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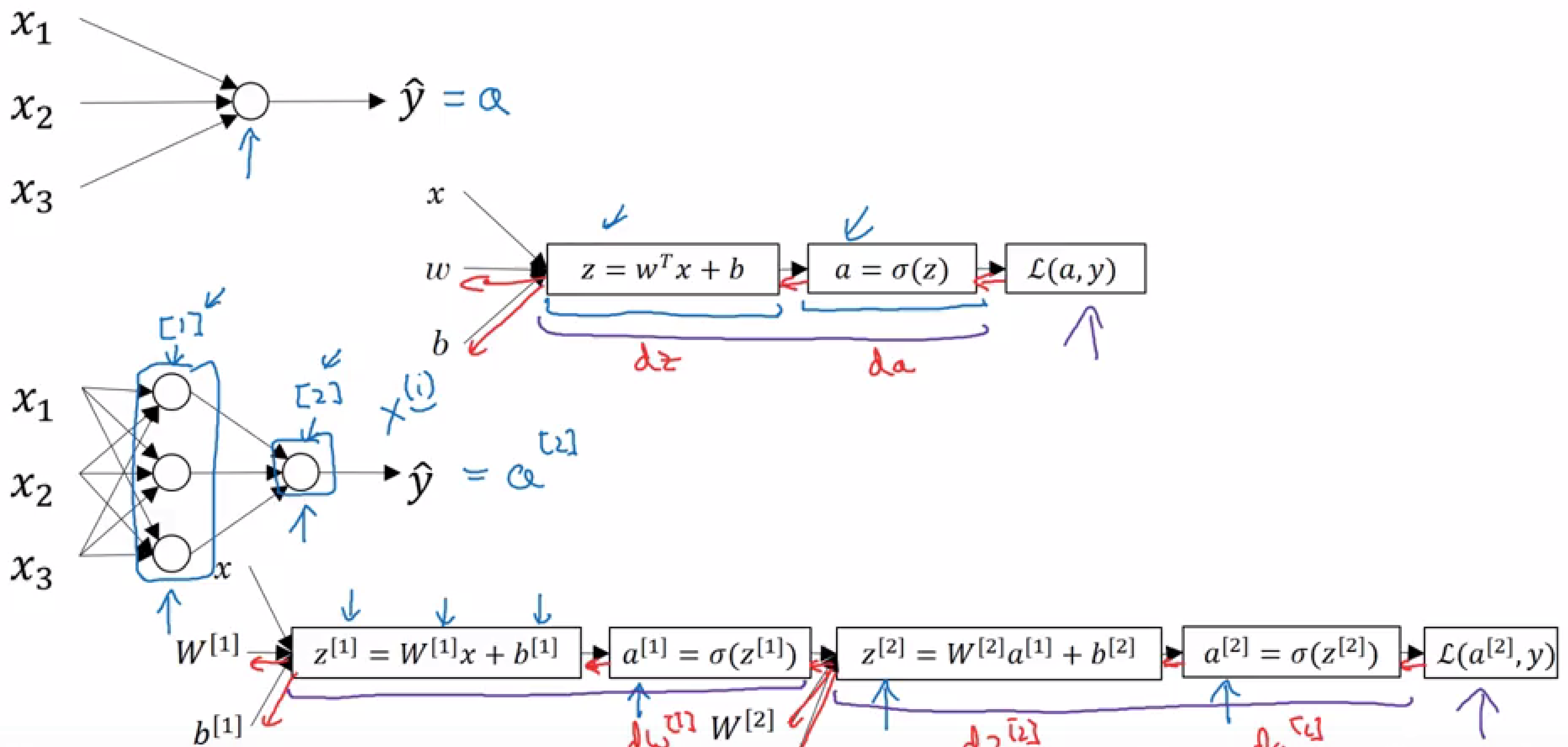
One hidden layer Neural Network

Neural Networks Overview

What is a Neural Network?



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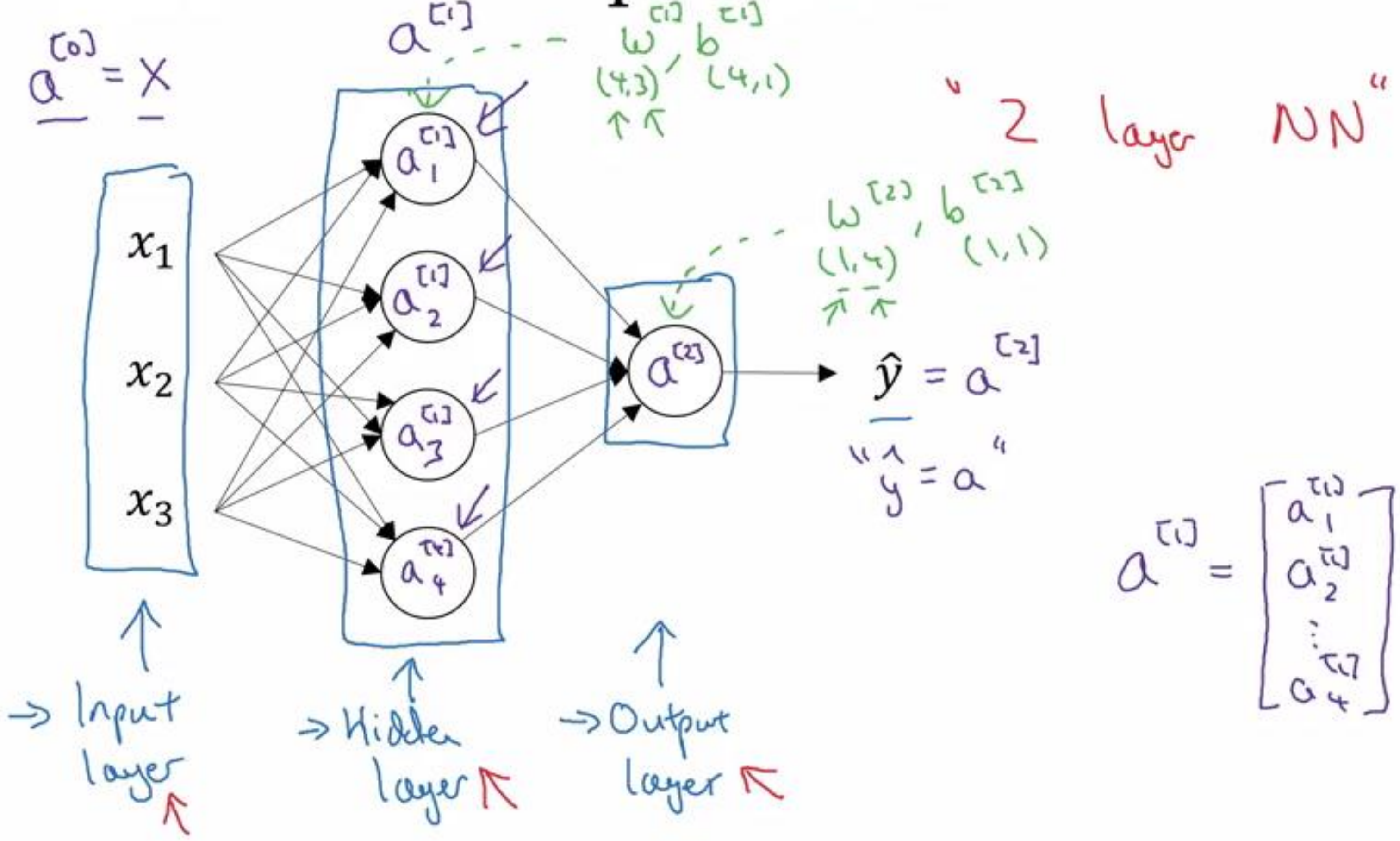
Neural Network Representation

Neural Network Representation



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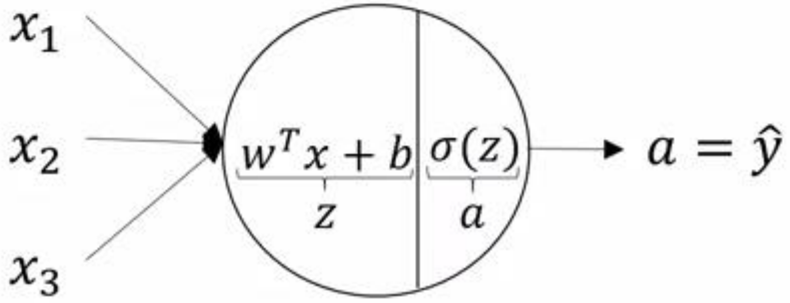
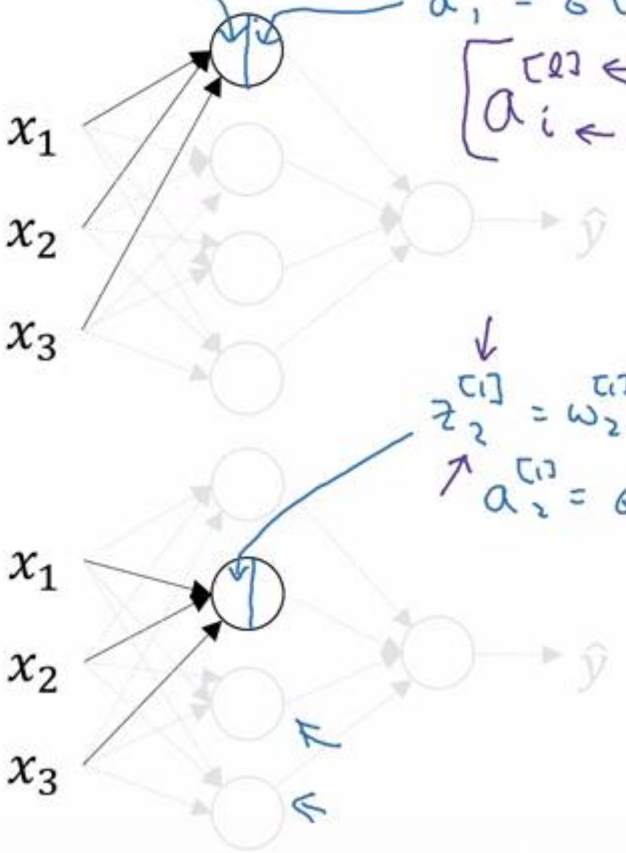
Computing a Neural Network's Output

Neural Network Representation



$z = w^Tx + b$

$a = \sigma(z)$



$z_1^{[1]} = w_1^{[1]T}x + b_1^{[1]}$

$a_1^{[1]} = \sigma(z_1^{[1]})$

$a_i^{[l]}$ ← layer, i ← node in layer.

$z_2^{[1]} = w_2^{[1]T}x + b_2^{[1]}$

$a_2^{[1]} = \sigma(z_2^{[1]})$

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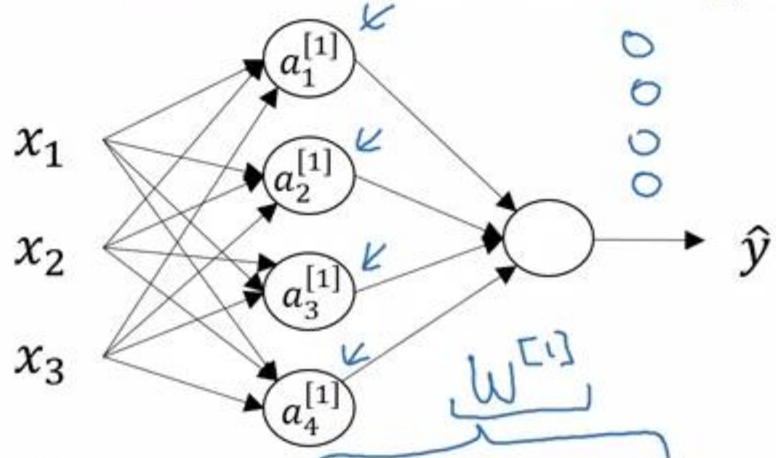
Neural Network Representation



$(w_1^{[1]})^T x$ $\quad a^{[1]}$

$$
\begin{aligned}
z_1^{[1]} &= w_1^{[1]T} x + b_1^{[1]}, & a_1^{[1]} &= \sigma(z_1^{[1]}) \\
z_2^{[1]} &= w_2^{[1]T} x + b_2^{[1]}, & a_2^{[1]} &= \sigma(z_2^{[1]}) \\
z_3^{[1]} &= w_3^{[1]T} x + b_3^{[1]}, & a_3^{[1]} &= \sigma(z_3^{[1]}) \\
z_4^{[1]} &= w_4^{[1]T} x + b_4^{[1]}, & a_4^{[1]} &= \sigma(z_4^{[1]})
\end{aligned}
$$

$$
z^{[1]} = \underset{(4,3)}{\overbrace{\begin{bmatrix} — w_1^{[1]T} — \\ — w_2^{[1]T} — \\ — w_3^{[1]T} — \\ — w_4^{[1]T} — \end{bmatrix}}^{W^{[1]}}} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \underbrace{\begin{bmatrix} b_1^{[1]} \\ b_2^{[1]} \\ b_3^{[1]} \\ b_4^{[1]} \end{bmatrix}}_{b^{[1]}\ (4,1)} = \begin{bmatrix} w_1^{[1]T} x + b_1^{[1]} \\ w_2^{[1]T} x + b_2^{[1]} \\ w_3^{[1]T} x + b_3^{[1]} \\ w_4^{[1]T} x + b_4^{[1]} \end{bmatrix} = \begin{bmatrix} z_1^{[1]} \\ z_2^{[1]} \\ z_3^{[1]} \\ z_4^{[1]} \end{bmatrix}
$$

$$
a^{[1]} = \begin{bmatrix} a_1^{[1]} \\ \vdots \\ a_4^{[1]} \end{bmatrix} = \sigma(z^{[1]})
$$

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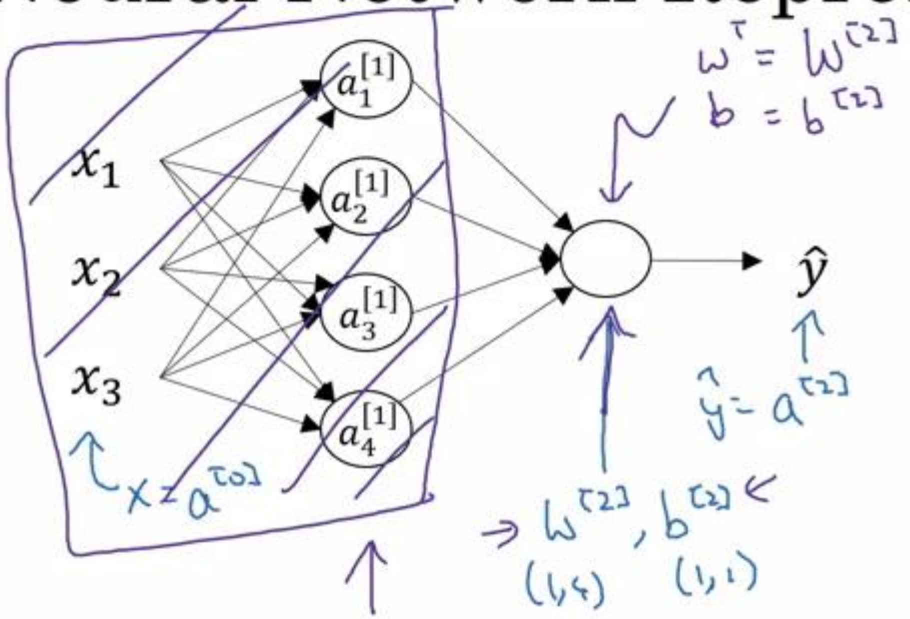
Neural Network Representation learning



$z = w^T x + b$

$\hat{y} = a = \sigma(z)$

Given input x:

$$\underset{(4,1)}{z^{[1]}} = \underset{(4,3)}{W^{[1]}} \underset{(3,1)}{\overset{a^{[0]}}{x}} + \underset{(4,1)}{b^{[1]}}$$

$$\underset{(4,1)}{a^{[1]}} = \sigma(\underset{(4,1)}{z^{[1]}})$$

$$\underset{(1,1)}{z^{[2]}} = \underset{(1,4)}{W^{[2]}} \underset{(4,1)}{a^{[1]}} + \underset{(1,1)}{b^{[2]}}$$

$$\underset{(1,1)}{a^{[2]}} = \sigma(\underset{(1,1)}{z^{[2]}})$$

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One hidden layer Neural Network

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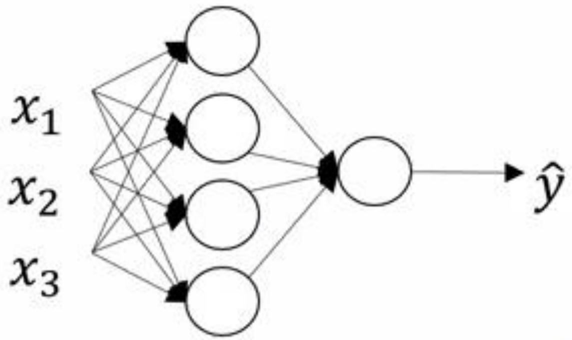
Vectorizing across multiple examples

Vectorizing across multiple examples



$$
\left\{
\begin{aligned}
z^{[1]} &= W^{[1]}x + b^{[1]} \\
a^{[1]} &= \sigma(z^{[1]}) \\
z^{[2]} &= W^{[2]}a^{[1]} + b^{[2]} \\
a^{[2]} &= \sigma(z^{[2]})
\end{aligned}
\right\}
\leftarrow
$$

$$x \longrightarrow a^{[2]} = \hat{y}$$

$$x^{(1)} \longrightarrow a^{[2](1)} = \hat{y}^{(1)}$$

$$x^{(2)} \longrightarrow a^{[2](2)} \quad \hat{y}^{(2)}$$

$$\vdots$$

$$x^{(m)} \longrightarrow a^{[2](m)} \quad \hat{y}^{(m)}$$

$a^{[2](i)}$ ← example i

← layer 2

$\rightarrow$ for $i = 1$ to m,

$$
\boxed{
\begin{aligned}
z^{[1](i)} &= W^{[1]}x^{(i)} + b^{[1]} \\
a^{[1](i)} &= \sigma(z^{[1](i)}) \\
z^{[2](i)} &= W^{[2]}a^{[1](i)} + b^{[2]} \\
a^{[2](i)} &= \sigma(z^{[2](i)})
\end{aligned}
}
$$

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Vectorizing across multiple examples

for i = 1 to m:

$$\boxed{z^{[1](i)}} = W^{[1]}x^{(i)} + b^{[1]}$$

$$\boxed{a^{[1](i)}} = \sigma(z^{[1](i)})$$

$$\boxed{z^{[2](i)}} = W^{[2]}a^{[1](i)} + b^{[2]}$$

$$\boxed{a^{[2](i)}} = \sigma(z^{[2](i)})$$

$$\boxed{\begin{aligned} Z^{[1]} &= W^{[1]}X + b^{[1]} \\ A^{[1]} &= \sigma(Z^{[1]}) \\ Z^{[2]} &= W^{[2]}A^{[1]} + b^{[2]} \\ A^{[2]} &= \sigma(Z^{[2]}) \end{aligned}}$$

$$X = \begin{bmatrix} | & | & & | \\ x^{(1)} & x^{(2)} & \cdots & x^{(m)} \\ | & | & & | \end{bmatrix}$$

(n_x, m)

training examples

hidden units.

$$Z^{[1]} = \begin{bmatrix} | & | & & | \\ z^{[1](1)} & z^{[1](2)} & \cdots & z^{[1](m)} \\ | & | & & | \end{bmatrix}$$

$$A^{[1]} = \begin{bmatrix} | & | & & | \\ a^{[1](1)} & a^{[1](2)} & \cdots & a^{[1](m)} \\ | & | & & | \end{bmatrix}$$

hidden units

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Explanation for vectorized implementation

Justification for vectorized implementation

$z^{[1](1)} = W^{[1]} \underbrace{x^{(1)}} + \cancel{b^{[1]}} \rightarrow 0, \quad z^{[1](2)} = W^{[1]} \underbrace{x^{(2)}} + \cancel{b^{[1]}} \rightarrow 0, \quad z^{[1](3)} = W^{[1]} \underbrace{x^{(3)}} + \cancel{b^{[1]}} \rightarrow 0$

$$W^{[1]} = \begin{bmatrix} \text{———} \\ \text{———} \\ \text{———} \\ \text{———} \end{bmatrix} \qquad W^{[1]}x^{(1)} = \begin{bmatrix} \cdot \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} \qquad W^{[1]}x^{(2)} = \begin{bmatrix} \cdot \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} \qquad W^{[1]}x^{(3)} = \begin{bmatrix} \cdot \\ \cdot \\ \cdot \\ \cdot \end{bmatrix}$$

$$W^{[1]} \underbrace{\begin{bmatrix} | & | & | & \\ x^{(1)} & x^{(2)} & x^{(3)} & \cdots \\ | & | & | & \end{bmatrix}}_{X} = \begin{bmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} = \begin{bmatrix} | & | & | & \\ z^{[1](1)} & z^{[1](2)} & z^{[1](3)} & \cdots \\ | & | & | & \\ +b^{[1]} & +b^{[1]} & +b^{[1]} & \end{bmatrix} = Z^{[1]}$$

$Z^{[1]} = W^{[1]}X + b^{[1]}$

$W^{[1]}x^{(i)} = z^{[1](i)}$

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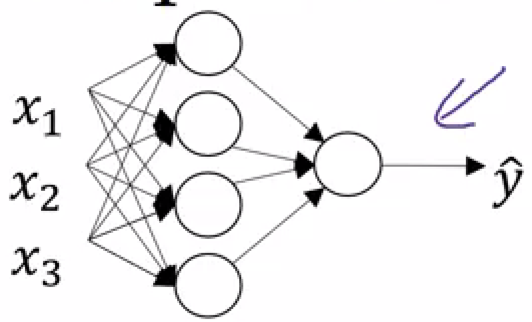
Recap of vectorizing across multiple examples



$$X = \begin{bmatrix} | & | & & | \\ x^{(1)} & x^{(2)} & \cdots & x^{(m)} \\ | & | & & | \end{bmatrix}$$

$$A^{[1]} = \begin{bmatrix} | & | & & | \\ a^{[1](1)} & a^{[1](2)} & \cdots & a^{[1](m)} \\ | & | & & | \end{bmatrix}$$

```
for i = 1 to m
```

$$\boxed{z^{[1](i)} = W^{[1]}x^{(i)} + b^{[1]}}$$

$$a^{[1](i)} = \sigma(z^{[1](i)})$$

$$z^{[2](i)} = W^{[2]}a^{[1](i)} + b^{[2]}$$

$$a^{[2](i)} = \sigma(z^{[2](i)})$$

$A^{[0]}$ $\quad X = a^{[0]} \quad x^{(i)} = a^{[0](i)}$

$$Z^{[1]} = W^{[1]}X + b^{[1]} \leftarrow W^{[1]}A^{[0]} + b^{[1]}$$

$$A^{[1]} = \sigma(Z^{[1]})$$

$$Z^{[2]} = W^{[2]}A^{[1]} + b^{[2]}$$

$$A^{[2]} = \sigma(Z^{[2]})$$

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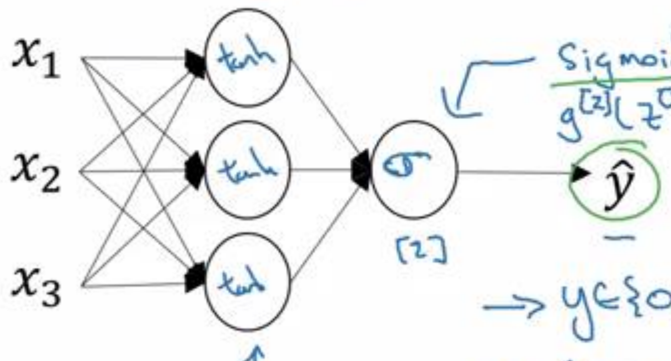
Activation functions

Activation functions

$g^{[1]}(z^{[1]}) = \tanh(z^{[1]})$

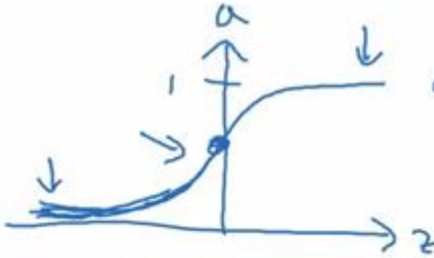


Sigmoid
$g^{[2]}(z^{[2]}) = \sigma(z^{[2]})$

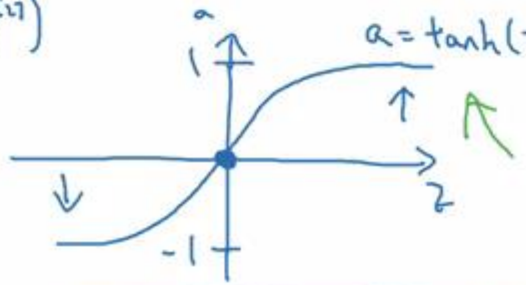
$\rightarrow y \in \{0, 1\}$

$0 \leq \hat{y} \leq 1$

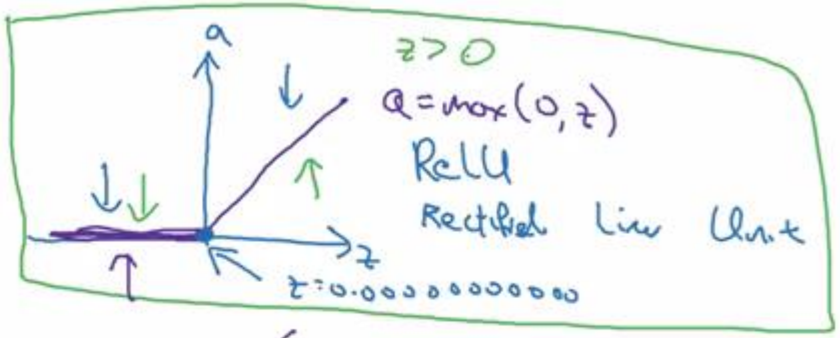
$-1 \qquad 1$



$a = \frac{1}{1+e^{-z}}$



$a = \tanh(z) = \frac{e^{z} - e^{-z}}{e^{z} + e^{-z}}$



Given x:

$$z^{[1]} = W^{[1]}x + b^{[1]}$$

$$\rightarrow a^{[1]} = \cancel{\sigma(z^{[1]})}\ g^{[1]}(z^{[1]})$$

$$z^{[2]} = W^{[2]}a^{[1]} + b^{[2]}$$

$$\rightarrow a^{[2]} = \cancel{\sigma(z^{[2]})}\ g^{[2]}(z^{[2]})$$

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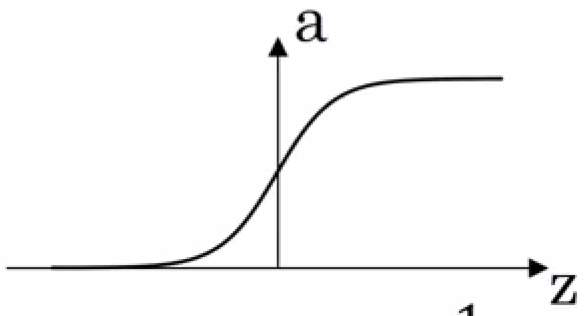
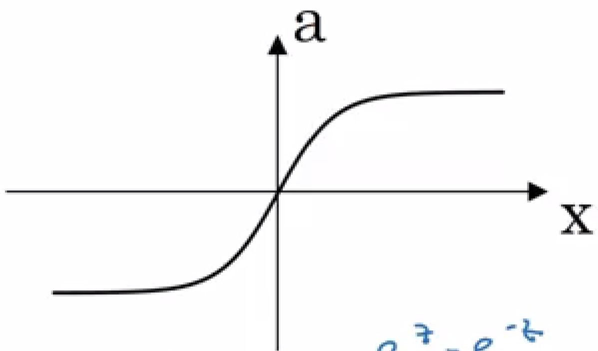
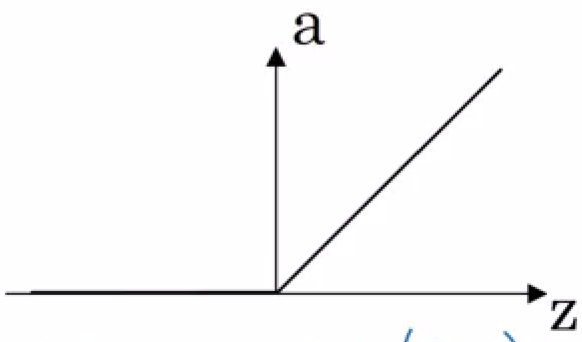
Pros and cons of activation functions



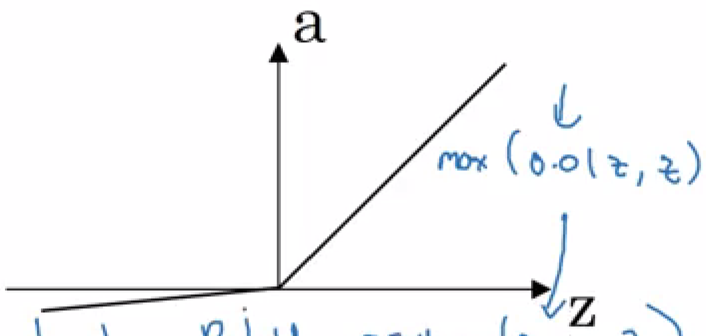
sigmoid: $a = \dfrac{1}{1 + e^{-z}}$



tanh: $a = \dfrac{e^{z} - e^{-z}}{e^{z} + e^{z}}$



ReLU $a = \max(0, z)$



Leaky ReLU $a = \max(0.01z, z)$

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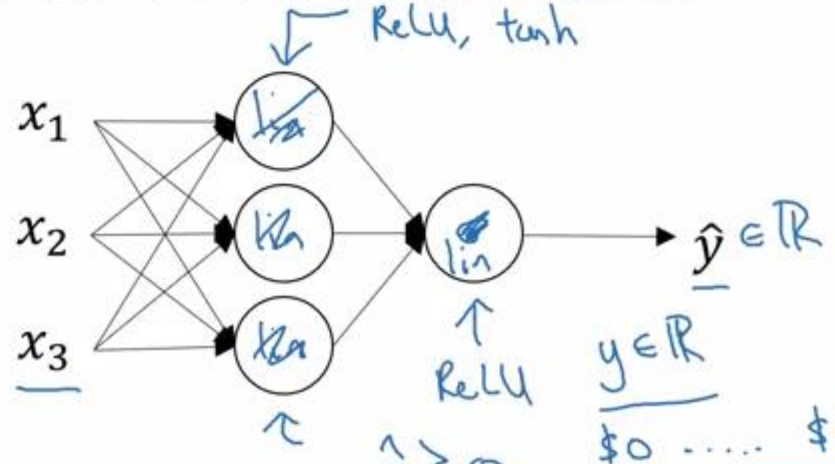
Why do you need non-linear activation functions?

Activation function



$y \in \mathbb{R}$

\$0 ..... \$1,000,000

$\hat{y} \geq 0$..

Given x:

$$\rightarrow z^{[1]} = W^{[1]}x + b^{[1]}$$
$$\rightarrow a^{[1]} = \cancel{g^{[1]}(z^{[1]})}\ z^{[1]}$$
$$\rightarrow z^{[2]} = W^{[2]}a^{[1]} + b^{[2]}$$
$$\rightarrow a^{[2]} = \cancel{g^{[2]}(z^{[2]})}\ z^{[2]}$$

$g(z) = z$

"linear activation function"

$$a^{[1]} = z^{[1]} = W^{[1]}x + b^{[1]}$$
$$a^{[2]} = z^{[2]} = W^{[2]}a^{[1]} + b^{[2]}$$
$$a^{[2]} = W^{[2]}\underbrace{(W^{[1]}x + b^{[1]})}_{a^{[1]}} + b^{[2]}$$
$$= \underbrace{(W^{[2]}W^{[1]})}_{W'}x + \underbrace{(W^{[2]}b^{[1]} + b^{[2]})}_{b'}$$
$$= W'x + b'$$

$g(z) = z$

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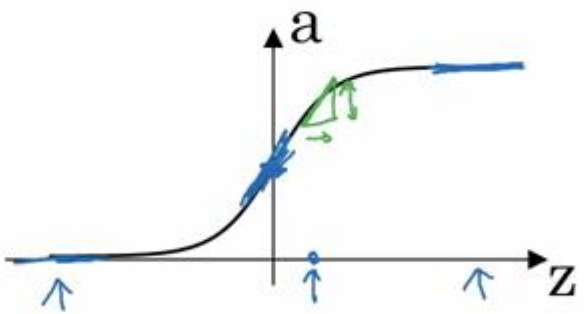
One hidden layer Neural Network

Derivatives of activation functions

Sigmoid activation function



$$\underline{g(z)} = \frac{1}{1+e^{-z}}$$

$$a = g(z) = \frac{1}{1+e^{-z}}$$

$$\boxed{g'(z)} = \boxed{\frac{d}{dz} g(z)} = \text{slope of } g(x) \text{ at } z$$

$$= \frac{1}{1+e^{-z}}\left(1 - \frac{1}{1+e^{-z}}\right)$$

$$= \underbrace{g(z)\left(1-g(z)\right)}$$

$$= \boxed{a\,(1-a)}$$

$$g'(z) = a(1-a)$$

$z = 10.$ $\quad g(z) \approx 1$

$$\frac{d}{dz} g(z) \approx 1\,(1-1) \approx 0$$

$z = -10$ $\quad g(z) \approx 0$

$$\frac{d}{dz} g(z) \approx 0 \cdot (1-0) \approx 0$$

$z = 0$ $\quad g(z) = \frac{1}{2}$

$$\frac{d}{dz} g(z) = \frac{1}{2}\left(1 - \frac{1}{2}\right) = \frac{1}{4}$$

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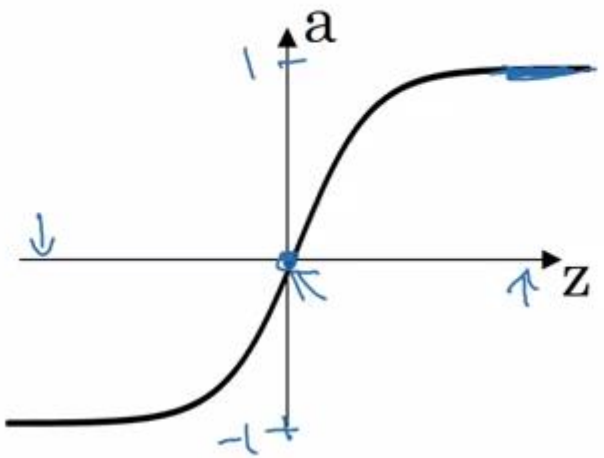
Tanh activation function



$$g(z) = \tanh(z)$$

$$= \frac{e^{z} - e^{-z}}{e^{z} + e^{-z}}$$

$$g'(z) = \frac{d}{dz} g(z) = \text{slope of } g(z) \text{ at } z$$

$$= 1 - (\tanh(z))^2 \leftarrow$$

$$a = g(z), \quad g'(z) = 1 - a^2$$

$z = 10 \quad \tanh(z) \approx 1$

$g'(z) \approx 0$

$z = -10 \quad \tanh(z) \approx -1$

$g'(z) \approx 0$

$z = 0 \quad \tanh(z) = 0$

$g'(z) = 1$

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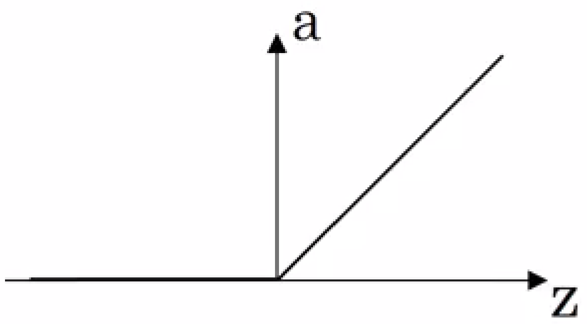
ReLU and Leaky ReLU

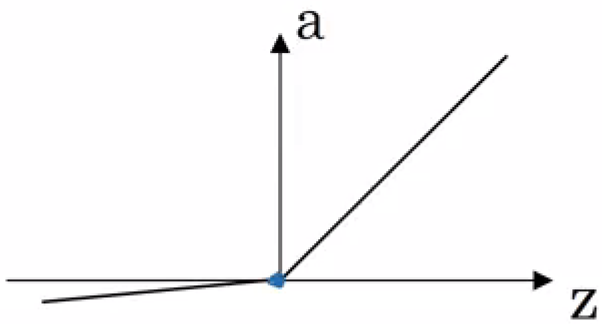


ReLU

$$g(z) = \max(0, z)$$

$$g'(z) = \begin{cases} 0 & \text{if } z < 0 \\ 1 & \text{if } z \geq 0 \\ \cancel{\text{undef} \quad \text{if } z = 0} \end{cases}$$

$z = 0.00000 \cdots 0$



Leaky ReLU

$$g(z) = \max(0.01z, z)$$

$$g'(z) = \begin{cases} 0.01 & \text{if } z < 0 \\ 1 & \text{if } z \geq 0 \end{cases}$$

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One hidden layer Neural Network

Gradient descent for neural networks

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Gradient descent for neural networks

Parameters: $\underset{(n^{[1]}, n^{[0]})}{W^{[1]}}, \underset{(n^{[1]}, 1)}{b^{[1]}}, \underset{(n^{[2]}, n^{[1]})}{W^{[2]}}, \underset{(n^{[2]}, 1)}{b^{[2]}}$ $\qquad n_x = n^{[0]}, n^{[1]}, n^{[2]} = 1$

Cost function: $J(W^{[1]}, b^{[1]}, W^{[2]}, b^{[2]}) = \frac{1}{m} \sum_{i=1}^{n} \mathcal{L}(\underset{a^{[2]}}{\hat{y}}, y)$

Gradient Descent:

→ Repeat {

→ Compute predicts ($\hat{y}^{(i)}$, $i = 1 \ldots, m$)

$dW^{[1]} = \frac{\partial J}{\partial W^{[1]}}$, $db^{[1]} = \frac{\partial J}{\partial b^{[1]}}$, ...

$W^{[1]} := W^{[1]} - \alpha \, dW^{[1]}$

$b^{[1]} := b^{[1]} - \alpha \, db^{[1]}$

$W^{[2]} := \ldots$

Formulas for computing derivatives

Forward propagation:

$$Z^{[1]} = W^{[1]}X + b^{[1]}$$

$$A^{[1]} = g^{[1]}(Z^{[1]})$$

$$Z^{[2]} = W^{[2]}A^{[1]} + b^{[2]}$$

$$A^{[2]} = g^{[2]}(Z^{[2]}) = \sigma(Z^{[2]})$$

Back propagation:

$$dZ^{[2]} = A^{[2]} - Y \qquad Y = [y^{(1)}\ y^{(2)} \dots, y^{(m)}]$$

$$dW^{[2]} = \frac{1}{m} dZ^{[2]} A^{[1]T} \qquad (n^{[2]},)$$

$$db^{[2]} = \frac{1}{m} \text{np.sum}(dZ^{[2]}, \text{axis}=1, \text{keepdims}=\text{True}) \qquad (n^{[2]}, 1)$$

$$dZ^{[1]} = \underbrace{W^{[2]T} dZ^{[2]}}_{(n^{[1]}, m)} * \underbrace{g^{[1]\prime}(Z^{[1]})}_{(n^{[1]}, m)}$$

element-wise product

$$dW^{[1]} = \frac{1}{m} dZ^{[1]} X^T$$

$$db^{[1]} = \frac{1}{m} \text{np.sum}(dZ^{[1]}, \text{axis}=1, \text{keepdims}=\text{True})$$

$(n^{[1]}, 1)$ $(n^{[1]},)$ reshape

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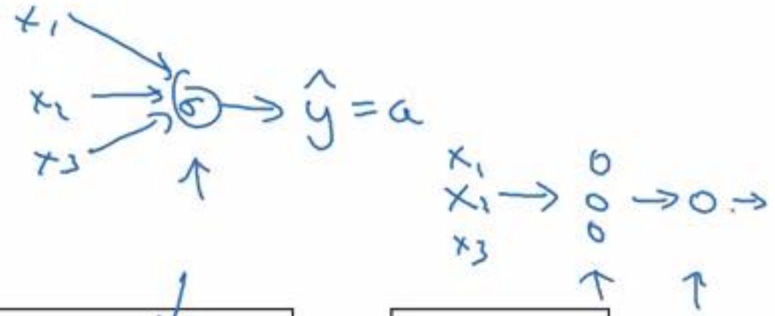
Backpropagation intuition (Optional)

Computing gradients

Logistic regression



$$x,\ w,\ b \to \boxed{z = w^T x + b} \to \boxed{a = \sigma(z)} \to \boxed{\mathcal{L}(a, y)}$$

$dz = a - y$

$dw = dz \cdot x$

$db = dz$

$$\boxed{dz = da \cdot g'(z)}$$

$g(z) = \sigma(z)$

$$\boxed{\underbrace{\frac{\partial \mathcal{L}}{\partial z}}_{\text{"}dz\text{"}} = \underbrace{\frac{\partial \mathcal{L}}{\partial a}}_{\text{"}da\text{"}} \cdot \boxed{\frac{da}{dz}}}$$

$$\frac{d}{dz} g(z) = g'(z)$$

$$da = \frac{d}{da} \mathcal{L}(a, y) = -y \log a - (1-y) \log(1-a)$$

$$= -\frac{y}{a} + \frac{1-y}{1-a}$$

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Neural network gradients

$x_1, x_2, x_3 \rightarrow \circ \rightarrow \circ \rightarrow \hat{y}$

$n_x = n^{[0]}$ $\quad n^{[1]}$ $\quad n^{[2]} = 1$

x, $W^{[1]}$, $b^{[1]}$ $\rightarrow$ $z^{[1]} = W^{[1]}x + b^{[1]}$ $\rightarrow$ $a^{[1]} = \sigma(z^{[1]})$ $\rightarrow$ $z^{[2]} = W^{[2]}a^{[1]} + b^{[2]}$ $\rightarrow$ $a^{[2]} = \sigma(z^{[2]})$ $\rightarrow$ $\mathcal{L}(a^{[2]}, y)$

$W^{[2]}$, $b^{[2]}$

$dW^{[1]}$, $db^{[1]}$ $\quad dW^{[2]}$, $db^{[2]}$

$dz^{[1]} = W^{[2]T} dz^{[2]}$ $\quad da^{[1]} = \cdots$ $\quad dz^{[2]} = a^{[2]} - y$ $\quad da^{[2]}$

$* \; g^{[1]\prime}(z^{[1]})$

element wise product

$dW^{[2]} = dz^{[2]} a^{[1]T}$ $\quad \rightarrow$ "$dw = dz \cdot x$"

$db^{[2]} = dz^{[2]}$

$w^{[1]}$: [———]

$W^{[2]}$ $\quad (n^{[2]}, n^{[1]})$

$\rightarrow z^{[2]}, dz^{[2]}$ $\quad (n^{[2]}, 1)$ $- (1,1)$

$\rightarrow z^{[1]}, dz^{[1]}$ $\quad (n^{[1]}, 1)$

foo $\quad W^{[1]}$

dfoo $\quad dW^{[1]}$

$dW^{[1]} = dz^{[1]} \cdot x^T$ $\quad a^{[0]T}$

$db^{[1]} = dz^{[1]}$

$$dz^{[1]} = \boxed{W^{[2]T} dz^{[2]}} * \boxed{g^{[1]\prime}(z^{[1]})}$$

$$(n^{[1]}, 1) = (n^{[1]}, n^{[2]}) \; (n^{[2]}, 1) * (n^{[1]}, 1)$$

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Summary of gradient descent

$dz^{[2]} = a^{[2]} - y$

$dW^{[2]} = dz^{[2]} a^{[1]^T}$

$db^{[2]} = dz^{[2]}$

$dz^{[1]} = W^{[2]T} dz^{[2]} * g^{[1]\prime}(\mathrm{z}^{[1]})$

$dW^{[1]} = dz^{[1]} x^T$

$db^{[1]} = dz^{[1]}$

Vectorized Implementation:

$z^{[1]} = W^{[1]} x + b^{[1]}$

$a^{[1]} = g^{[1]}(z^{[1]})$

$Z^{[1]} = \begin{bmatrix} | & | & & | \\ z^{[1](1)} & z^{[1](2)} & \cdots & z^{[1](m)} \\ | & | & & | \end{bmatrix}$

$Z^{[1]} = W^{[1]} X + b^{[1]}$

$A^{[1]} = g^{[1]}(Z^{[1]})$

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Summary of gradient descent

$$dz^{[2]} = a^{[2]} - y$$

$$dW^{[2]} = dz^{[2]} a^{[1]^T}$$

$$db^{[2]} = dz^{[2]}$$

$$\underbrace{dz^{[1]}}_{(n^{[1]},1)} = W^{[2]T} dz^{[2]} * g^{[1]\prime}(z^{[1]})$$

$$dW^{[1]} = dz^{[1]} x^T$$

$$db^{[1]} = dz^{[1]}$$

$$dZ^{[2]} = A^{[2]} - Y$$

$$J(\ldots) = \frac{1}{m} \sum_{i=1}^{n} \mathcal{L}(\hat{y}, y)$$

$$dW^{[2]} = \frac{1}{m} dZ^{[2]} A^{[1]^T}$$

$$db^{[2]} = \frac{1}{m} np.sum(dZ^{[2]}, axis = 1, keepdims = True)$$

elementwise product

$$\underbrace{dZ^{[1]}}_{(n^{[1]},m)} = \underbrace{W^{[2]T} dZ^{[2]}}_{(n^{[1]},m)} * \underbrace{g^{[1]\prime}(Z^{[1]})}_{(n^{[1]},m)}$$

$$dW^{[1]} = \frac{1}{m} dZ^{[1]} X^T$$

$$db^{[1]} = \frac{1}{m} np.sum(dZ^{[1]}, axis = 1, keepdims = True)$$

Andrew Ng

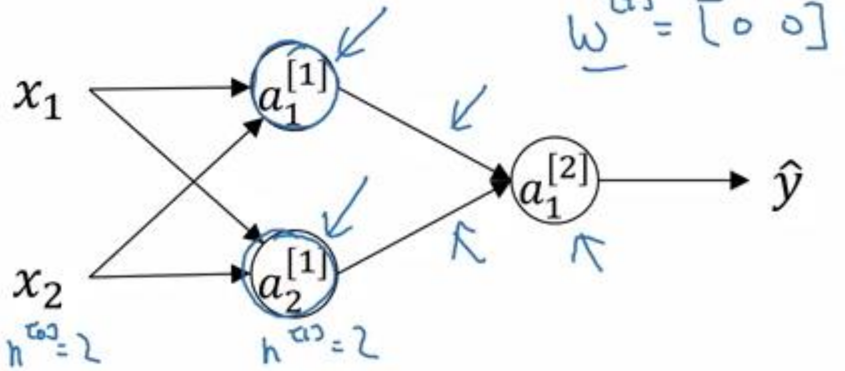
One hidden layer Neural Network

Random Initialization

deeplearning.ai

What happens if you initialize weights to zero?

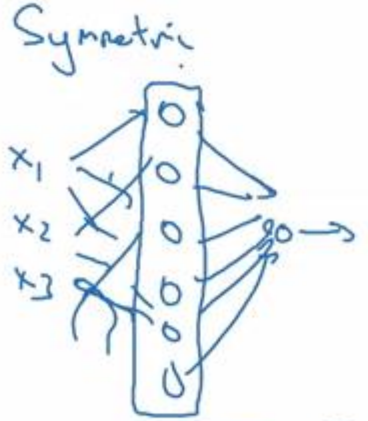
$W^{[2]} = [0 \quad 0]$



$W^{[1]} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$ $b^{[1]} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

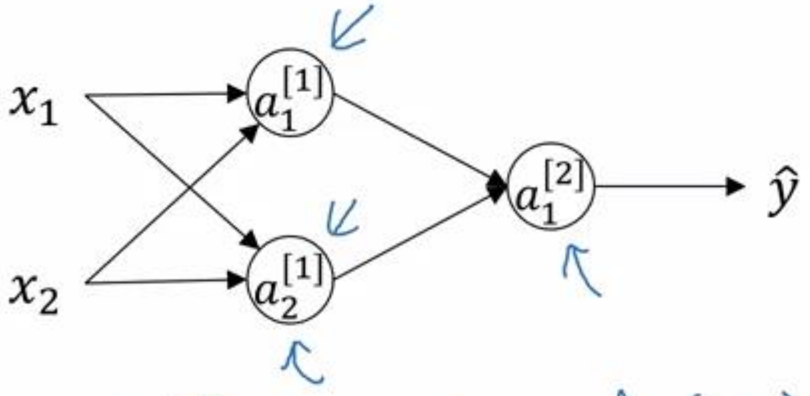
$a_1^{[1]} = a_2^{[1]}$ $dz_1^{[1]} = dz_2^{[1]}$

$dw = \begin{bmatrix} u & v \\ u & v \end{bmatrix}$ $W^{[1]} = W^{[1]} - \alpha dW$



$W^{[1]} = \begin{bmatrix} \cdots\cdots \\ \cdots\cdots \end{bmatrix}$

Random initialization



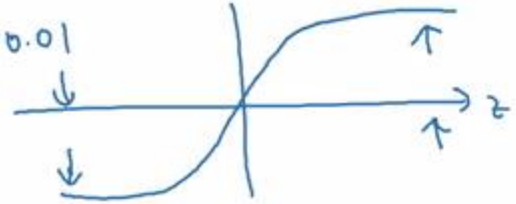
$\rightarrow W^{[1]} = \text{np.random.randn}((2,2)) * \underline{0.01}$

100?

$b^{[1]} = \text{np.zeros}((2,1))$

$W^{[2]} = \text{np.random.randn}((1,2)) * 0.01$

$b^{[2]} = 0$



$\rightarrow z^{[1]} = W^{[1]} x + b^{[1]}$

$a^{[1]} = g^{[1]}(z^{[1]})$

Andrew Ng