

# COMP9444 Neural Networks and Deep Learning

## Term 2, 2020

### Solutions to Exercises 2: Backprop

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#### 1. Identical Inputs

Consider a degenerate case where the training set consists of just a single input, repeated 100 times. In 80 of the 100 cases, the target output value is 1; in the other 20, it is 0. What will a back-propagation neural network predict for this example, assuming that it has been trained and reaches a global optimum? (Hint: to find the global optimum, differentiate the error function and set to zero.)

When sum-squared-error is minimized, we have

$$\begin{aligned} E &= 80*(z-1)^2/2 + 20*(z-0)^2/2 \\ dE/dz &= 80*(z-1) + 20*(z-0) \\ &= 100*z - 80 \\ &= 0 \text{ when } z = 0.8 \end{aligned}$$

When cross entropy is minimized, we have

$$\begin{aligned} E &= -80*\log(z) - 20*\log(1-z) \\ dE/dz &= -80/z + 20/(1-z) \\ &= (-80*(1-z) + 20*z)/(z*(1-z)) \\ &= (100*z - 80)/(z*(1-z)) \\ &= 0 \text{ when } z = 0.8, \text{ as before.} \end{aligned}$$

#### 2. Linear Transfer Functions

Suppose you had a neural network with linear transfer functions. That is, for each unit the activation is some constant  $c$  times the weighted sum of the inputs.

- Assume that the network has one hidden layer. We can write the weights from the input to the hidden layer as a matrix  $\mathbf{W}^{HI}$ , the weights from the hidden to output layer as  $\mathbf{W}^{OH}$ , and the bias at the hidden and output layer as vectors  $\mathbf{b}^H$  and  $\mathbf{b}^O$ . Using matrix notation, write down equations for the value  $\mathbf{O}$  of the units in the output layer as a function of these weights and biases, and the input  $\mathbf{I}$ . Show that, for any given assignment of values to these weights and biases, there is a simpler network with no hidden layer that computes the same function.

Using vector and matrix multiplication, the hidden activations can be written as

$$\mathbf{H} = c * (\mathbf{b}^H + \mathbf{W}^{HI} * \mathbf{I})$$

The output activations can be written as

$$\begin{aligned}
\mathbf{O} &= \mathbf{c} * [ \mathbf{b}^{\mathbf{O}} + \mathbf{W}^{\mathbf{OH}} * \mathbf{H} ] \\
&= \mathbf{c} * [ \mathbf{b}^{\mathbf{O}} + \mathbf{W}^{\mathbf{OH}} * \mathbf{c} * ( \mathbf{b}^{\mathbf{H}} + \mathbf{W}^{\mathbf{HI}} * \mathbf{I} ) ] \\
&= \mathbf{c} * [ ( \mathbf{b}^{\mathbf{O}} + \mathbf{W}^{\mathbf{OH}} * \mathbf{c} * \mathbf{b}^{\mathbf{H}} ) + ( \mathbf{W}^{\mathbf{OH}} * \mathbf{c} * \mathbf{W}^{\mathbf{HI}} ) * \mathbf{I} ]
\end{aligned}$$

Because of the associativity of matrix multiplication, this can be written as

$$\mathbf{O} = \mathbf{c} * ( \mathbf{b}^{\mathbf{OI}} + \mathbf{W}^{\mathbf{OI}} * \mathbf{I} )$$

where

$$\mathbf{b}^{\mathbf{OI}} = \mathbf{b}^{\mathbf{O}} + \mathbf{W}^{\mathbf{OH}} * \mathbf{c} * \mathbf{b}^{\mathbf{H}}$$

$$\mathbf{W}^{\mathbf{OI}} = \mathbf{W}^{\mathbf{OH}} * \mathbf{c} * \mathbf{W}^{\mathbf{HI}}$$

Therefore, the same function can be computed with a simpler network, with no hidden layer, using the weights  $\mathbf{W}^{\mathbf{OI}}$  and bias  $\mathbf{b}^{\mathbf{OI}}$ .

- b. Repeat the calculation in part (a), this time for a network with any number of hidden layers. What can you say about the usefulness of linear transfer functions?

By removing the layers one at a time as above, a simpler network with no hidden layer can be constructed which computes exactly the same function as the original multi-layer network. In other words, with linear activation functions, you don't get any benefit from having more than one layer.

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