

# Assignment 7 in Artificial Intelligence

## Spring 2018

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### Task 1

#### 1.1

In nature a pheromone is a chemical substance left by ants to inform other ants which path to follow. In computer science instead of chemical substances we use numerical values to represent pheromones. The more pheromones (higher pheromone value) are left on a specific path, the more likely is it that other ants will choose given path instead of wandering at random. In turn leaving their own pheromones there (increasing the pheromone value). Pheromones evaporate over time (pheromone value decreases) therefore a longer path means that pheromones left on it have more time to evaporate than on shorter route. Shorter route makes it possible for more ants to travel quickly back and forth, leaving even more pheromones. This means that soon all or almost all ants will choose the best path as long as it gives the positive results.

#### 1.2

a

Using the formula:

$$P = \frac{\tau(r, u)^\alpha \cdot \eta(r, u)^\beta}{\sum_{k=1}^K \tau(r, k)^\alpha \cdot \eta(r, k)^\beta}$$

I calculate which path will be chosen using values:  $\alpha = \beta = 0.9$ .  $\tau(r, u)$  is simply the amount of pheromones on path  $r \rightarrow u$  and  $\eta(r, u)$  is the desirability of path given by  $\frac{1}{d(r, u)}$ ,  $d(r, u)$  is the distance between  $r$  and  $u$ .  $\alpha$  and  $\beta$  are heuristic weights given to pheromone level and distance respectively and they vary between 0 and 1.

$$\begin{aligned}
P(a, b) &= \frac{\tau(a, b)^\alpha \cdot \eta(a, b)^\beta}{\sum_{k=1}^K \tau(a, k)^\alpha \cdot \eta(a, k)^\beta} \\
&= \frac{2^{0.9} \cdot \frac{1}{8}^{0.9}}{2^{0.9} \cdot \frac{1}{8}^{0.9} + 3^{0.9} \cdot \frac{1}{10}^{0.9} + 1^{0.9} \cdot \frac{1}{4}^{0.9} + 2.5^{0.9} \cdot \frac{1}{7}^{0.9}} \\
&= \underline{0.2194505374} \\
P(a, c) &= \frac{\tau(a, c)^\alpha \cdot \eta(a, c)^\beta}{\sum_{k=1}^K \tau(a, k)^\alpha \cdot \eta(a, k)^\beta} \\
&= \frac{3^{0.9} \cdot \frac{1}{10}^{0.9}}{2^{0.9} \cdot \frac{1}{8}^{0.9} + 3^{0.9} \cdot \frac{1}{10}^{0.9} + 1^{0.9} \cdot \frac{1}{4}^{0.9} + 2.5^{0.9} \cdot \frac{1}{7}^{0.9}} \\
&= \underline{0.2585828812} \\
P(a, d) &= \frac{\tau(a, d)^\alpha \cdot \eta(a, d)^\beta}{\sum_{k=1}^K \tau(a, k)^\alpha \cdot \eta(a, k)^\beta} \\
&= \frac{1^{0.9} \cdot \frac{1}{4}^{0.9}}{2^{0.9} \cdot \frac{1}{8}^{0.9} + 3^{0.9} \cdot \frac{1}{10}^{0.9} + 1^{0.9} \cdot \frac{1}{4}^{0.9} + 2.5^{0.9} \cdot \frac{1}{7}^{0.9}} \\
&= \underline{0.2194505374} \\
P(a, e) &= \frac{\tau(a, e)^\alpha \cdot \eta(a, e)^\beta}{\sum_{k=1}^K \tau(a, k)^\alpha \cdot \eta(a, k)^\beta} \\
&= \frac{2.5^{0.9} \cdot \frac{1}{7}^{0.9}}{2^{0.9} \cdot \frac{1}{8}^{0.9} + 3^{0.9} \cdot \frac{1}{10}^{0.9} + 1^{0.9} \cdot \frac{1}{4}^{0.9} + 2.5^{0.9} \cdot \frac{1}{7}^{0.9}} \\
&= \underline{0.3025160441}
\end{aligned}$$

Since  $\alpha$  and  $\beta$  give equal weight to pheromone level and distances we end up with solution that path  $A \rightarrow E$  is most likely to be chosen.

**b**

Using path from previous point I will calculate pheromone level left on the path by ant traveling across it. This is given by a formula:

$$\tau_{i,j}(t) = (1 - \rho)\tau_{i,j}(t - 1) + \Delta\tau_{i,j}(k)$$

$\rho = 0.9$  and  $Q = 10$ .  $\Delta\tau_{i,j}(k)$  is the amount of pheromone left by the ant and it is given by  $\Delta\tau_{i,j}(k) = Q \cdot \frac{1}{d(k)}$  where  $Q$  stands for pheromone deposition capability,  $d(k)$  is the length of path  $k$ .  $\rho$  is the decay factor of the pheromone.

$$\begin{aligned}
\tau_{a,e}(t) &= (1 - \rho)\tau_{a,e}(t - 1) + \Delta\tau_{a,e}(E) \\
&= (1 - 0.9)2.5 + 10 \cdot \frac{1}{7} \\
&= \underline{1.678571429}
\end{aligned}$$

Given probability that other paths may be chosen I have also calculated pheromone levels for them.

$$\begin{aligned}
\tau_{a,b}(t) &= (1 - \rho)\tau_{a,b}(t - 1) + \Delta\tau_{a,b}(E) \\
&= (1 - 0.9)2 + 10 \cdot \frac{1}{8} \\
&= \underline{1.45} \\
\tau_{a,c}(t) &= (1 - \rho)\tau_{a,c}(t - 1) + \Delta\tau_{a,c}(E) \\
&= (1 - 0.9)3 + 10 \cdot \frac{1}{10} \\
&= \underline{1.3} \\
\tau_{a,d}(t) &= (1 - \rho)\tau_{a,d}(t - 1) + \Delta\tau_{a,d}(E) \\
&= (1 - 0.9)1 + 10 \cdot \frac{1}{4} \\
&= \underline{2.6}
\end{aligned}$$

From this we can see that if some ant decides to go to D its pheromone level would increase greatly and make it more probable that D will be chosen by other ants thus increasing its value. That is quite easy to believe since D has the shortest distance of 4 compared to others, which are 7, 8, 10.

**c**

Values of  $\alpha$  and  $\beta$  decide how much weight is put on the pheromone and distance respectively when ant chooses the path it will take. If  $\alpha$  is higher, then pheromone level will take precedence over distance and vice versa.

## Task 2

**a**

The general shape of a perceptron can be seen in figure 1. In our case it will have only two dendrites one for x value input and one for y value input. Dendrites is used to gather data while Axon sends data to synapses that connect to other Perceptrons.

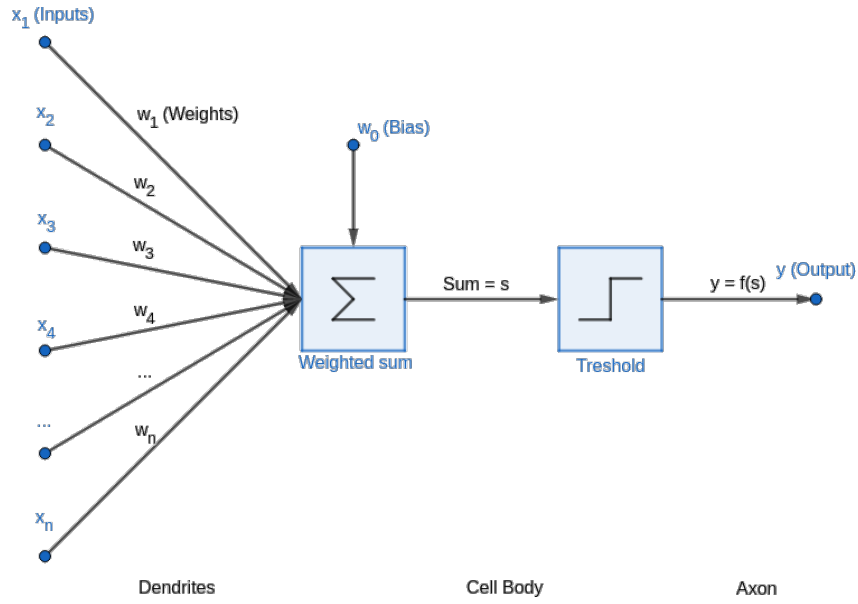


Figure 1: General shape of a perceptron

b

Since training and testing values are invalid (they are not linearly separable) I have taken liberty to change them so that they are separable. They can be seen in tables 1 and 2.

Table 1: Training Values

Category 1									Category 2									
x	-10	-10	-9	-5	-3	2	5	5	x	5	5	4	1	1	-2	-3	-6	-10
y	8	14	12	5	0	-3	-7	-8	y	-6	0	0	0	1	5	11	18	24

Table 2: Testing Values

Category 1									Category 2									
x	-8	-6	-5	-5	0	1	6	6	x	-7	-9	-5	-1	1	2	2	3	6
y	4	12	6	10	2	0	-12	-14	y	18	30	15	14	4	0	11	0	-5

Resulting values have been plotted and can be seen in figures 2 and 3.

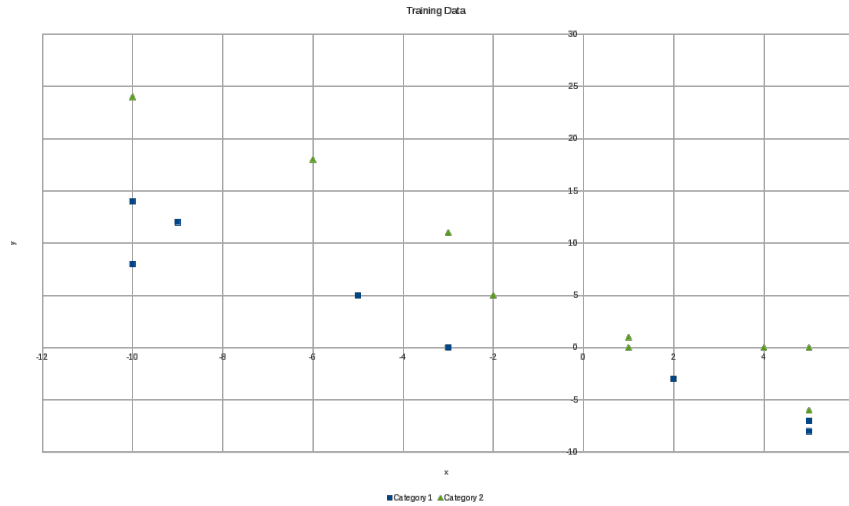


Figure 2: Training values for perceptron

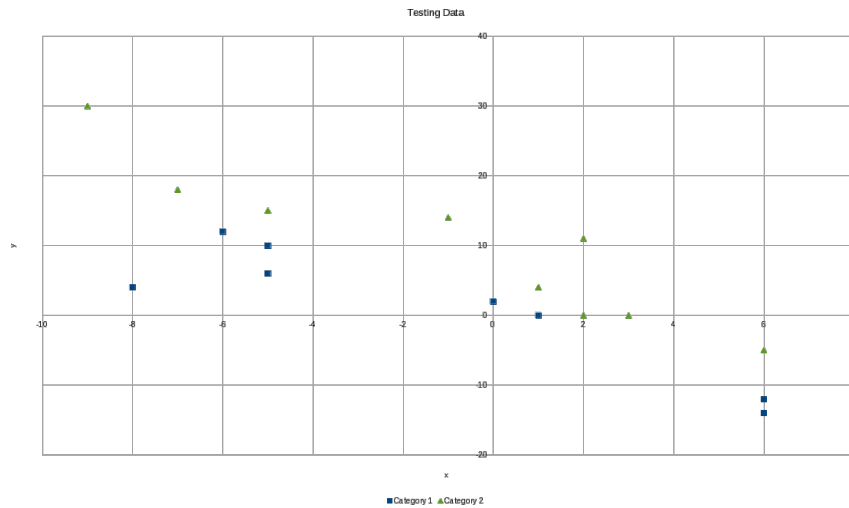


Figure 3: Testing values for perceptron

Results:

Average<sub>training</sub> error: 0.23529411764705882  
 Average<sub>testing</sub> error: 0.29411764705882354  
 Average<sub>training</sub> error: 0.11764705882352941  
 Average<sub>testing</sub> error: 0.23529411764705882  
 Average<sub>training</sub> error: 0.17647058823529413  
 Average<sub>testing</sub> error: 0.29411764705882354  
 Average<sub>training</sub> error: 0.17647058823529413  
 Average<sub>testing</sub> error: 0.23529411764705882  
 Average<sub>training</sub> error: 0.11764705882352941  
 Average<sub>testing</sub> error: 0.23529411764705882  
 Average<sub>training</sub> error: 0.11764705882352941  
 Average<sub>testing</sub> error: 0.23529411764705882  
 Average<sub>training</sub> error: 0.058823529411764705  
 Average<sub>testing</sub> error: 0.23529411764705882

Average\_training\_error: 0.0  
Average\_testing\_error: 0.23529411764705882  
Average\_training\_error: 0.0  
Average\_testing\_error: 0.23529411764705882  
Average\_training\_error: 0.0  
Average\_testing\_error: 0.23529411764705882

After 10 epochs I can see no more improvements. Graphs showing average error for training and testing sets can be seen in figures 4 and 5.

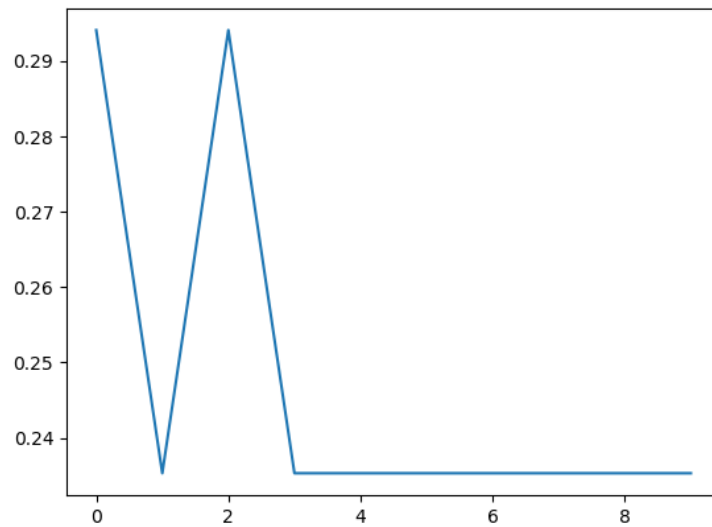


Figure 4: Training errors for perceptron

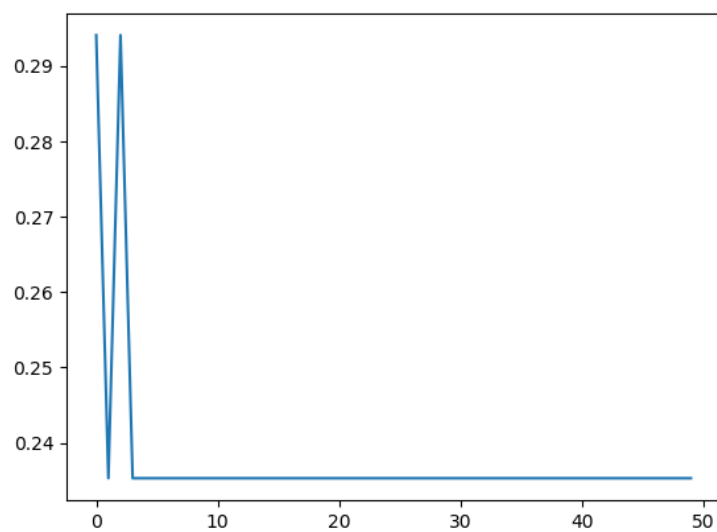


Figure 5: Testing errors for perceptron