# CS224N PA4: Neural Networks for Named Entity Recognition

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## 1 Gradients for Backpropagation

Let $w^l_{jk}$ denote the weight for connecting the $k^{th}$ neuron in the $(l-1)^{th}$ layer to the $j^{th}$ neuron in the $l^{th}$ layer; $b^l_j$ denote the bias for the $j^{th}$ neuron in the $l^{th}$ layer; $a^l_j$ denote the activation of the $j^{th}$ neuron in the $l^{th}$ layer; $z^l_j$ denote the weighted input to the $j^{th}$ neuron in the $l^{th}$ layer; $h_l(.)$ denote the activation function for the weighted input $\mathbf{z}_l$. Note that $z^l_j = \sum_i w^l_{ji} a^{l-1}_i + b^l_j$ and $a^l_j = h_l(z^l_j)$. Let's define $\delta^l_j = \frac{\partial J}{\partial z^l_j}$, the error of neuron $j$ in layer $l$. Then it can be easily derived that the following four equations are true for any backpropagation system:

$$\delta^L = \frac{\partial J}{\partial a^L} \odot h'_L(z^L) \tag{1a}$$

$$\delta^l = (W^{l+1})^T \delta^{l+1} \odot h'_l(z^l) \tag{1b}$$

$$\frac{\partial J}{\partial b^l_j} = \delta^l_j \tag{1c}$$

$$\frac{\partial J}{\partial w^l_{jk}} = a^{l-1}_k \delta^l_j \tag{1d}$$

For current system, we've three layers: input layer, hidden layer and output layer. The cost function is $J = -[y ln a^L + (1-y) ln(1-a^L)]$. Using the above general system, we can obtain the following:

$$\delta^3 = p_\theta - y \tag{2a}$$

$$\delta^2 = (W^3)^T \delta^3 \odot tanh'(z^2) = U^T(p_\theta - y) \odot tanh'(Wx + b^{(1)}) \tag{2b}$$

$$\delta^1 = (W^2)^T \delta^2 \odot I'(x) = W^T \delta^2 = W^T U^T \delta^3 \odot tanh'(Wx + b^{(1)}) \tag{2c}$$

And

$$\frac{\partial J}{\partial U} = a^2\delta^3 = tanh(Wx + b^{(1)})(p_\theta - y) \tag{3a}$$

$$\frac{\partial J}{\partial W} = a^1\delta^2 = LU^T(p_\theta - y) \odot tanh'(Wx + b^{(1)}) \tag{3b}$$

$$\frac{\partial J}{\partial b^{(2)}} = \delta^3 = p_\theta - y \tag{3c}$$

$$\frac{\partial J}{\partial b^{(1)}} = \delta^2 = U^T(p_\theta - y) \odot tanh'(Wx + b^{(1)}) \tag{3d}$$

$$\frac{\partial J}{\partial L} = W^TU^T(p_\theta - y) \odot tanh'(Wx + b^{(1)}) \tag{3e}$$