

# Training Neural Networks

FINAL POINTS

1. In this exercise you'll look in more detail about back-propagation, using the chain rule, in order to train our neural network.

1/1 points

Let's look again at our two-node network.



Recall the activation equations are,

$$u^{(i)} = w x^{(i)}$$

$$y^{(i)} = u^{(i)} a^{(i)} + b^{(i)}$$

Where  $u^{(i)}$  is the weighted sum of activation and bias.

We can formalise how good (or bad) our neural network is at getting the desired behaviour. For a particular input,  $x$ , and desired output  $y$ , we can define the cost of that specific training example as the square of the difference between the network's output and the desired output, that is,

$$C_1 = (y^{(i)} - y)^2$$

Where  $i$  labels the training example and  $u^{(i)}$  is assumed to be the activation of the output neuron when the input neuron  $u^{(i)}$  is set to  $x$ .

Perf'g us into detail about how to apply this to an entire set of training data later on, but for now, let's look at our toy example.

Recall our ACT function example from the previous quiz. For the input  $x = 1$  we would like that the network outputs  $y = 0$ . For the starting weight and bias  $w^{(1)} = 1.8$  and  $b^{(1)} = -8.1$ , the network actually outputs  $y^{(1)} = 6.884$ . If we wish to use the cost function for this example, we get

$$C_1 = (3.884 - 0)^2 = 6.886$$

Do the same calculation for an input  $x = 8$  and desired output  $y = 1$ . Use the code block to help you.

```
1 # Given we set the state of the network
2 x = 8; b=0.0
3 w = 1.8
4 y = -8.1
5
6 # Now we define the neuron activation.
7 def act(u):
8     return 1/(1+np.exp(-u))
9
10 # Experiment with different values of w below.
11 w = 1.8
12 y = 0.0
```

What is  $C_2$  for this particular case? Give your result to 1 decimal place.

1.2

✔ **Correct**  
You have calculated  $C_2 = (-8.286 - 1)^2 = 1.2$ .

2. The cost function of a training set is the average of the individual cost functions of the data in the training set.

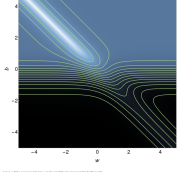
1/1 points

$$C = \frac{1}{N} \sum_{i=1}^N C_1$$

where  $N$  is the number of examples in the training set.

For the ACT function we've been considering, where we have ten examples in our training set ( $x = 0, y = 1$ ) and ( $x = 1, y = 0$ ), the training set cost function is  $C = \frac{1}{2}(C_1 + C_2)$ .

Since our parameter space is  $(w, b)$  and  $b^{(1)}$ , we can draw the total cost function for this neural network as a contour map.



Here, white represents low costs and black represents high costs.

Which of the following statements are true?

- ☐ There are many different local minima in this system.
- ☐ The optimal configuration lies along the line  $b = 0$ .
- ☒ Descending perpendicular to the contours will improve the performance of the network.
- ☒ **Correct**  
Moving across the contours will get you closer to the minimum valley.
- ☒ The optimal configuration lies somewhere along the line  $b = -w$ .
- ☒ **Correct**  
In this example the system asymptotically approaches a minimum along this line.
- ☐ None of the other statements are true.

3. To improve the performance of the neural network on the training data, we can vary the weights and biases. We can calculate the derivative of the example cost with respect to these quantities using the chain rule.

1/1 points

$$\frac{\partial C_1}{\partial w^{(1)}} = \frac{\partial C_1}{\partial u^{(1)}} \frac{\partial u^{(1)}}{\partial w^{(1)}} \frac{\partial y^{(1)}}{\partial u^{(1)}}$$
$$\frac{\partial C_1}{\partial b^{(1)}} = \frac{\partial C_1}{\partial u^{(1)}} \frac{\partial u^{(1)}}{\partial b^{(1)}} \frac{\partial y^{(1)}}{\partial u^{(1)}}$$

Individually, these derivatives take fairly simple form. So, ahead and calculate them. Perf'g us the defining equations for convenience.

$$u^{(i)} = w x^{(i)}$$

$$y^{(i)} = u^{(i)} a^{(i)} + b^{(i)}$$

$$C_1 = (y^{(i)} - y)^2$$

Select all true statements below.

- ☒  $\frac{\partial y^{(1)}}{\partial u^{(1)}} = a^{(1)}$
- ☒ **Correct**  
Since  $y^{(1)} = u^{(1)} a^{(1)} + b^{(1)}$  is a linear function, differentiating with respect to  $u^{(1)}$  returns the coefficient  $a^{(1)}$ .
- ☒  $\frac{\partial y^{(1)}}{\partial b^{(1)}} = 1$
- ☒ **Correct**  
The weighted sum changes exactly with the bias, if the bias is increased by some amount, then the weighted sum increases by the same amount.
- ☒  $\frac{\partial C_1}{\partial u^{(1)}} = a^{(1)} (y^{(1)})$
- ☒ **Correct**  
The derivative of the activation  $a^{(1)}$  with respect to the weighted sum  $u^{(1)}$  is just the derivative of the sigmoid function, applied to the weighted sum.
- ☒  $\frac{\partial C_1}{\partial u^{(1)}} = 2(u^{(1)} - y)$
- ☒ **Correct**  
This is an application of the power rule and the chain rule.
- ☐  $\frac{\partial C_1}{\partial u^{(1)}} = (1 - y)^2$
- ☐  $\frac{\partial C_1}{\partial u^{(1)}} = y$
- ☐ None of the other statements.
- ☐  $\frac{\partial C_1}{\partial u^{(1)}} = u^{(1)}$
- ☐  $\frac{\partial C_1}{\partial u^{(1)}} = a^{(1)}$

4. Using your answer to the previous questions, let's now implement it in code.

1/1 points

The following code block has an example implementation of  $\frac{\partial C_1}{\partial w^{(1)}}$ . It is up to you to implement  $\frac{\partial C_1}{\partial b^{(1)}}$ .

Don't worry if you don't know exactly how the code works, it's more important that you get a feel for what's going on.

We will introduce the following derivative in the code.

$$\frac{\partial C_1}{\partial u^{(1)}} = \frac{\partial C_1}{\partial y^{(1)}} \frac{\partial y^{(1)}}{\partial u^{(1)}}$$

Complete the function code below. Replace the  $???$  towards the bottom, with the expression you calculated in the previous question.

```
1 # Given we set the state of the network
2 x = 8; b=0.0
3 w = 1.8
4 y = -8.1
5
6 # Now we define the neuron activation.
7 def act(u):
8     return 1/(1+np.exp(-u))
9
10 # The individual cost function is the square of the difference between
11 # the network output and the training data output.
12 def cost(u, y, x):
13     return 0.5*(u - y)**2
14
15 # This function returns the derivative of the cost function with
16 # respect to the weight.
17 def dCdw(u, y, x):
18     # u = w * x + b
19     # du = 1 + 1/(1+np.exp(-u))**2 # derivative of cost with activation
20     # du = 1/(1+np.exp(-u))**2 # derivative of activation with weighted sum u
21     # du = x # derivative of weighted sum u with weight
22     return du * du * du # du is du from the chain rule product.
23
24 # This function returns the derivative of the cost function with
25 # respect to the bias.
26 # It is very similar to the previous function.
27 def dCdb(u, y, x):
28     # u = w * x + b
29     # du = 1/(1+np.exp(-u))**2 # derivative of cost with activation
30     # du = 1/(1+np.exp(-u))**2 # derivative of activation with weighted sum u
31     # du = 1 # derivative of weighted sum u with bias
32     return du * du * du # du is du from the chain rule product.
33
34 # This function returns the derivative of the cost function with
35 # respect to the bias.
36 # It is very similar to the previous function.
37 def dCdb(u, y, x):
38     # u = w * x + b
39     # du = 1/(1+np.exp(-u))**2 # derivative of cost with activation
40     # du = 1/(1+np.exp(-u))**2 # derivative of activation with weighted sum u
41     # du = 1 # derivative of weighted sum u with bias
42     return du * du * du # du is du from the chain rule product.
43
44 # Change the last line to give the derivative of
45 # the weighted sum, u, with respect to the bias, b.
46 # du = 1
47 return du * du * du
48
49 # Test your code before submitting.
50 # Let's start with an old w, b, and x.
51 w = 1.8
52 b = 0.0
53 x = 8
54 # We can test on a single data point pair of x and y.
55 y = 1
56 # Return how the cost would change
57 # in proportion to a small change in the bias.
58 print(dCdb(u, y, x))
```

✔ **Correct**  
Well done. Feel free to continue to use the code block and experiment with varying other parameters.

5. Recall that when we add more neurons to the network, our quantities are upgraded to vectors or matrices.

1/1 points



$$u^{(i)} = w x^{(i)}$$

$$y^{(i)} = W u^{(i)} + b^{(i)}$$

The individual cost functions remain scalars. Instead of summing vectors, the components are summed over each output neuron.

$$C_1 = \sum_{i=1}^N (y^{(i)} - y)^2$$

Now here  $i$  labels the output neuron and is summed over, whereas  $k$  labels the training example.

The training data becomes a vector too.

$x \rightarrow \mathbf{x}$  and has the same number of elements as input neurons.

$y \rightarrow \mathbf{y}$  and has the same number of elements as output neurons.

This allows us to write the cost function in vector form using the modulus squared.

$$C_1 = \|\mathbf{y}^{(i)} - \mathbf{y}\|^2$$

Use the code block below to play with calculating the cost function for this network.

```
1 # Define the activation function.
2 def act(u):
3     return 1/(1+np.exp(-u))
4
5 # Let's use a random initial weight and bias.
6 w = np.random.rand(3, 3) * 0.0001
7 b = np.random.rand(3, 1) * 0.0001
8 x = np.random.rand(3, 1) * 0.0001
9
10 # We can use our forward function
11 def fwd(x):
12     # Define the cost function.
13     # We'll use the same bias as previously.
14     # We'll use the same weight as previously.
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