - false positive
57          // 1 - false negative
58          if( err != 0.0 ) {
59            errors++;
60  //            double loss = -1.0 * err * VectorUtils.dotProduct(inputs, weights)
        ;
61
62            final double[] scaledInputs = VectorUtils.scale(inputs, alpha * err
                );
```

```
63            homogeneousWeights = VectorUtils.add(scaledInputs,
                  homogeneousWeights);
64          }
65        }
66
67        if(errors == 0) {
68          break;
69        }
70
71        iterations++;
72      }
73
74      calculateMargin();
75
76      for( int i = 1; i < homogeneousWeights.length; i++ ) {
77        weights[i-1] = homogeneousWeights[i];
78      }
79
80      System.out.println("The training took " + iterations + " epochs.");
81      System.out.println("Threshhold: " + homogeneousWeights[0]);
82      System.out.println("\\( \\gamma \\rightarrow " + margin + " \\)");
83    }
84
85    public void testWeightVector(DataSet dataSet) {
86      int falseNegatives = 0;
87      int falsePositives = 0;
88      int truePositives = 0;
89      int trueNegatives = 0;
90      double totalLoss = 0.0;
91      for( int i = 0; i < dataSet.exData.length; i++ ) {
92        double[] heterogeneousInputs = dataSet.exData[i];
93        double[] inputs = new double[heterogeneousInputs.length + 1];
94        inputs[0] = -1;
95        for(int j = 1; j < inputs.length; j++) {
96          inputs[j] = heterogeneousInputs[j-1];
97        }
98
99        final double percepResult = percepW( inputs );
100       final double err = dataSet.exLabels[i] - percepResult; // use last value
              in array as label
101
102       // 0 - correct
103       // -1 - false positive
104       // 1 - false negative
105       if( err > 0.0 ) {
106         falseNegatives++;
107         System.out.println("False Negative Found: ");
108         System.out.println("Index: " + i);
109         System.out.println("Inputs: " + vectorToString(inputs));
110         totalLoss += Math.abs(-1.0 * err * VectorUtils.dotProduct(inputs,
                homogeneousWeights ));
111       } else if ( err < 0.0 ) {
112         falsePositives++;
113         System.out.println("False Positive Found: ");
```

```
114           System.out.println("Index: " + i);
115           System.out.println("Inputs: " + vectorToString(inputs));
116           totalLoss += Math.abs(-1.0 * err * VectorUtils.dotProduct(inputs,
                  homogeneousWeights ));
117         } else {
118           if( percepResult == 1 ) {
119             truePositives++;
120           } else {
121             trueNegatives++;
122           }
123         }
124       }
125
126       System.out.println("True Positives: " + truePositives );
127       System.out.println("True Negatives: " + trueNegatives );
128       System.out.println("False positives: " + falsePositives);
129       System.out.println("False negatives: " + falseNegatives);
130       System.out.println("Total loss: " + totalLoss);
131       System.out.println("Total items: " + dataSet.exData.length );
132     }
133
134     private String vectorToString( final double[] x ) {
135       StringBuilder stringBuilder = new StringBuilder();
136       stringBuilder.append("(");
137       for( int i = 1; i < x.length; i++ ) {
138         stringBuilder.append(x[i]);
139         if( i != x.length - 1) {
140           stringBuilder.append(", ");
141         }
142       }
143       stringBuilder.append(")");
144       return stringBuilder.toString();
145     }
146
147     public List<Double> applyWeightVector(DataSet dataSet) {
148       List<Double> classifications = new ArrayList<Double>();
149       for( int i = 0; i < dataSet.exData.length; i++ ) {
150         double[] heterogeneousInputs = dataSet.exData[i];
151         double[] inputs = new double[heterogeneousInputs.length + 1];
152         inputs[0] = -1;
153         for(int j = 1; j < inputs.length; j++) {
154           inputs[j] = heterogeneousInputs[j-1];
155         }
156         double classification = percepW(inputs);
157         classifications.add(classification);
158       }
159       return classifications;
160     }
161
162     private void calculateMargin() {
163       margin = Double.MAX_VALUE;
164       final double[] unitWeightVector = VectorUtils.unitVector(
              homogeneousWeights);
165
```

```
166     for( int i = 0; i < x.length; i++ ) {
167       double[] inputs = x[i];
168
169       double dotProduct = Math.abs( VectorUtils.dotProduct(unitWeightVector,
              inputs) );
170       double norm = VectorUtils.norm(inputs);
171
172       double marginPart = dotProduct / norm;
173
174       margin = Math.min(margin, marginPart);
175     }
176   }
177
178   private double percepW( final double[] curInputVector ) {
179     double sum = 0.0;
180
181     sum += VectorUtils.dotProduct( curInputVector, homogeneousWeights );
182
183     if( sum > 0 ) return 1;
184     else if ( sum < 0 ) return 0;
185     else return 0;
186   }
187
188   public double[] getWeights() {
189     return weights;
190   }
191   public double[][] getX() {
192     return x;
193   }
194
195   public double getAlpha() {
196     return alpha;
197   }
198
199   public double getThreshold() {
200     return threshold;
201   }
202
203   public double[] getLabels() {
204     return labels;
205   }
206
207   public double getMargin() {
208     return margin;
209   }
210
211 }
```