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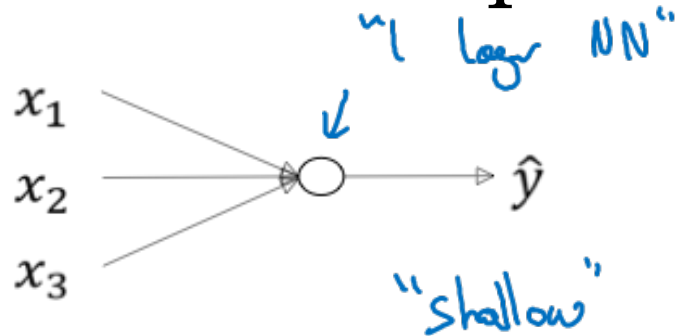


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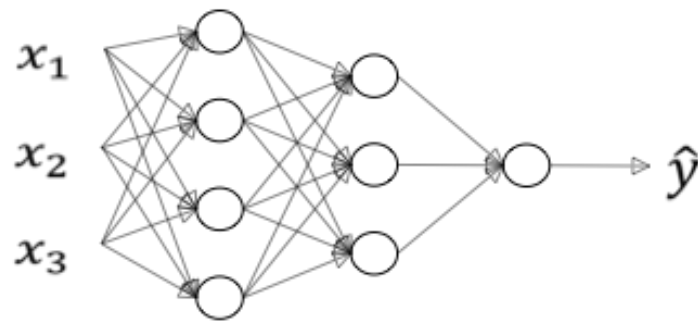
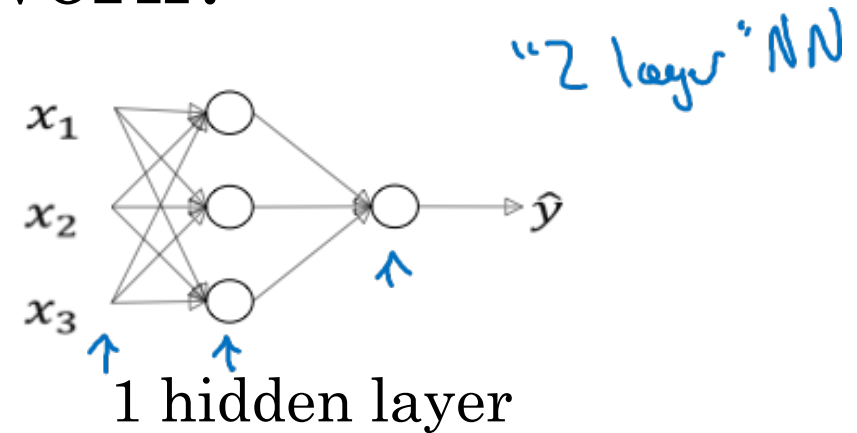
Deep Neural Networks

Deep L-layer
Neural network

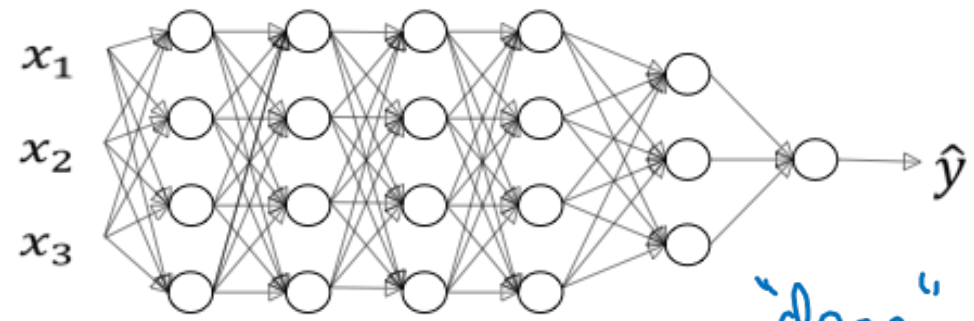
What is a deep neural network?



logistic regression



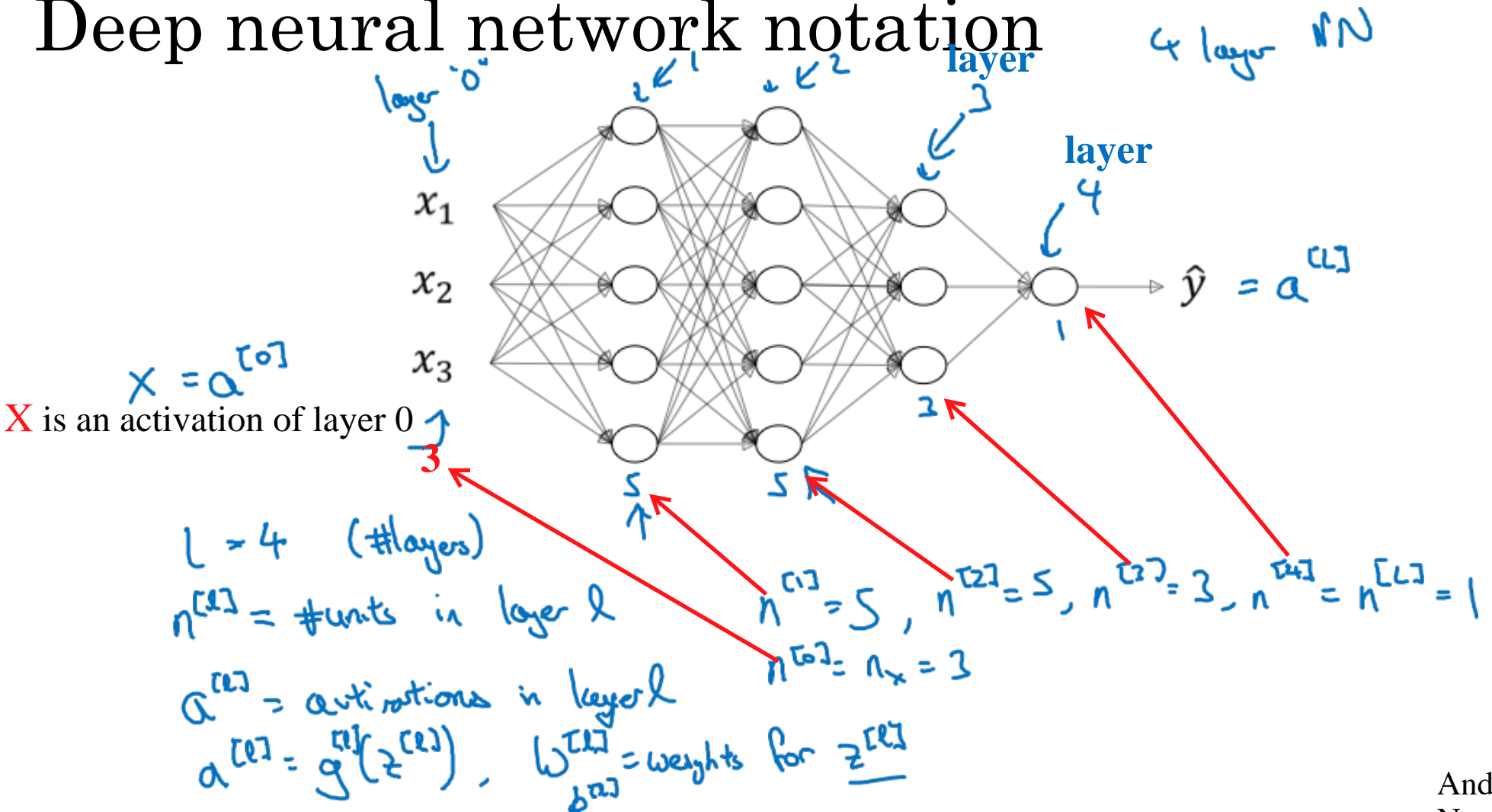
2 hidden layers



5 hidden layers

"deep"

Deep neural network notation



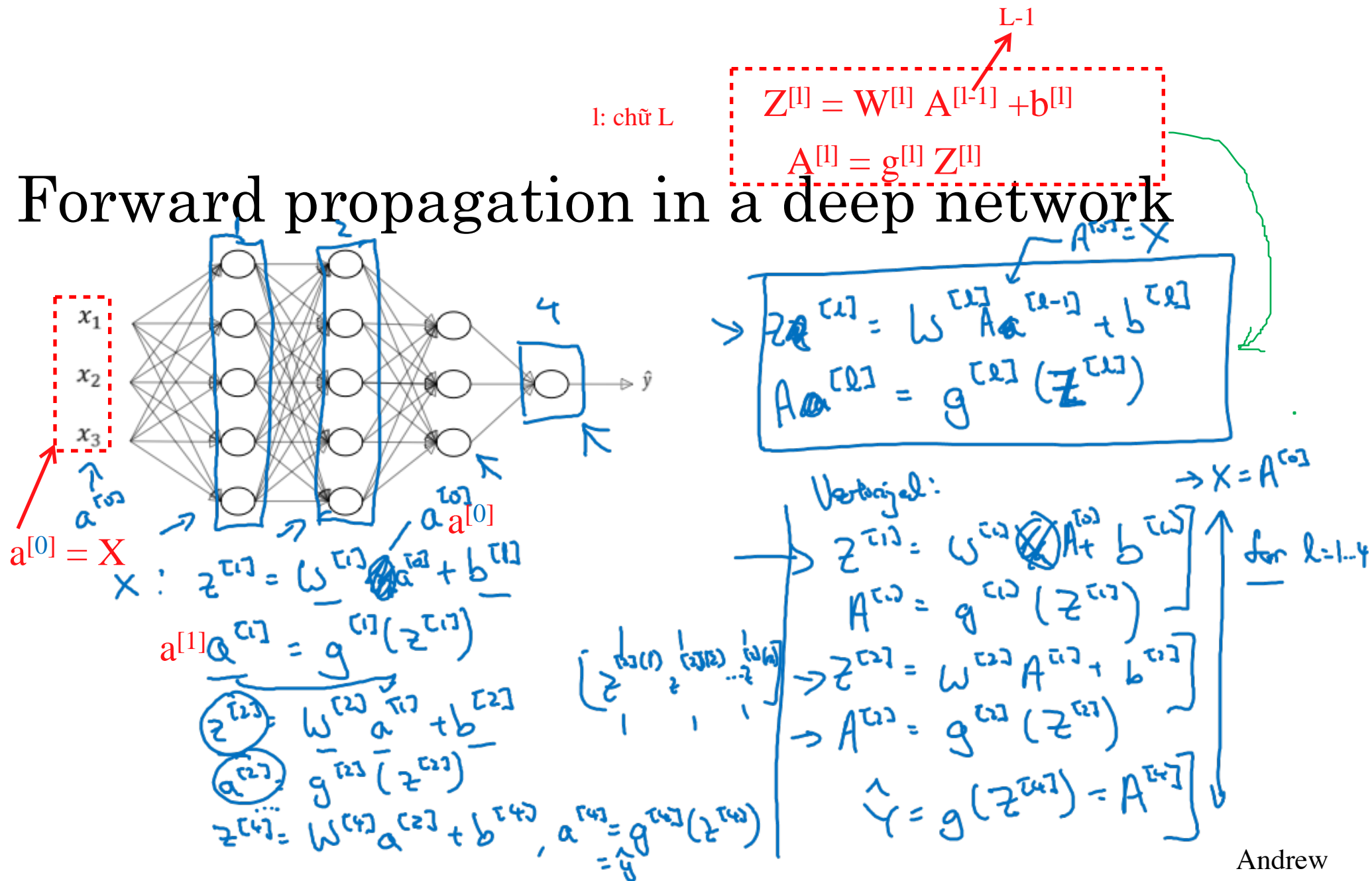


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Deep Neural Networks

Forward Propagation in a Deep Network

Forward propagation in a deep network



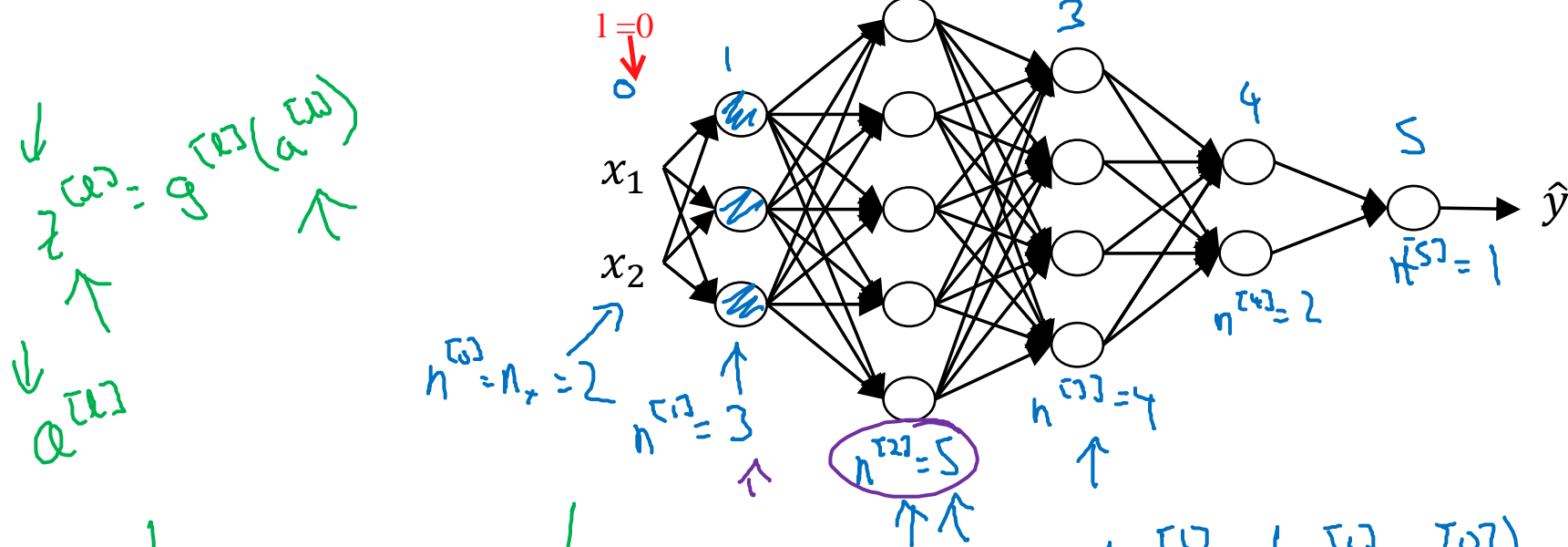


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Deep Neural Networks

Getting your matrix
dimensions right

Parameters $W^{[l]}$ and $b^{[l]}$



$L=5$

$$\begin{aligned} \rightarrow W^{[L]} &: (n^{[L]}, n^{[L-1]}) \\ \rightarrow b^{[L]} &: (n^{[L]}, 1) \\ \rightarrow W^{[L-1]} &: (n^{[L-1]}, n^{[L-2]}) \\ \rightarrow b^{[L-1]} &: (n^{[L-1]}, 1) \end{aligned}$$

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

$(3,1) \leftarrow (3,2) \quad (2,1)$
 $(n^{[1]}, 1) \quad (n^{[1]}, n^{[0]}) \quad (n^{[0]}, 1)$

$$\begin{bmatrix} \vdots \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots \\ \vdots \end{bmatrix} \begin{bmatrix} \vdots \end{bmatrix}$$

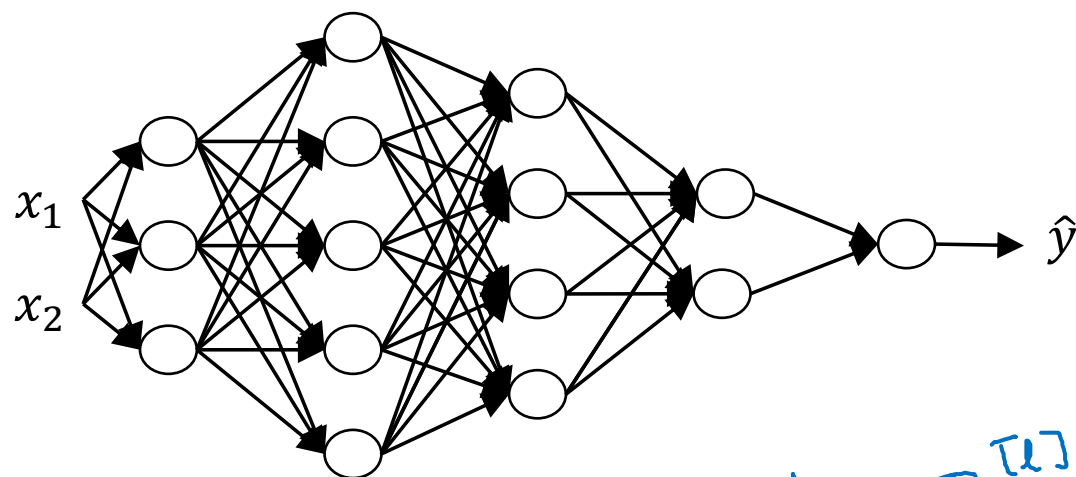
$$W^{[1]}: (n^{[1]}, n^{[0]})$$

$$W^{[2]}: (5, 3) \quad (n^{[2]}, n^{[1]})$$

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

$\rightarrow (5,1) \quad (5,3) \quad (2,1)$
 $W^{[3]}: (4, 5)$
 $W^{[4]}: (2, 4)$, $W^{[5]}: (1, 2)$

Vectorized implementation



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

$(n^{[1]}, 1)$ $(n^{[1]}, n^{[0]})$ $(n^{[0]}, 1)$ $(n^{[1]}, 1)$

$$[z^{1} \ z^{[1](2)} \ \dots \ z^{[1](m)}]$$

$$z^{[1]} = W^{[1]} \cdot X + b^{[1]}$$

$(n^{[1]}, m)$ $(n^{[1]}, n^{[0]})$ $(n^{[0]}, m)$ $(n^{[1]}, 1)$
 $(n^{[0]}, m)$

$$z^{[2]}, a^{[2]} : (n^{[2]}, 1)$$

$$z^{[2]}, A^{[2]} : (n^{[2]}, m)$$

$$l=0 \quad A^{[0]} = X = (n^{[0]}, m)$$

$$dz^{[2]}, dA^{[2]} : (n^{[2]}, m)$$

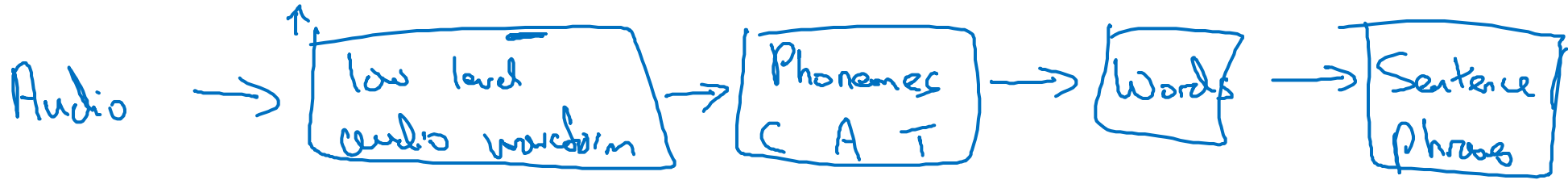
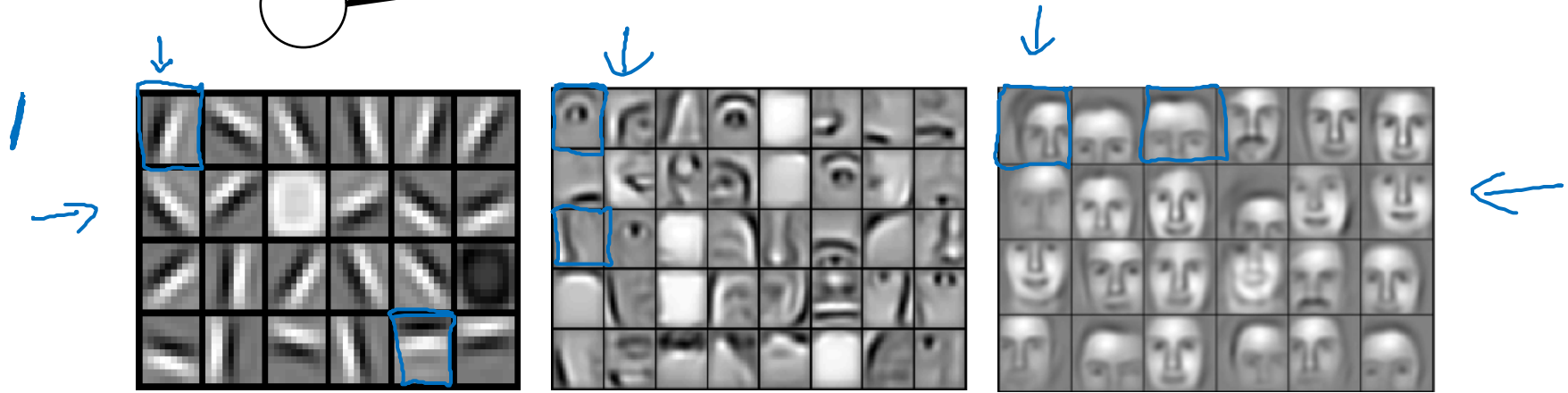
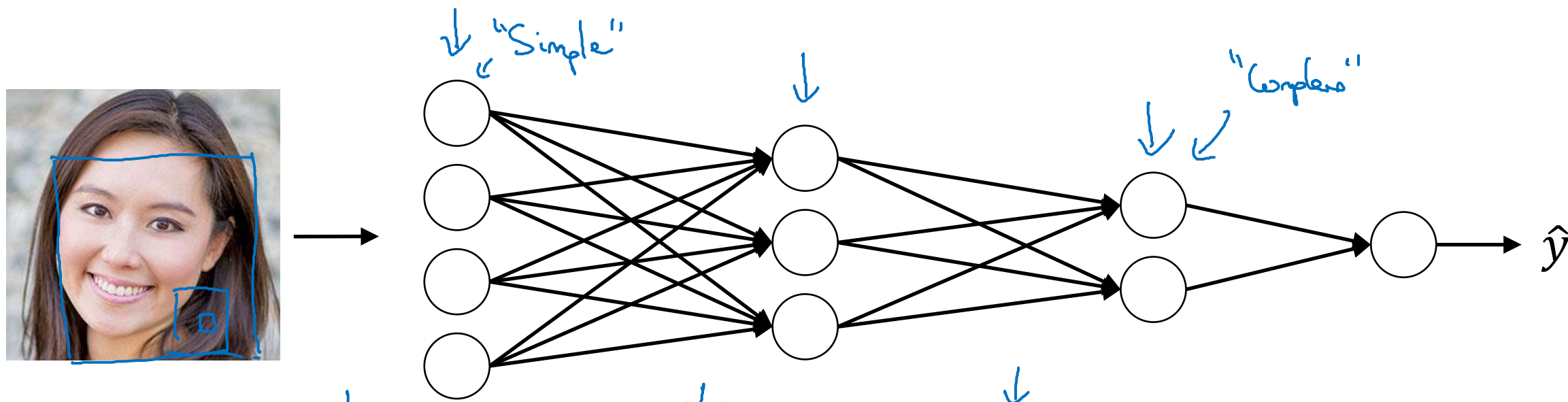


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Deep Neural Networks

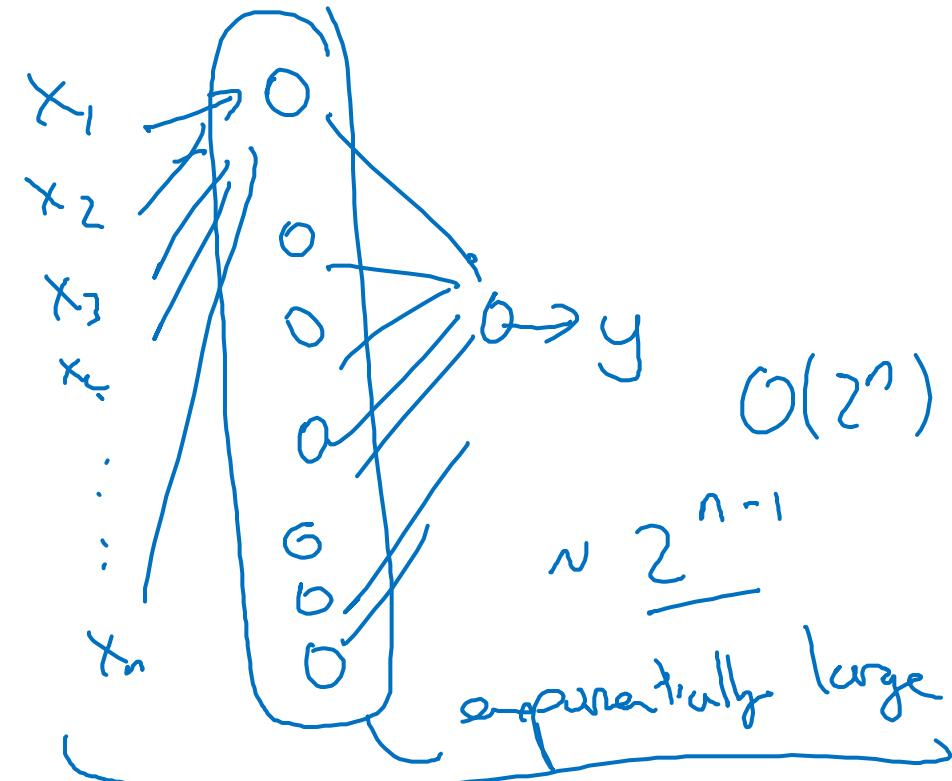
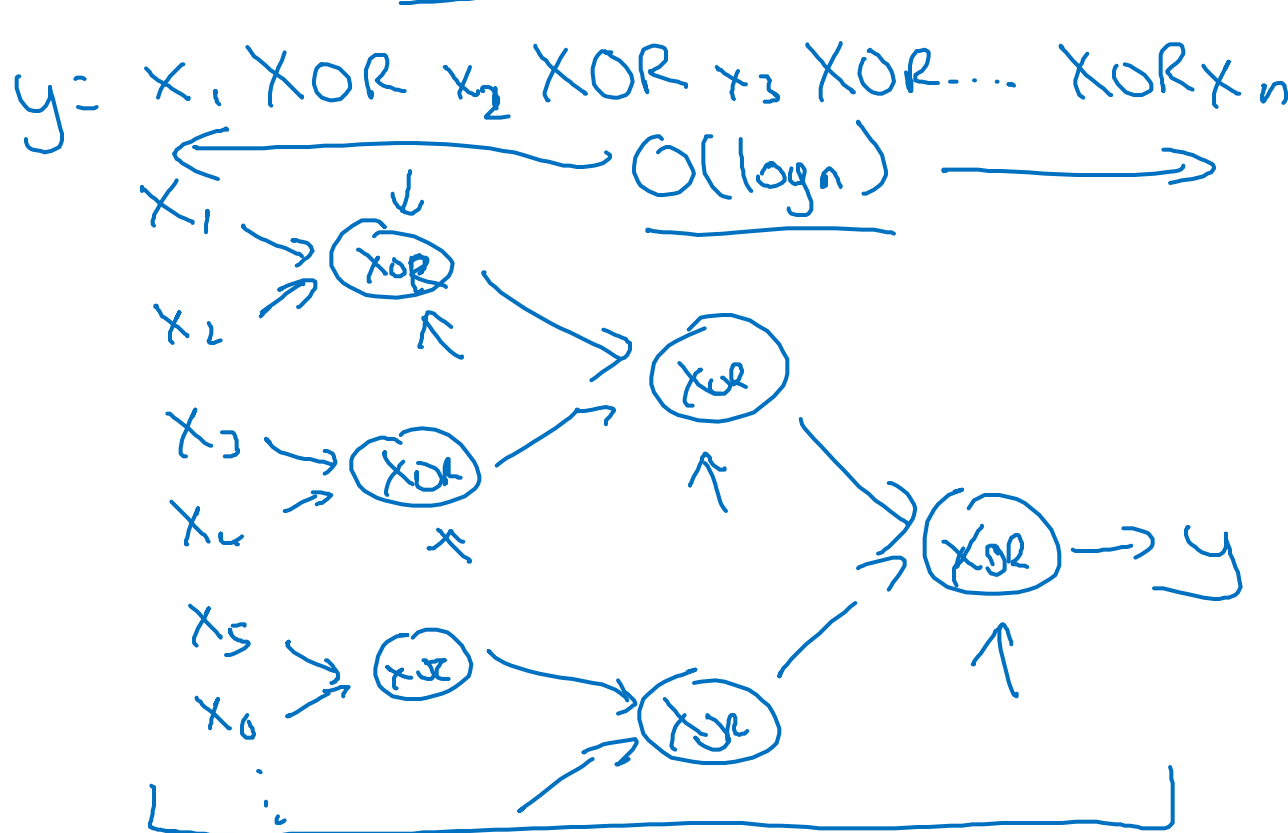
Why deep
representations?

Intuition about deep representation



Circuit theory and deep learning

Informally: There are functions you can compute with a “small” L-layer deep neural network that shallower networks require exponentially more hidden units to compute.



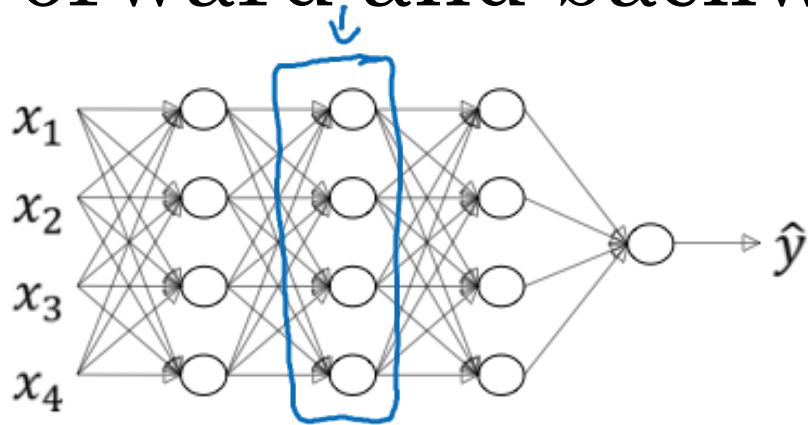


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Deep Neural Networks

Building blocks of
deep neural networks

Forward and backward functions



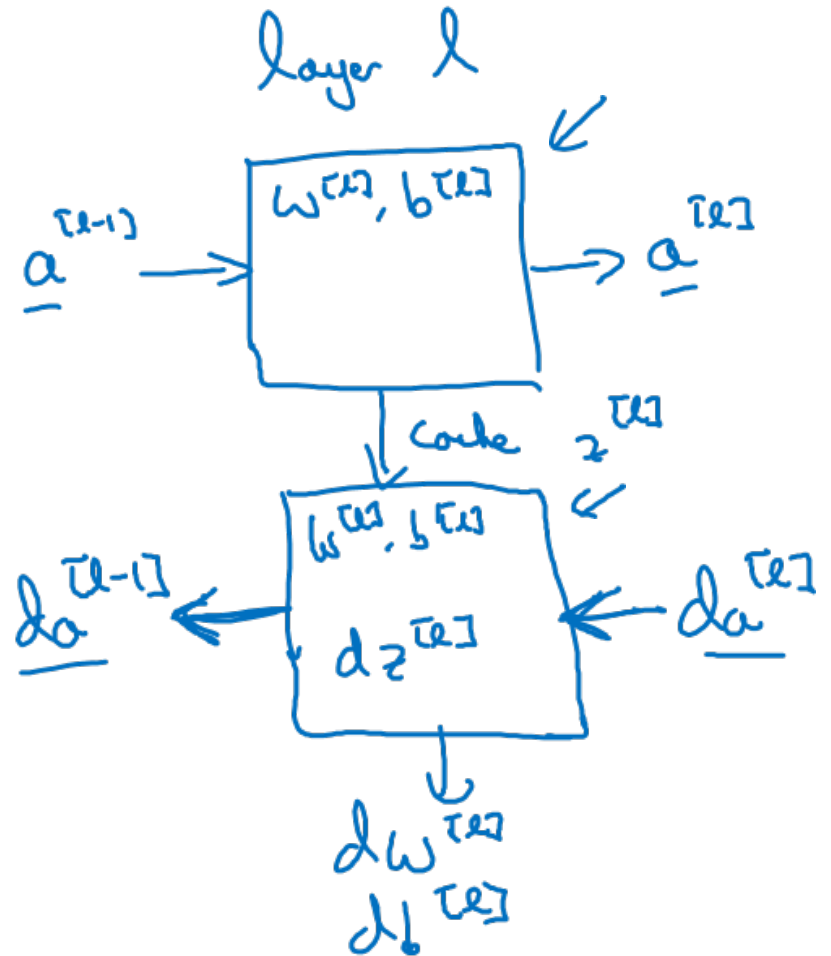
layer l : $W^{[l]}, b^{[l]}$

→ Forward: Input $a^{[l-1]}$, output $a^{[l]}$

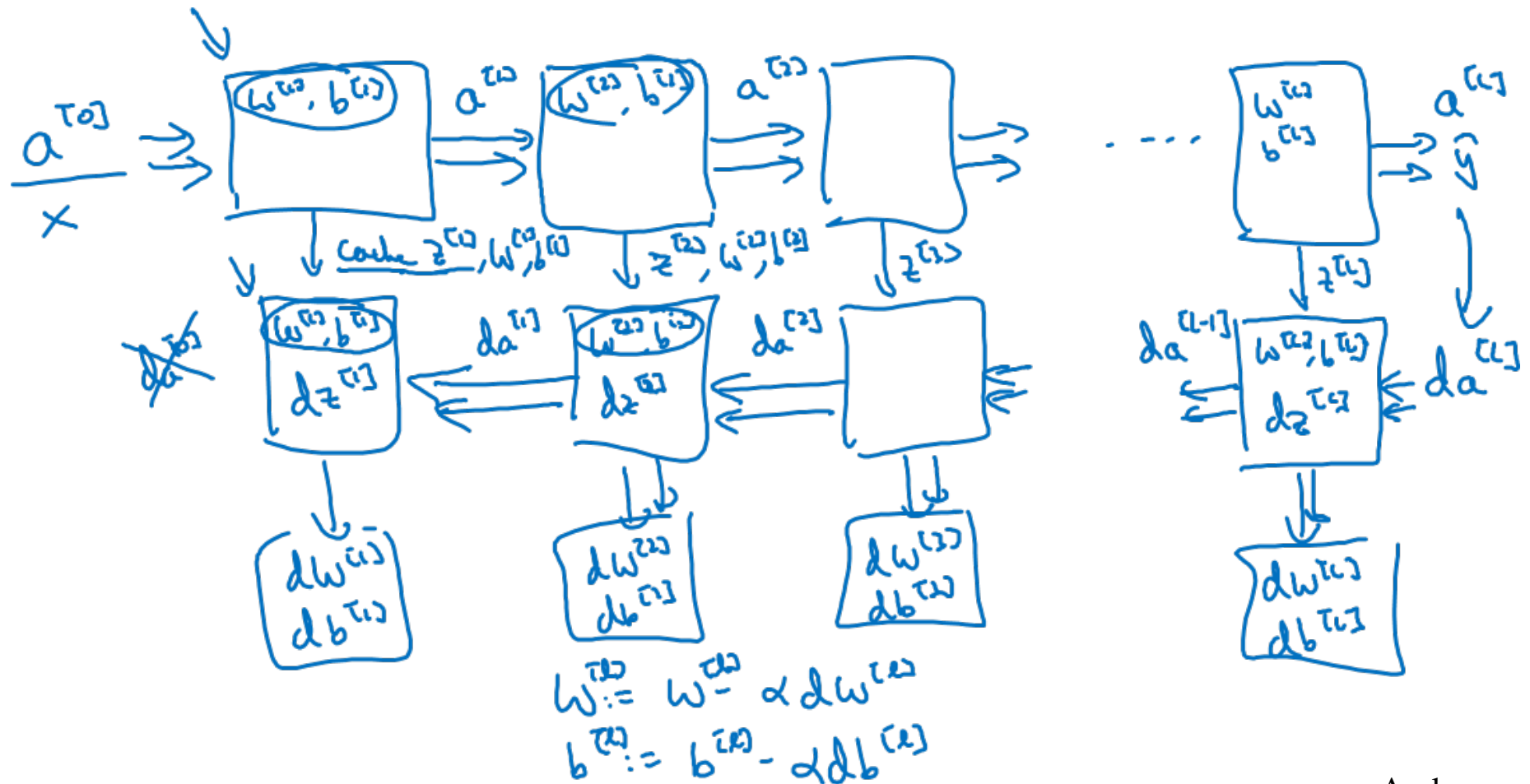
$$z^{[l]} = W^{[l]} a^{[l-1]} + b^{[l]} \quad \text{cache } z^{[l]}$$

$$\underline{a}^{[l]} = g^{[l]}(z^{[l]})$$

→ Backward: Input $da^{[l]}$, output $da^{[l-1]}$
 cache $(z^{[l]})$
 $\frac{dL}{dW^{[l]}}$
 $\frac{dL}{db^{[l]}}$



Forward and backward functions





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Deep Neural Networks

Forward and backward
propagation

Backward propagation for layer l

→ Input $da^{[l]}$

→ Output $da^{[l-1]}, dW^{[l]}, db^{[l]}$

$$dz^{[l]} = da^{[l]} * g^{[l]'}(z^{[l]})$$

$$dW^{[l]} = dz^{[l]} \cdot \underline{a^{[l-1]}}$$

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

$$da^{[l-1]} = W^{[l]T} \cdot dz^{[l]}$$

$$dz^{[l]} = W^{[l+1]T} dz^{[l+1]} * g^{[l]'}(z^{[l]})$$

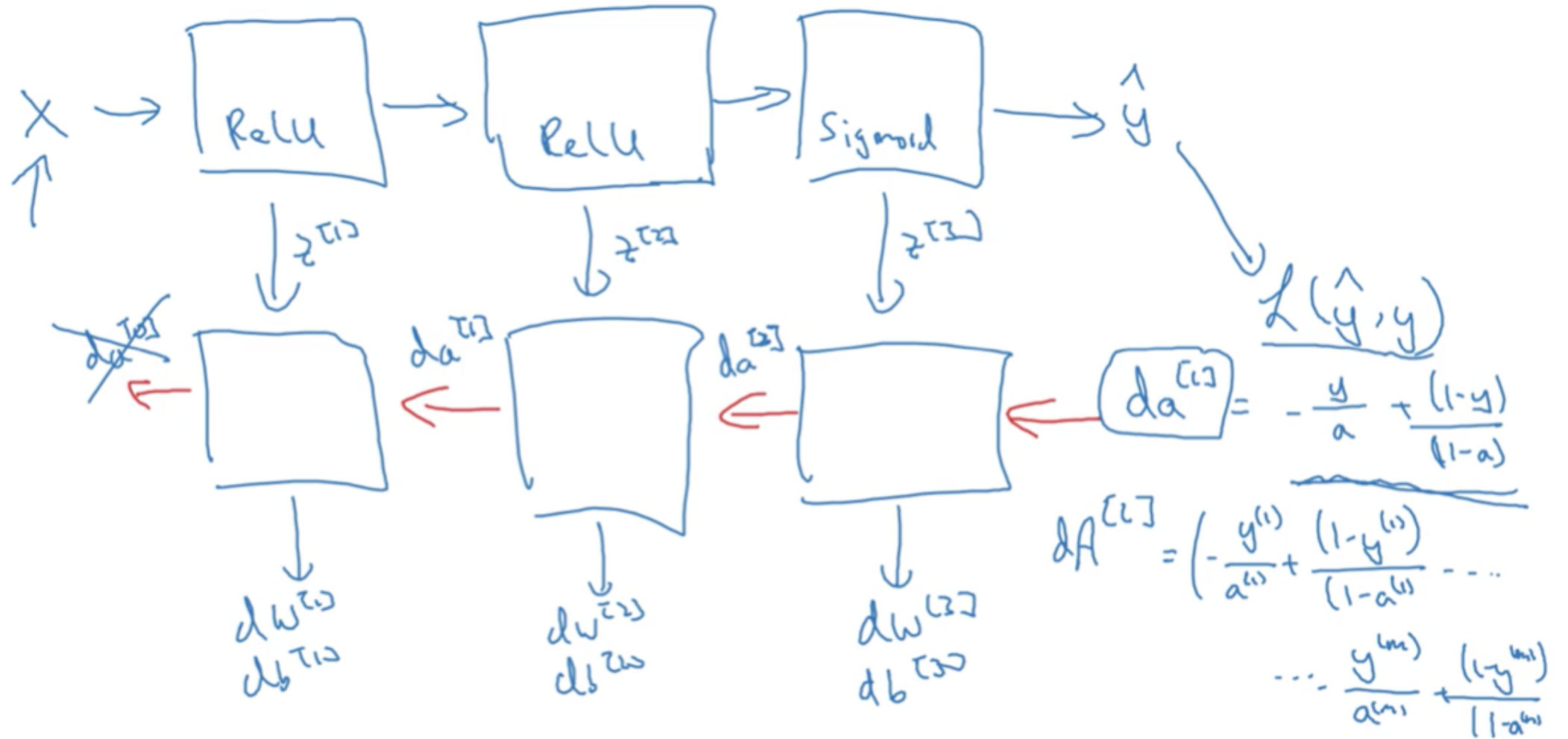
$$dz^{[l]} = dA^{[l]} * g^{[l]'}(z^{[l]})$$

$$dW^{[l]} = \frac{1}{n} dz^{[l]} \cdot A^{[l-1]T}$$

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

$$dA^{[l-1]} = W^{[l]T} \cdot dz^{[l]}$$

Summary





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Deep Neural Networks

Parameters vs Hyperparameters

What are hyperparameters?

Parameters: $W^{[1]}, b^{[1]}, W^{[2]}, b^{[2]}, W^{[3]}, b^{[3]} \dots$

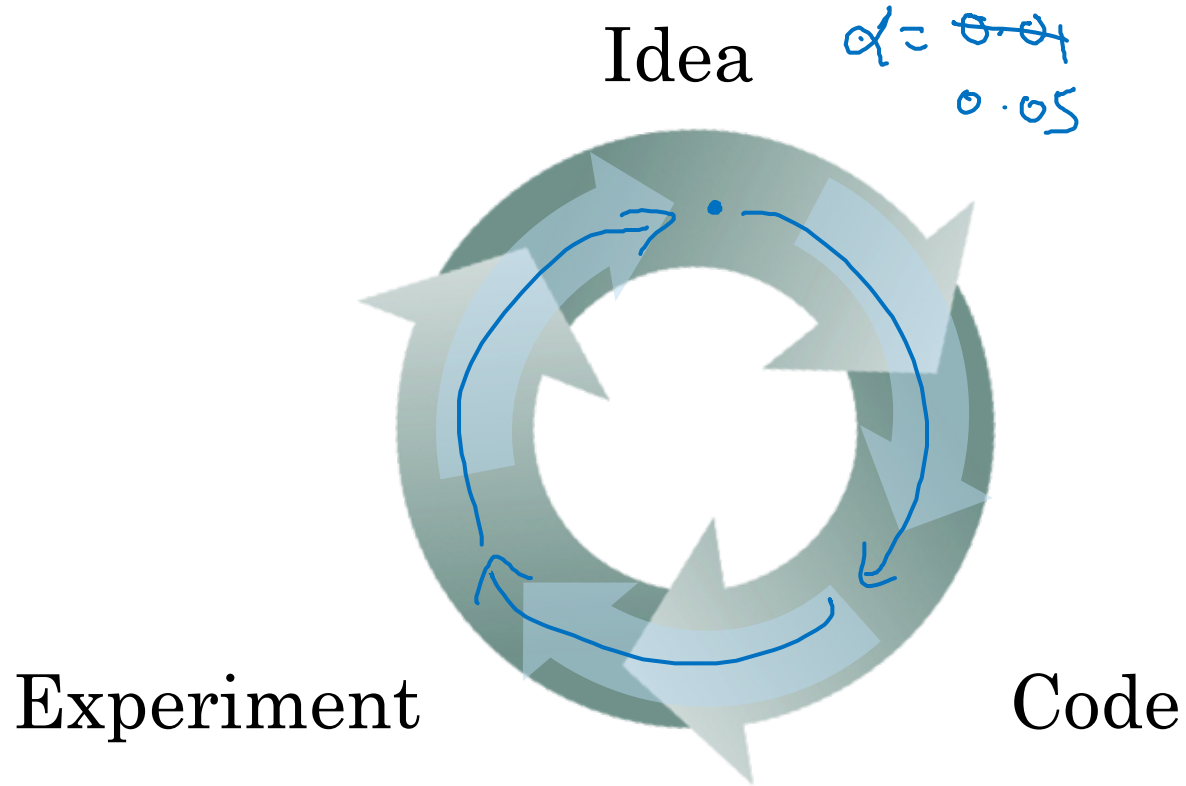


Hyperparameters:

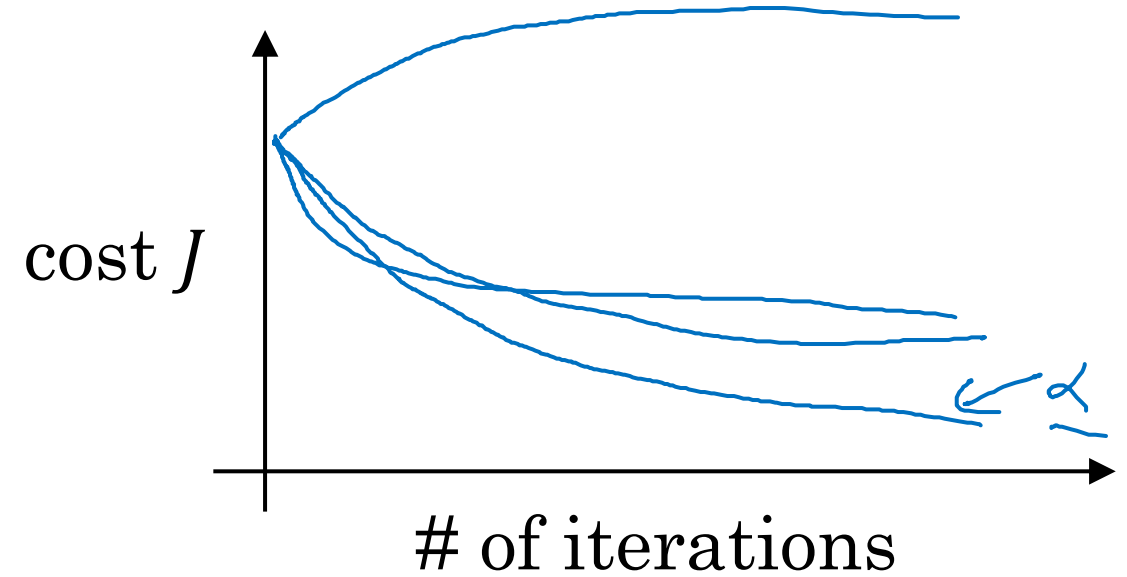
- learning rate α
- τ
- #iterations
- #hidden layers L
- # hidden units $n^{[1]}, n^{[2]}, \dots$
- choice of activation function

Later: Momentum, mini-batch size, regularizations, ...

Applied deep learning is a very empirical process



Vision, Speech, NLP, Ad, Search, Recommendation.





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Deep Neural Networks

What does this
have to do with
the brain?

Forward and backward propagation

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

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

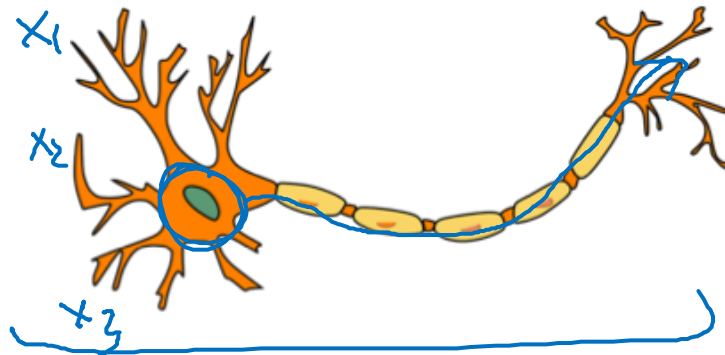
$$Z^{[2]} = W^{[2]}A^{[1]} + b^{[2]}$$

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

$$\vdots$$

$$A^{[L]} = g^{[L]}(Z^{[L]}) = \hat{Y}$$

"It's like the brain"



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

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

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

$$dZ^{[L-1]} = dW^{[L]T} dZ^{[L]} g'^{[L]}(Z^{[L-1]})$$

$$\vdots$$
$$dZ^{[1]} = dW^{[L]T} dZ^{[2]} g'^{[1]}(Z^{[1]})$$

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

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