Week 7(1/3)

Feed-forward Neural Network

Machine Learning with Python

Handong Global University
Prof. Youngsup Kim
idebtor@gmail.com

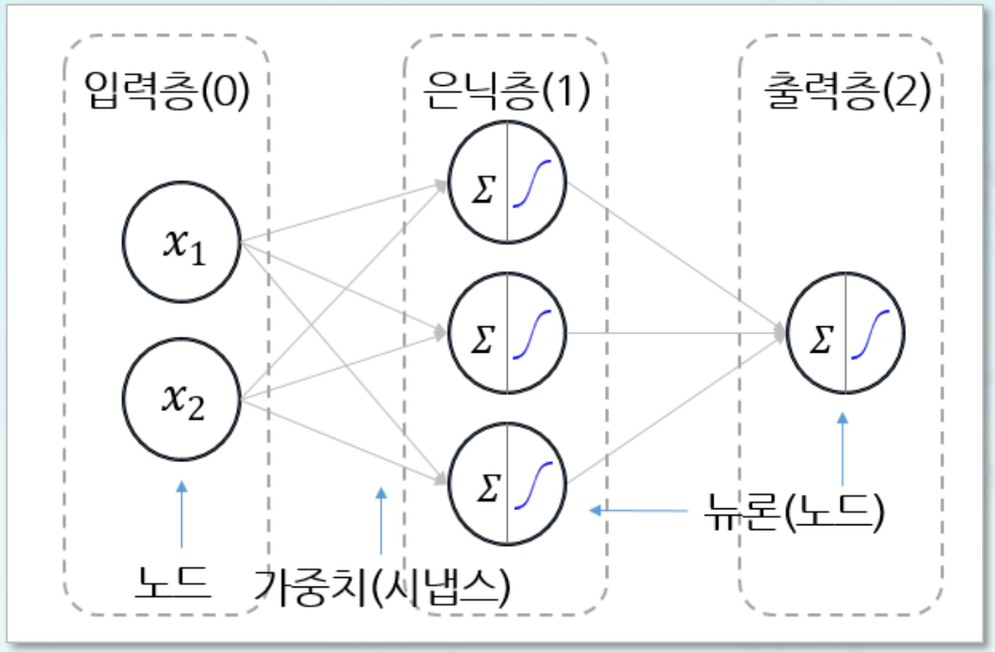
Feed-forward Neural Network

- Objectives
  - Understanding Feed-forward NN Processing.

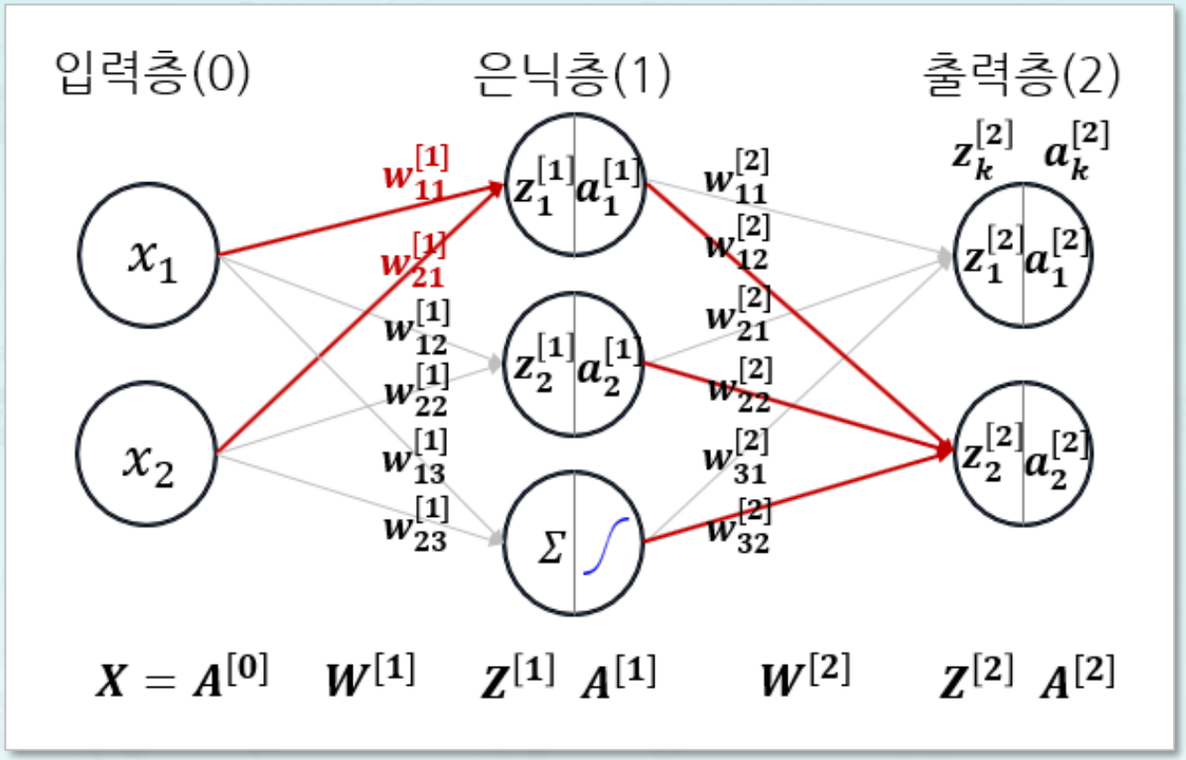
- Contents
  - Feed-forward NN Notations
  - Feed-forward NN Signal Processing
  - Weights Notation
  - Feed-forward NN Example

1. Feed-forward Neural Network: Notations

- **Multi-layer Neural Network**

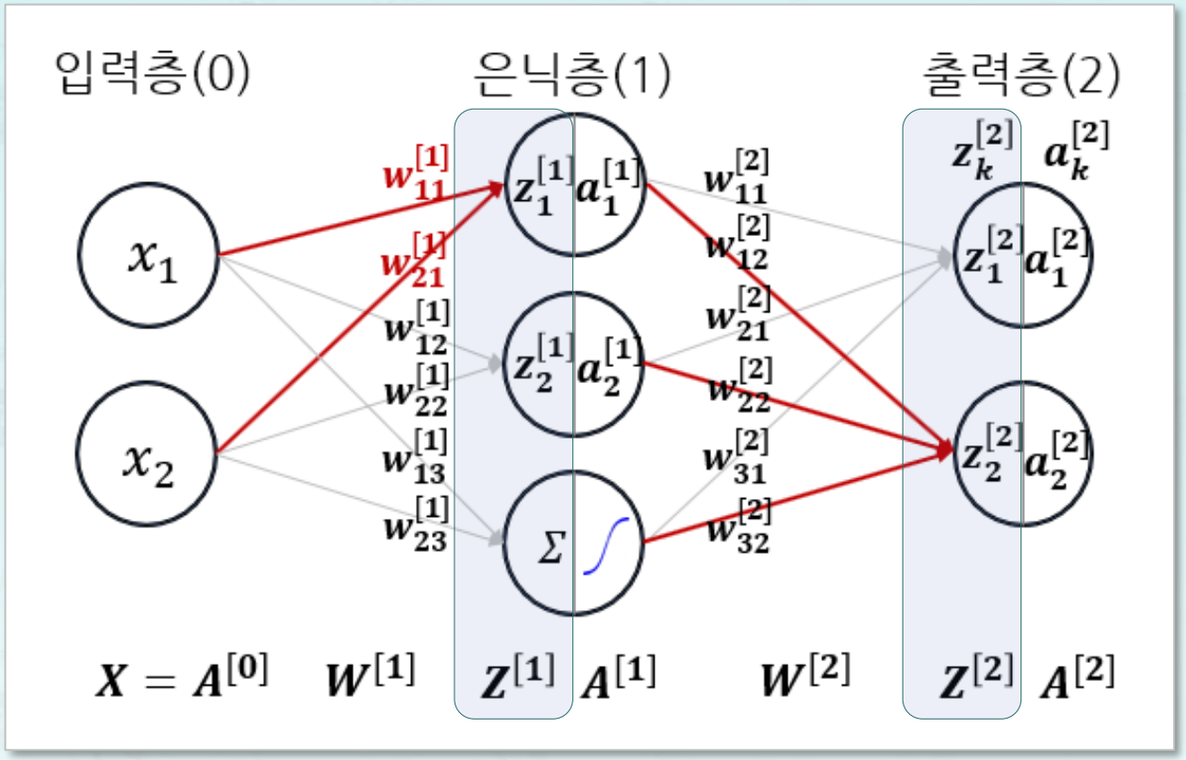


1. Feed-forward Neural Network: Notations



1. Feed-forward Neural Network: Notations

- Z: Input to Neuron
- A: Output from Neuron
- L: Total Number Of Layers
- l: Layer Number(lowercase L)



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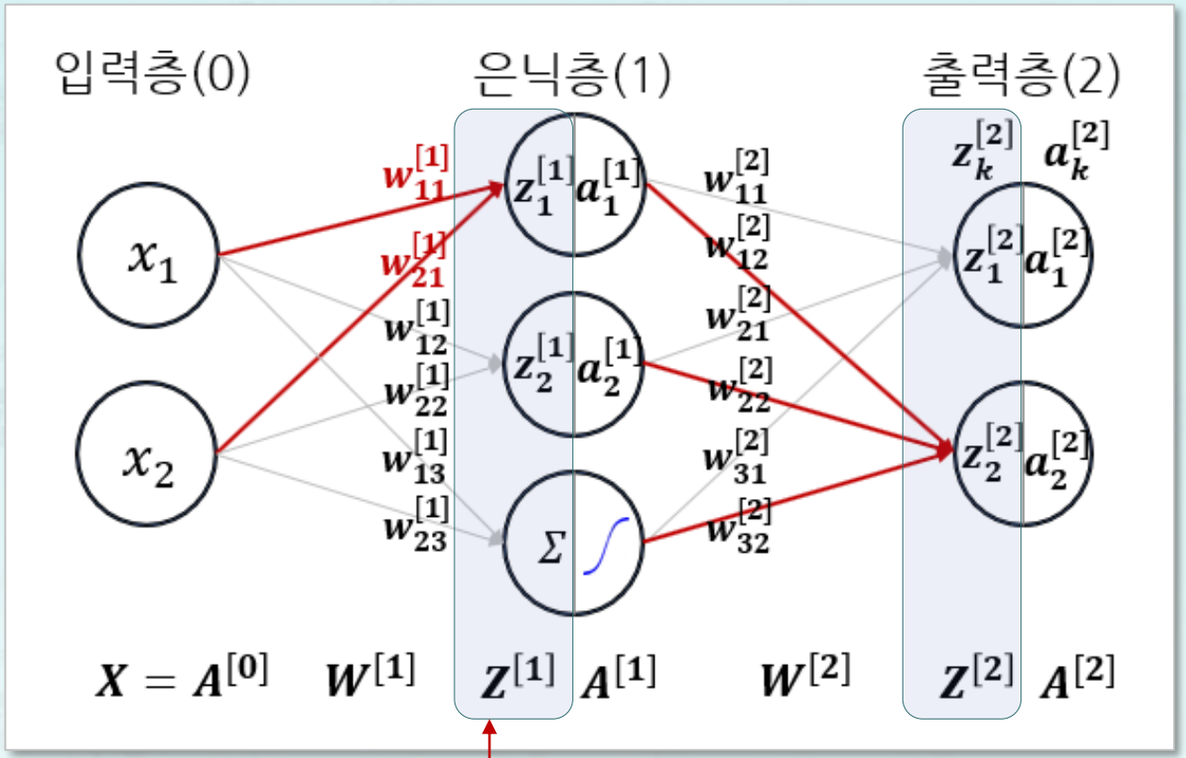
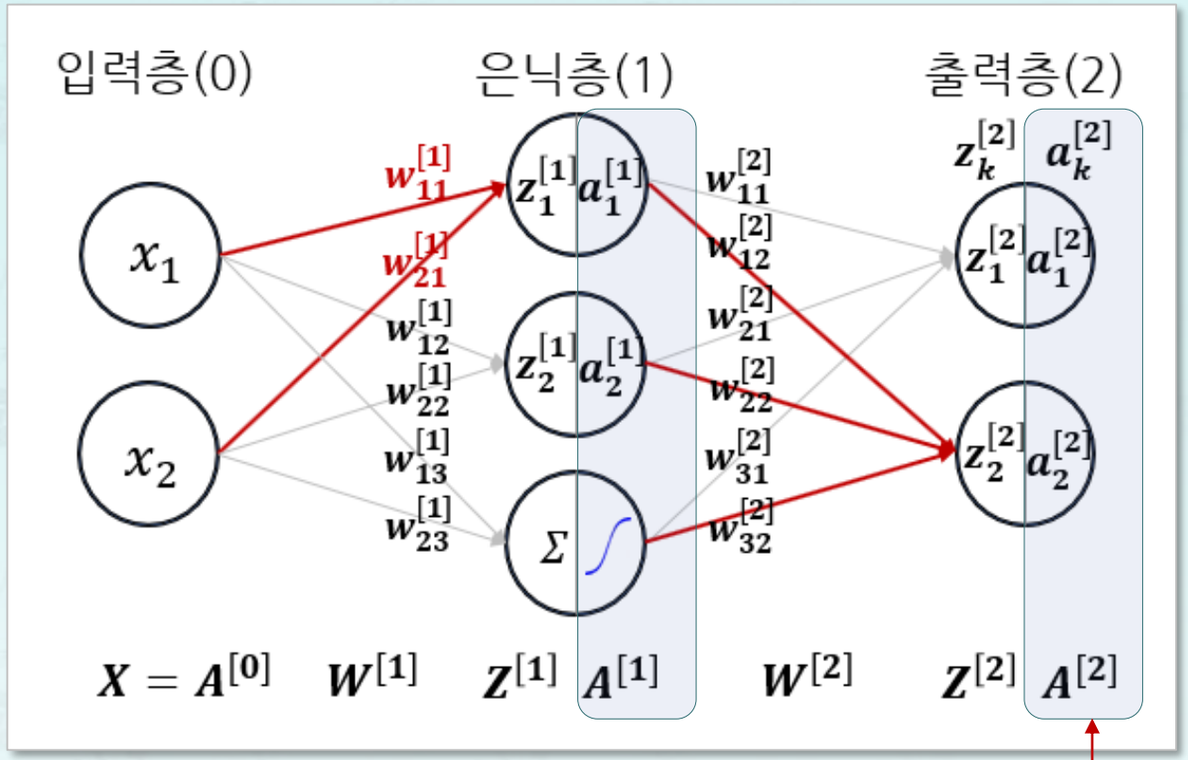


- $Z^{[1]}$: Input to Hidden Layer(1)

1. Feed-forward Neural Network: Notations

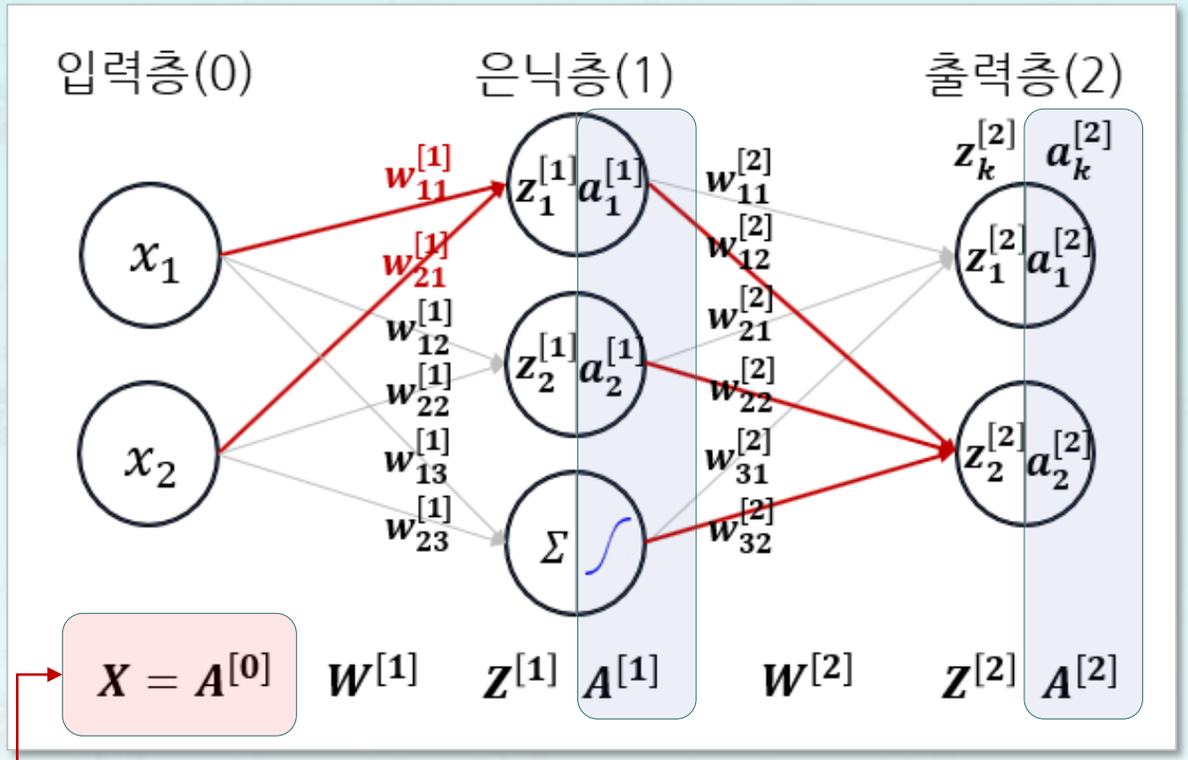
- Z: Input to Neuron
- A: Output from Neuron
- L: Total Number Of Layers
- l: Layer Number(lowercase L)



- $Z^{[1]}$: Input to Hidden Layer(1)
- $A^{[2]}$: Output from Output Layer(2)

1. Feed-forward Neural Network: Notations

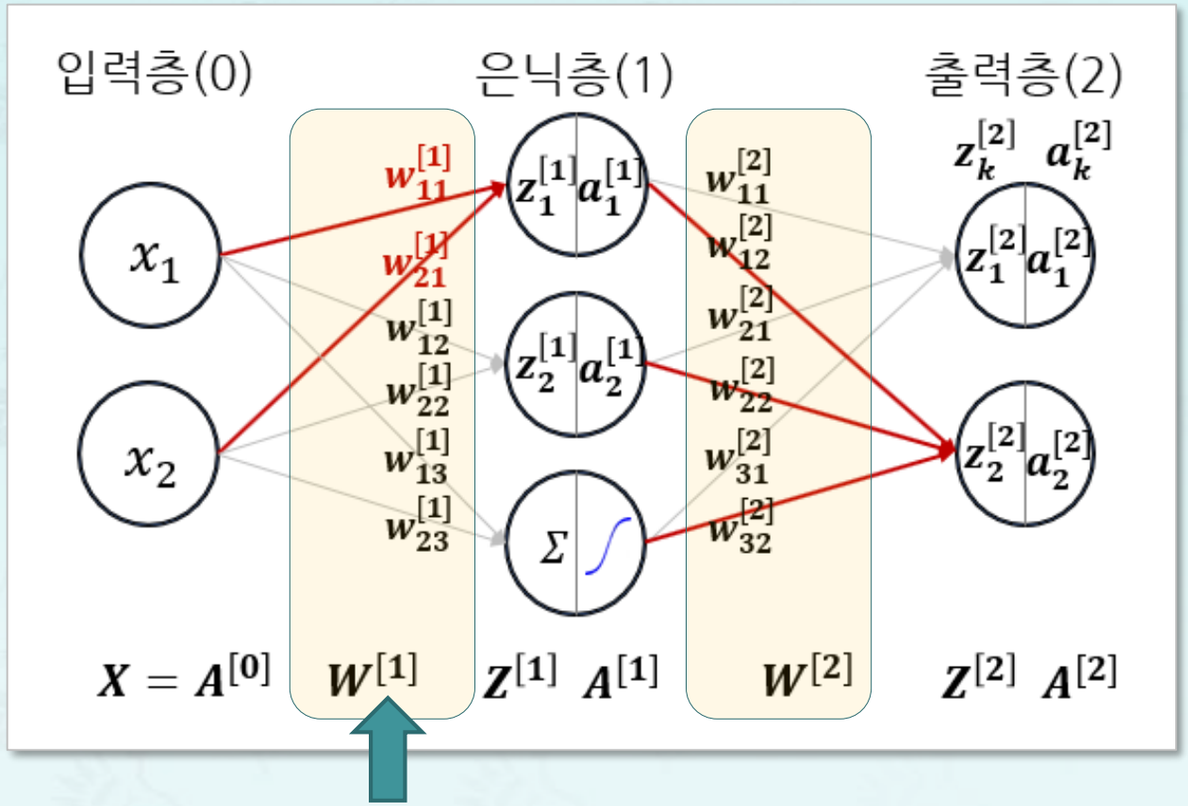
- Z: Input to Neuron
- A: Output from Neuron
- L: Total Number Of Layers
- l: Layer Number(lowercase L)



- $Z^{[1]}$: Input to Hidden Layer(1)
- $A^{[2]}$: Output from Output Layer(2)
- $A^{[0]}$: Output from Input Layer(0)

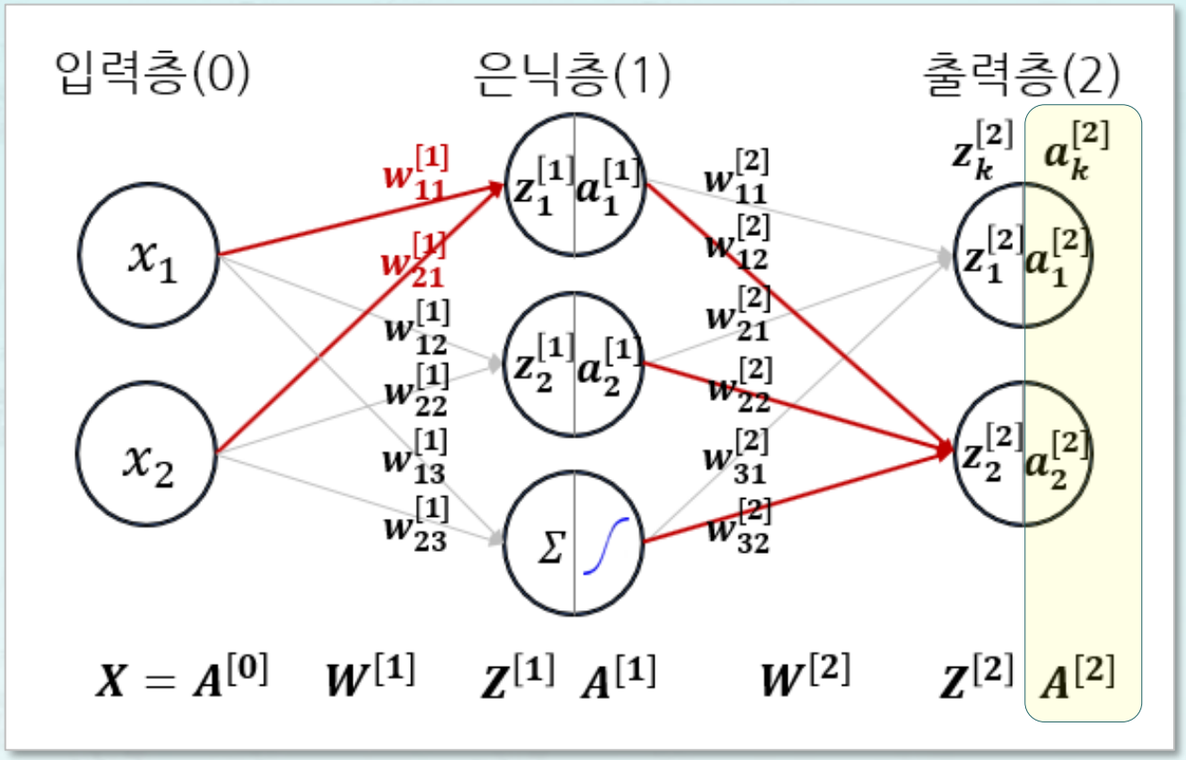
1. Feed-forward Neural Network: Notations

- Z: Input to Neuron
- A: Output from Neuron
- L: Total Number Of Layers
- I: Layer Number
- W: Weights



1. Feed-forward Neural Network: Notations

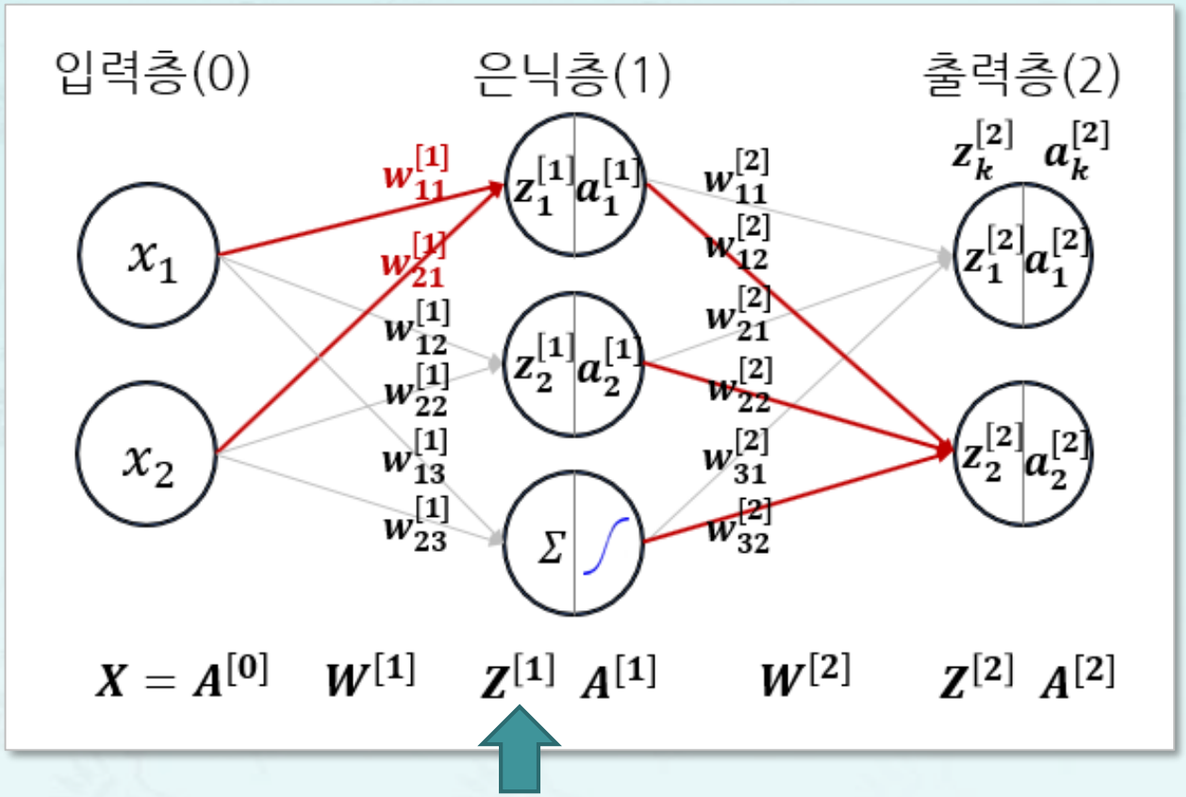
- Z: Input to Neuron
- A: Output from Neuron
- L: Total Number Of Layers
- l: Layer Number
- W: Weights
- $\hat{y}$: Output predicted



- $\hat{y} = A^{[2]}$

1. Feed-forward Neural Network: Signal Processing

- **Z:** $\sum(\text{Weights} * \text{Input})$
  - **Net input or Weighted sum**



1. Feed-forward Neural Network: Signal Processing

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  - **Net input**
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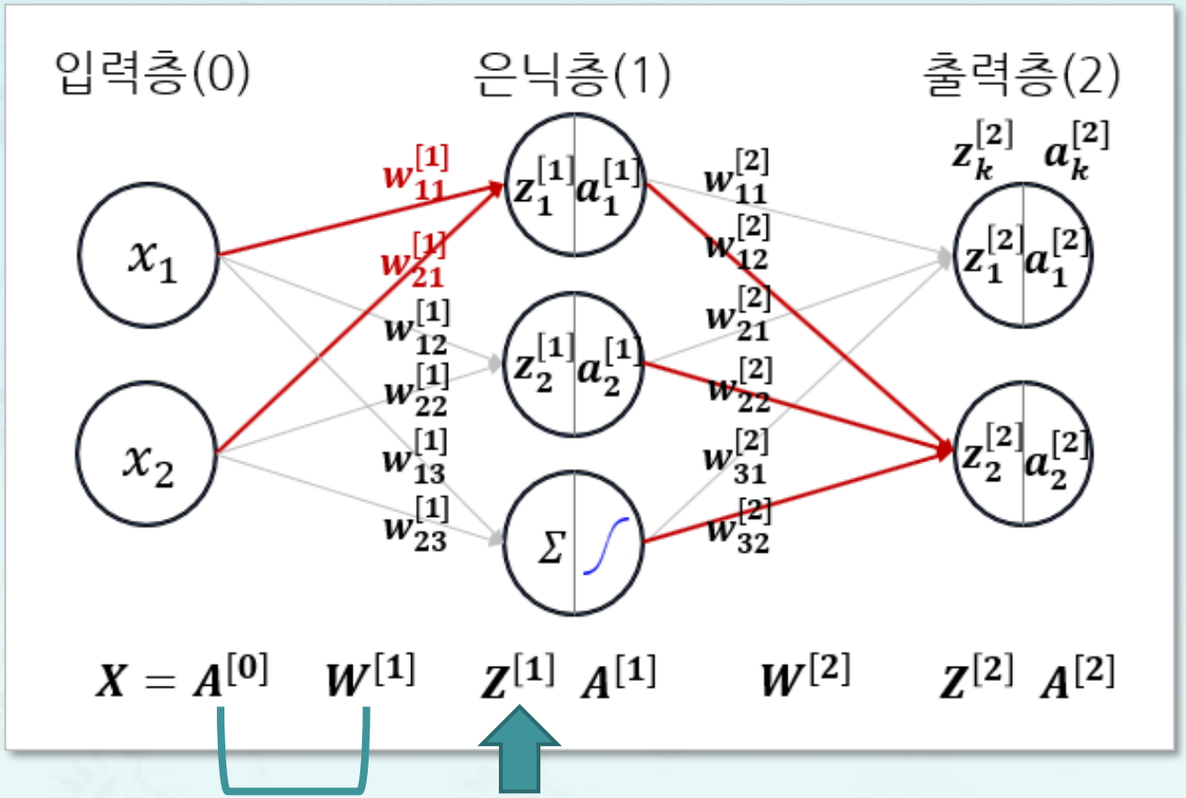
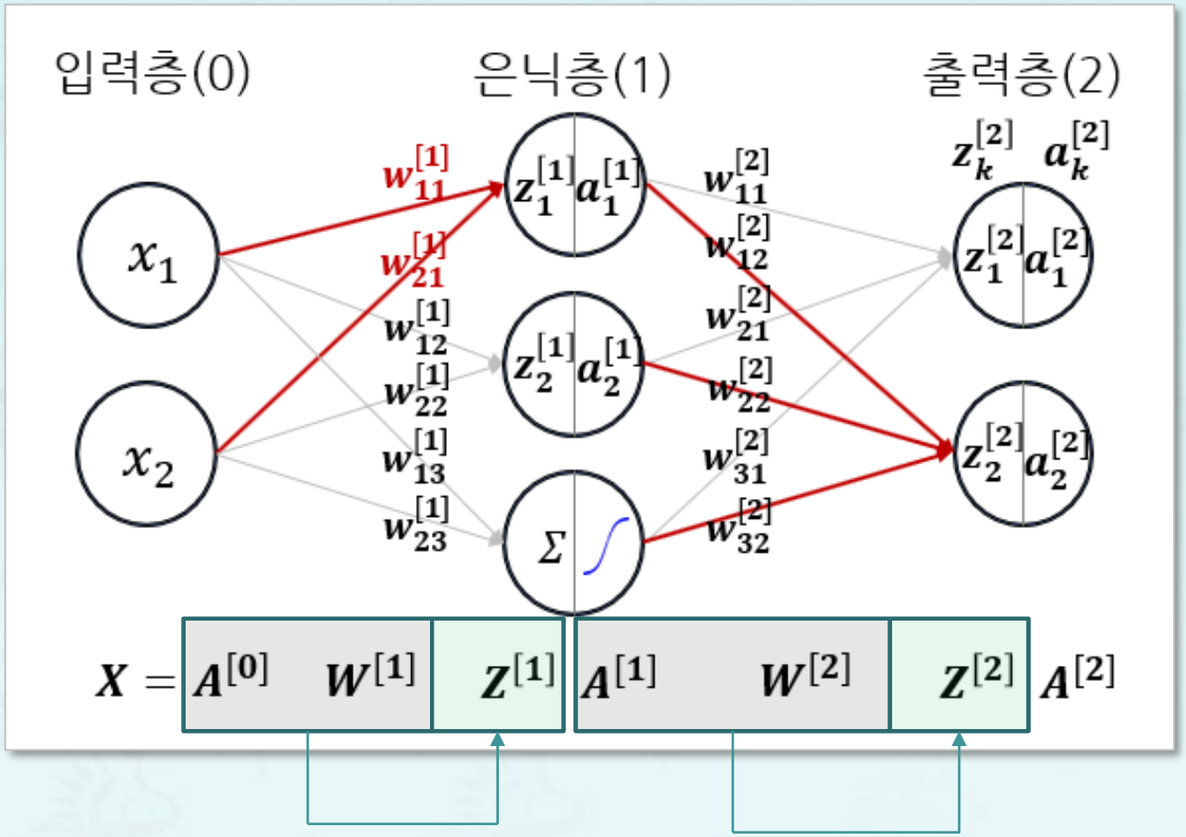


1. Feed-forward Neural Network: Signal Processing

- **Z:** $\sum(\text{Weights} * \text{Input})$
  - **Net input**
  - **net input or weighted sum**

$$Z^{[l]} = W^{[l]T} A^{[l-1]}$$



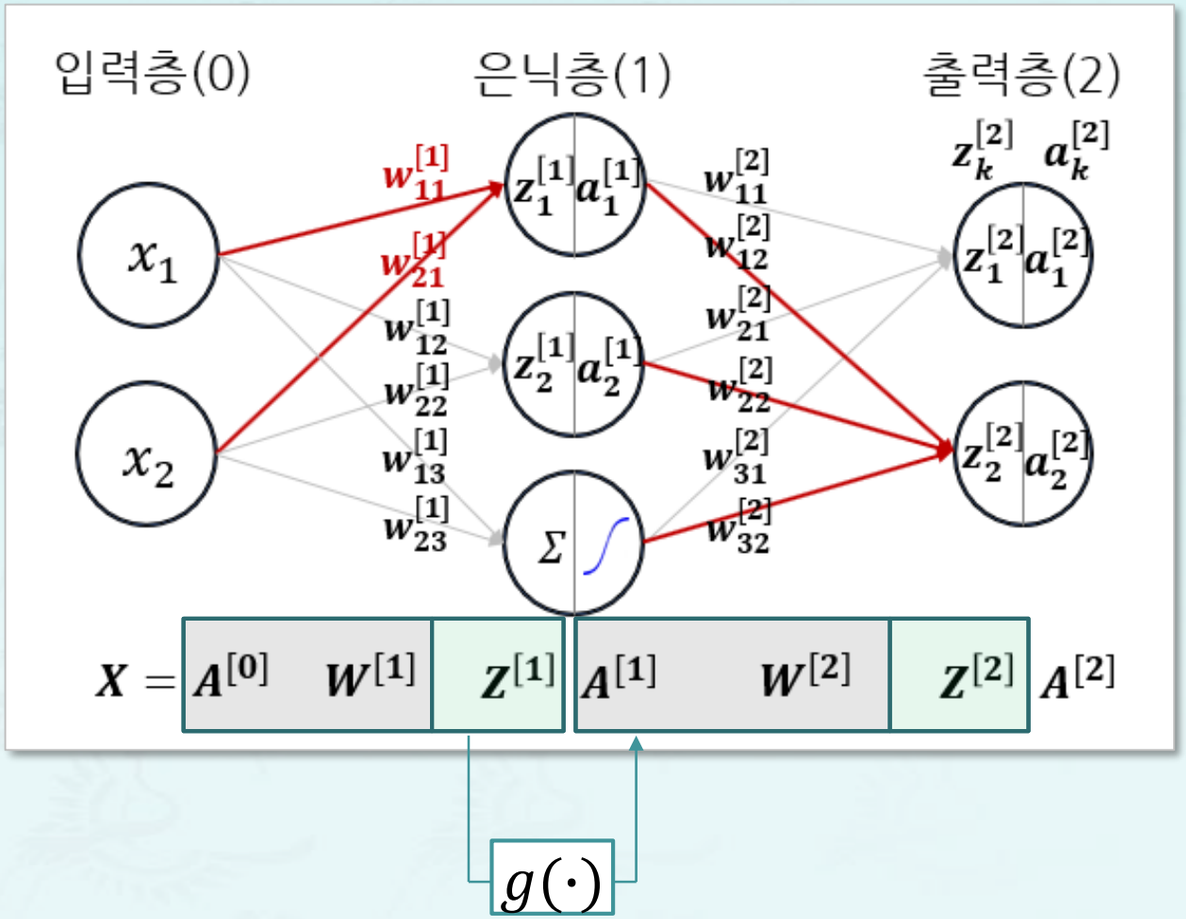
1. Feed-forward Neural Network: Signal Processing

- **Z:** $\sum(\text{Weights} * \text{Input})$
  - **Net input**
  - **net input or weighted sum**

$$Z^{[l]} = W^{[l]T} A^{[l-1]}$$

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

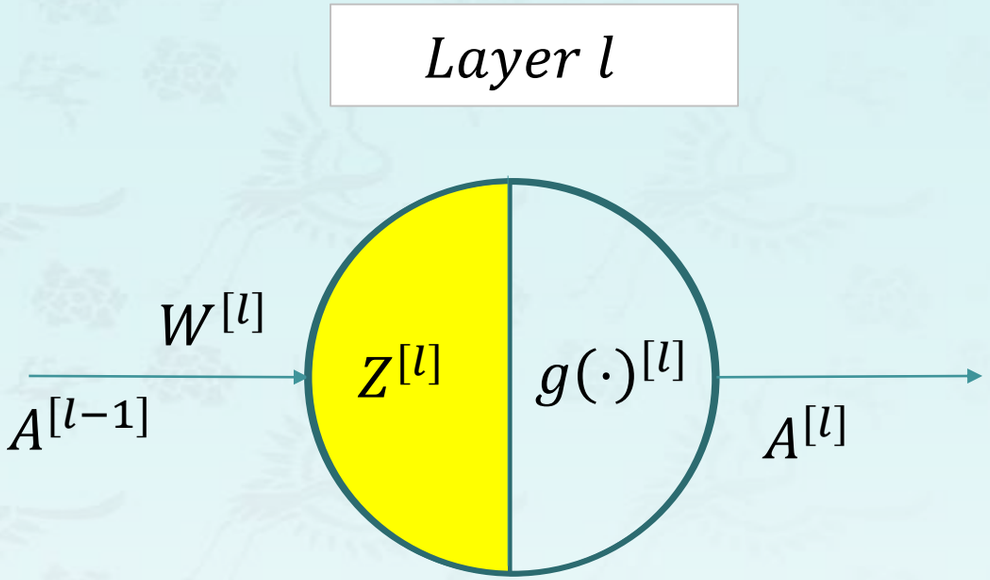
Activation Function



1. Feed-forward Neural Network: Signal Processing

$$Z^{[l]} = W^{[l]T} \; A^{[l-1]}$$

$[l]$층 **Net input**

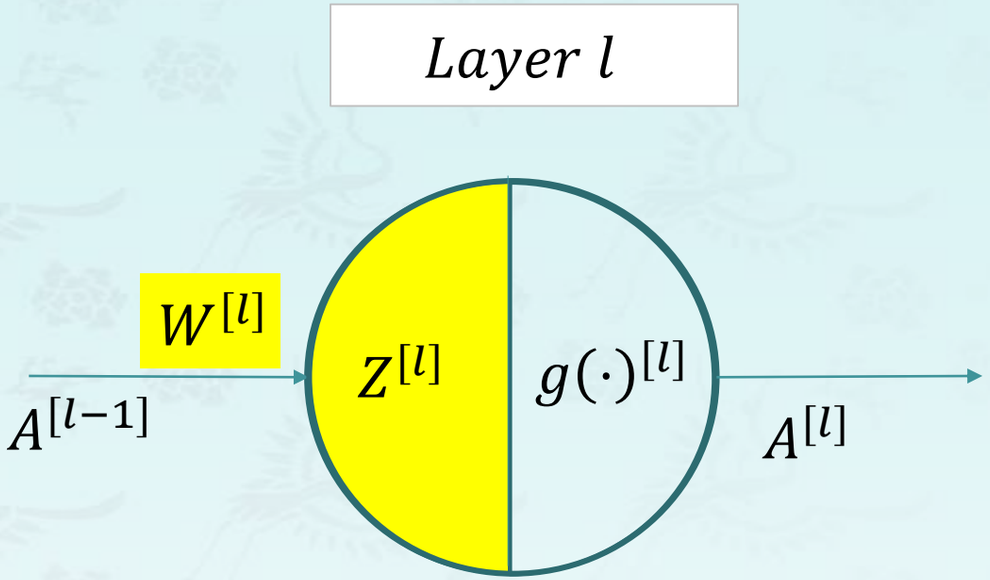


1. Feed-forward Neural Network: Signal Processing

$$Z^{[l]} = W^{[l]T} \; A^{[l-1]}$$

Layer $[l]$ **Net input**

Layer $[l]$ Weights Transpose



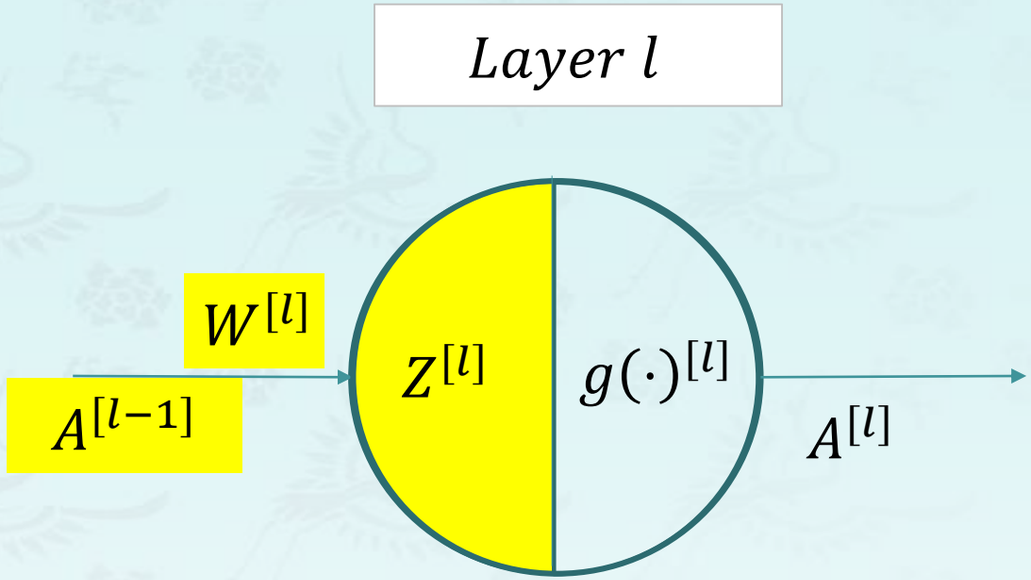
1. Feed-forward Neural Network: Signal Processing

$$Z^{[l]} = W^{[l]T} \; A^{[l-1]}$$

Layer $[l]$ **Net input**

$Layer\ [l]$ Weights Transpose

$[l-1]$Output



1. Feed-forward Neural Network: Signal Processing

$$Z^{[l]} = W^{[l]T} \; A^{[l-1]}$$

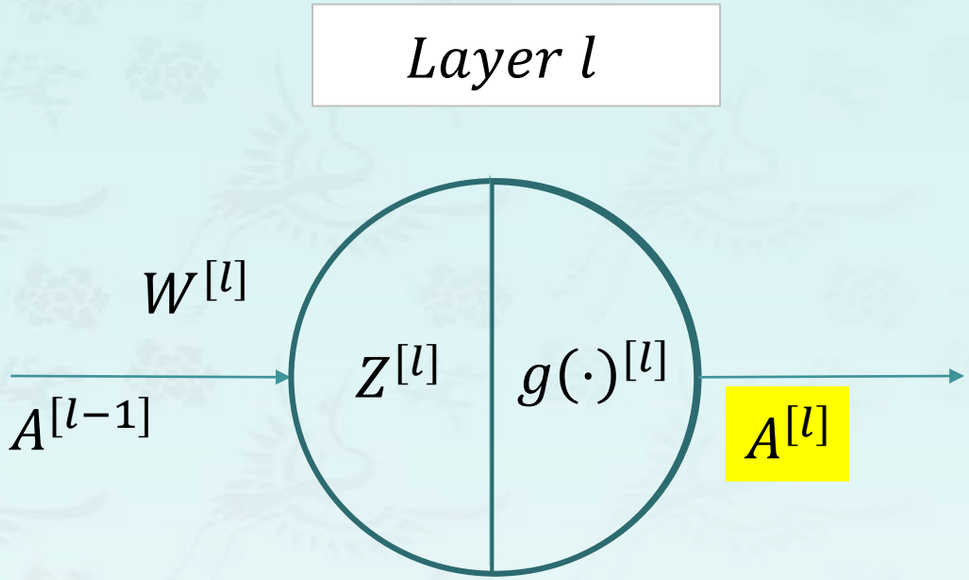
Layer $[l]$ **Net input**

$Layer\ [l]$ Weights Transpose

$[l-1]$Output

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

$[l]$**Output**



1. Feed-forward Neural Network: Signal Processing

$$Z^{[l]} = W^{[l]T} \; A^{[l-1]}$$

Layer $[l]$ **Net input**

$Layer\ [l]$ Weights Transpose

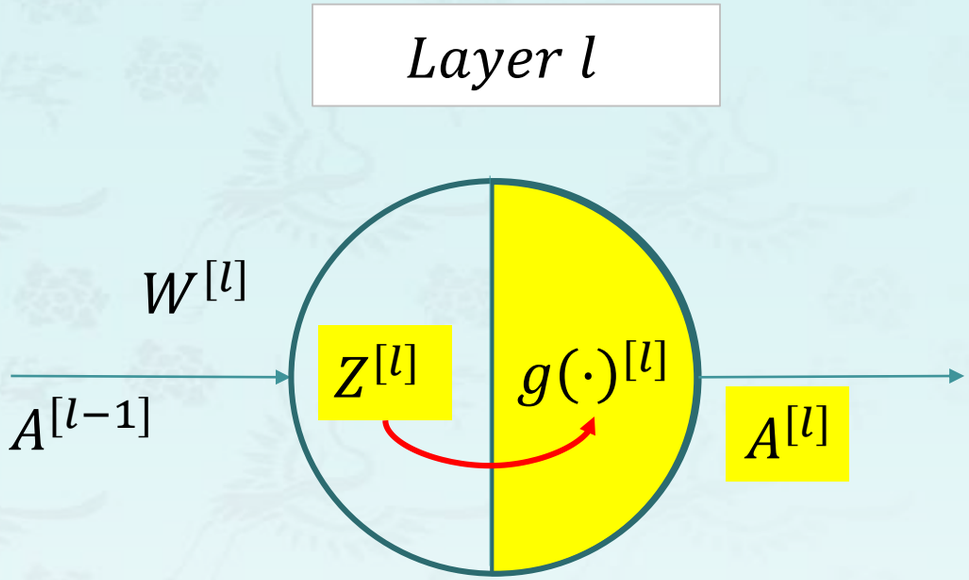
$Layer\ [l-1]$Output

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

$[l]$**Output**

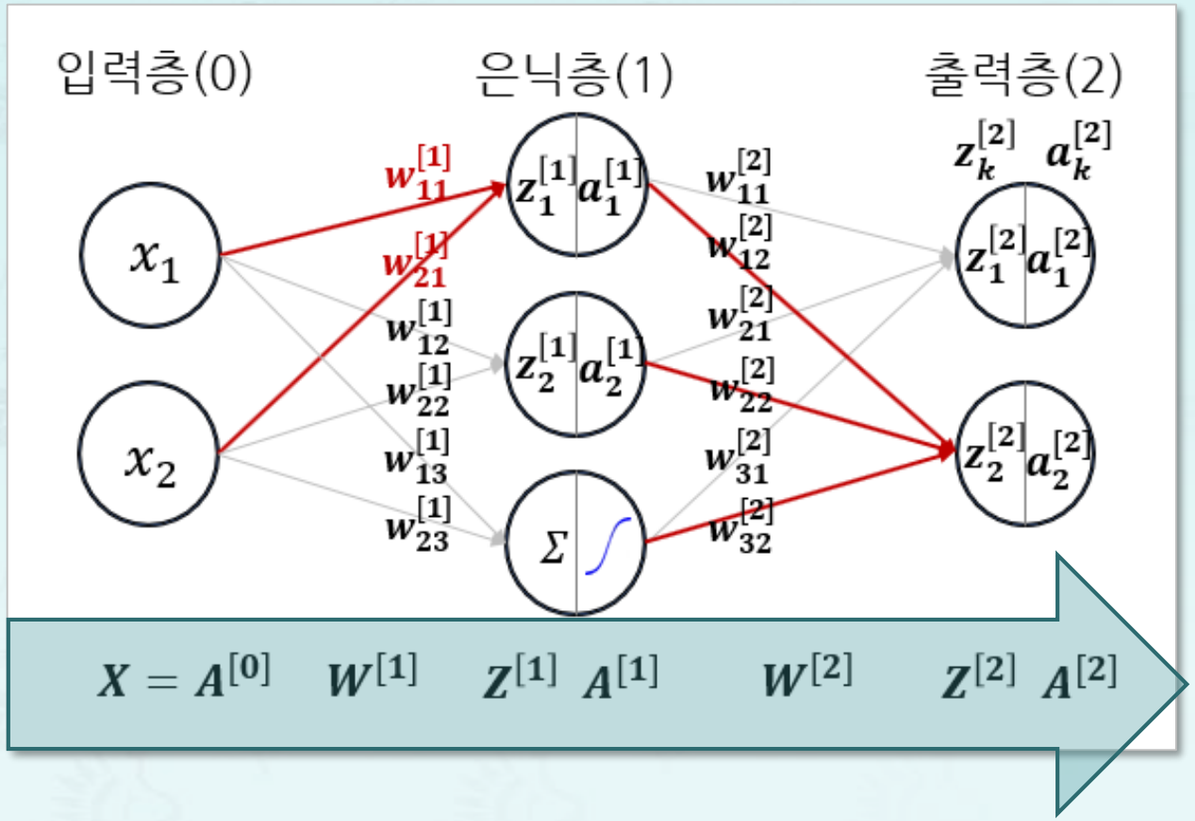
Activation Function

Layer$[l]$ **Net input**



1. Feed-forward Neural Network: Signal Processing

- **Z:** $\sum(\text{Weights} * \text{Input})$
  - **Net input**
  - **net input or weighted sum**



2. Weights Notation: W_{ij} Style

$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

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$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

$$\mathbf{W}^{(l)} = \begin{pmatrix} w_{11}^{(l)} & w_{12}^{(l)} & w_{13}^{(l)} \\ w_{21}^{(l)} & w_{22}^{(l)} & w_{23}^{(l)} \end{pmatrix}$$

Layer l Weights

2. Weights Notation: W_{ij} Style

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Layer l Weights

$$\mathbf{W}^{(1)} = \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}$$

Hidden Layer Weights

2. Weights Notation: W_{ij} Style

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$$\mathbf{W}^{(l)} = \begin{pmatrix} w_{11}^{(l)} & w_{12}^{(l)} & w_{13}^{(l)} \\ w_{21}^{(l)} & w_{22}^{(l)} & w_{23}^{(l)} \end{pmatrix}$$

Layer l Weights

$$\mathbf{W}^{(1)} = \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}$$

Hidden Layer Weights

$$\mathbf{Z}^{[1]} = W^{[1]T} A^{[0]}$$

2. Weights Notation: W_{ij} Style

$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

$$\mathbf{W}^{(l)} = \begin{pmatrix} w_{11}^{(l)} & w_{12}^{(l)} & w_{13}^{(l)} \\ w_{21}^{(l)} & w_{22}^{(l)} & w_{23}^{(l)} \end{pmatrix}$$

Layer l Weights

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Hidden Layer Weights

$$\mathbf{Z}^{[1]} = W^{[1]T} A^{[0]}$$

$$= \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}^{T} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

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$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

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Hidden Layer Weights

$$\begin{aligned} \mathbf{Z}^{[1]} &= W^{[1]T} A^{[0]} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}^T \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \end{aligned}$$

2. Weights Notation: W_{ij} Style

$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

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Layer l Weights

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Hidden Layer Weights

$$\begin{aligned} \mathbf{Z}^{[1]} &= W^{[1]T} A^{[0]} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}^T \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &= \begin{pmatrix} w_{11}^{(1)} x_1 + w_{21}^{(1)} x_2 \\ w_{12}^{(1)} x_1 + w_{22}^{(1)} x_2 \\ w_{13}^{(1)} x_1 + w_{23}^{(1)} x_2 \end{pmatrix} = \begin{pmatrix} z_1^{(1)} \\ z_2^{(1)} \\ z_3^{(1)} \end{pmatrix} \end{aligned}$$

2. Weights Notation: W_{ij} Style

$$\mathbf{Z}^{[l]} = W^{[l]T} A^{[l-1]}$$

$$\mathbf{W}^{(l)} = \begin{pmatrix} w_{11}^{(l)} & w_{12}^{(l)} & w_{13}^{(l)} \\ w_{21}^{(l)} & w_{22}^{(l)} & w_{23}^{(l)} \end{pmatrix}$$

$$\mathbf{W}^{(1)} = \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}$$

Hidden Layer Net input

$$\begin{aligned} &]^T A^{[0]} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}^T \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &= \begin{pmatrix} w_{11}^{(1)} x_1 + w_{21}^{(1)} x_2 \\ w_{12}^{(1)} x_1 + w_{22}^{(1)} x_2 \\ w_{13}^{(1)} x_1 + w_{23}^{(1)} x_2 \end{pmatrix} = \begin{pmatrix} z_1^{(1)} \\ z_2^{(1)} \\ z_3^{(1)} \end{pmatrix} \end{aligned}$$

Hidden Layer Net inp

2. Weights Notation: W_{ij} Style

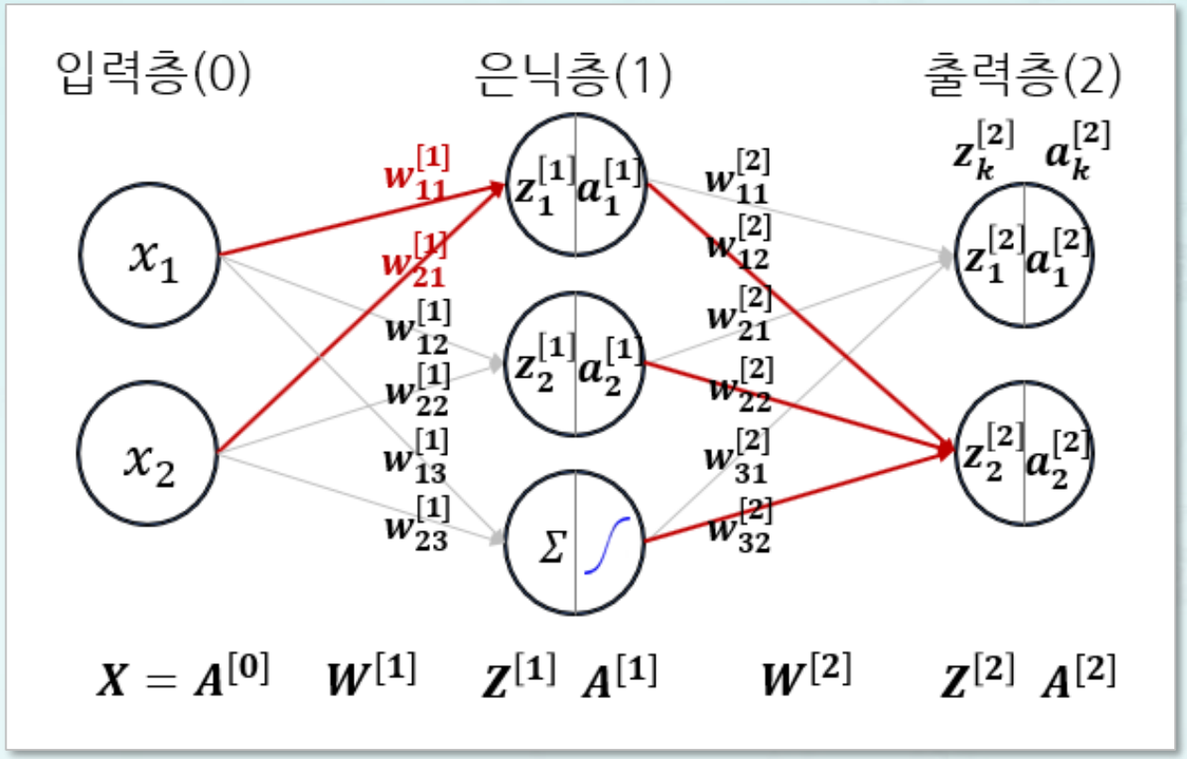
Hidden Layer Net input

$$A^{[1]} = g(Z^{[1]}) = \begin{pmatrix} a_1^{[1]} \\ a_2^{[1]} \\ a_3^{[1]} \end{pmatrix}$$

Activation Function

$$\begin{aligned}
\mathbf{Z}^{[1]} &= W^{[1]T} A^{[0]} \\
&= \begin{pmatrix} w_{11}^{(1)} & w_{12}^{(1)} & w_{13}^{(1)} \\ w_{21}^{(1)} & w_{22}^{(1)} & w_{23}^{(1)} \end{pmatrix}^T \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\
&= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\
&= \begin{pmatrix} w_{11}^{(1)} x_1 + w_{21}^{(1)} x_2 \\ w_{12}^{(1)} x_1 + w_{22}^{(1)} x_2 \\ w_{13}^{(1)} x_1 + w_{23}^{(1)} x_2 \end{pmatrix} = \begin{pmatrix} z_1^{(1)} \\ z_2^{(1)} \\ z_3^{(1)} \end{pmatrix}
\end{aligned}$$

2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)



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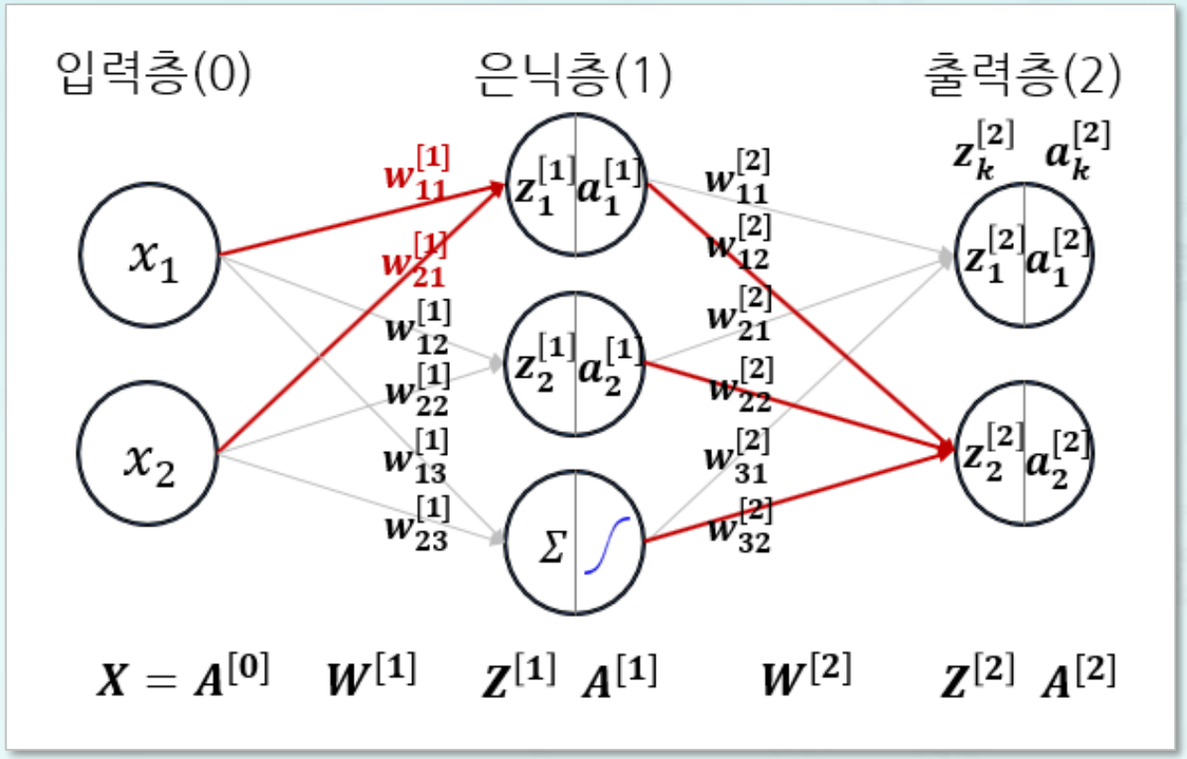
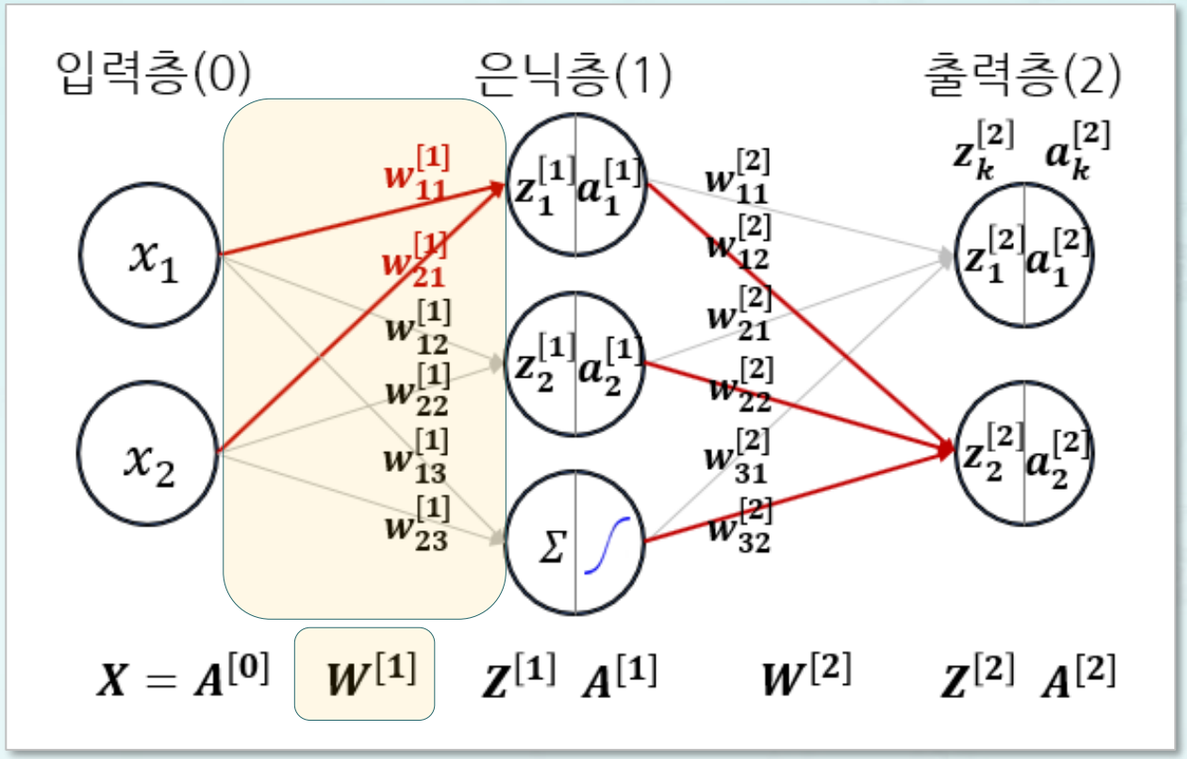


- W_{ij}^T **Shape**
  - Layer l Node Nums **x** Layer $(l-1)$ Node Nums

2. Weights Notation: W_{ij}^T Style(or W_{ji}Style)

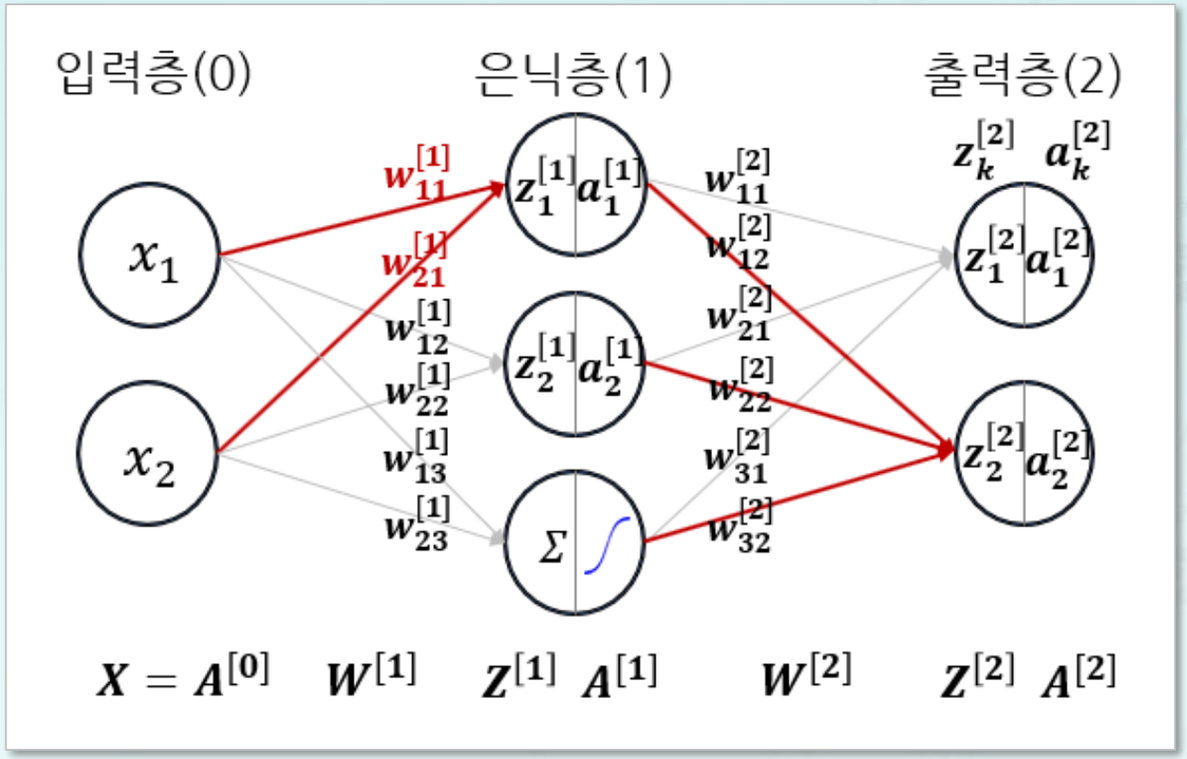


- W_{ij}^T **Shape**
  - Layer l Node Nums **x** Layer $(l-1)$ Node Nums
- **W¹.shape = (3,2)**

$$W^{[1]} = \begin{pmatrix} w_{11}^{[1]} & w_{21}^{[1]} \\ w_{12}^{[1]} & w_{22}^{[1]} \\ w_{13}^{[1]} & w_{23}^{[1]} \end{pmatrix}$$

$$W^{[2]} = \begin{pmatrix} w_{11}^{[2]} & w_{21}^{[2]} & w_{31}^{[2]} \\ w_{12}^{[2]} & w_{22}^{[2]} & w_{32}^{[2]} \end{pmatrix}$$

2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)



$$\mathbf{Z}^{[l]} = W^{[l]} A^{[l-1]}$$

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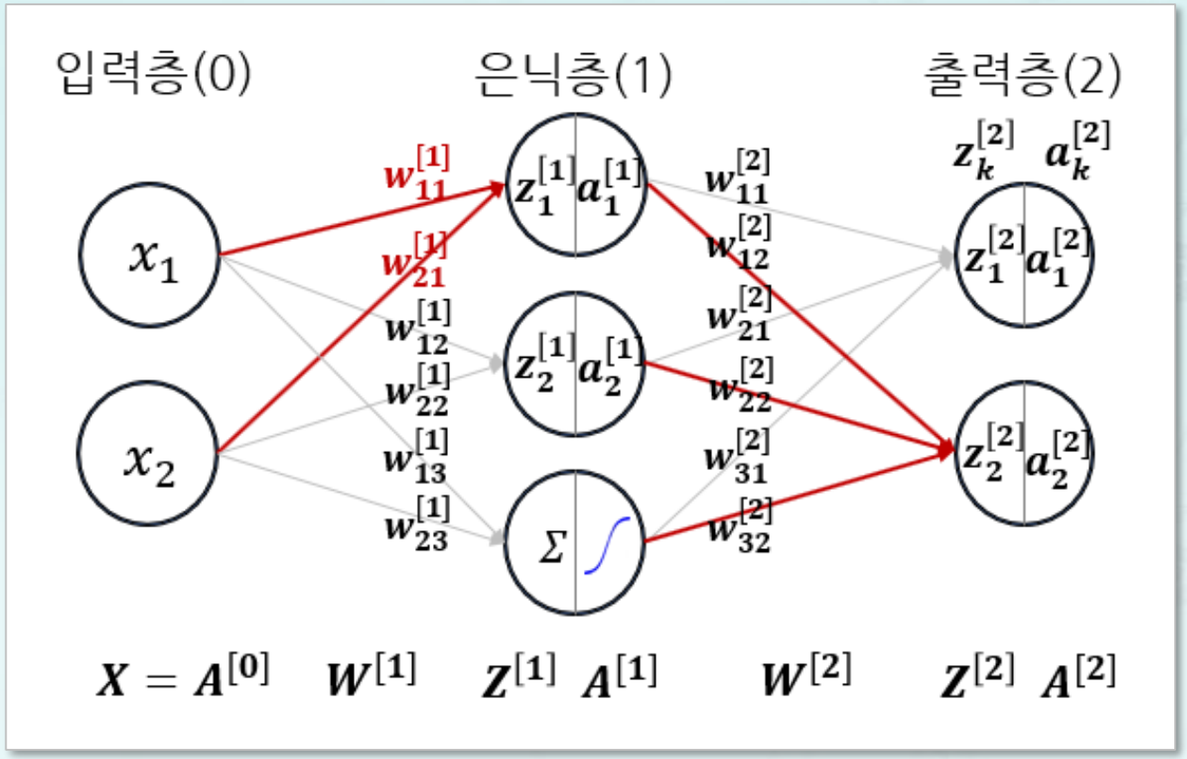
2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)

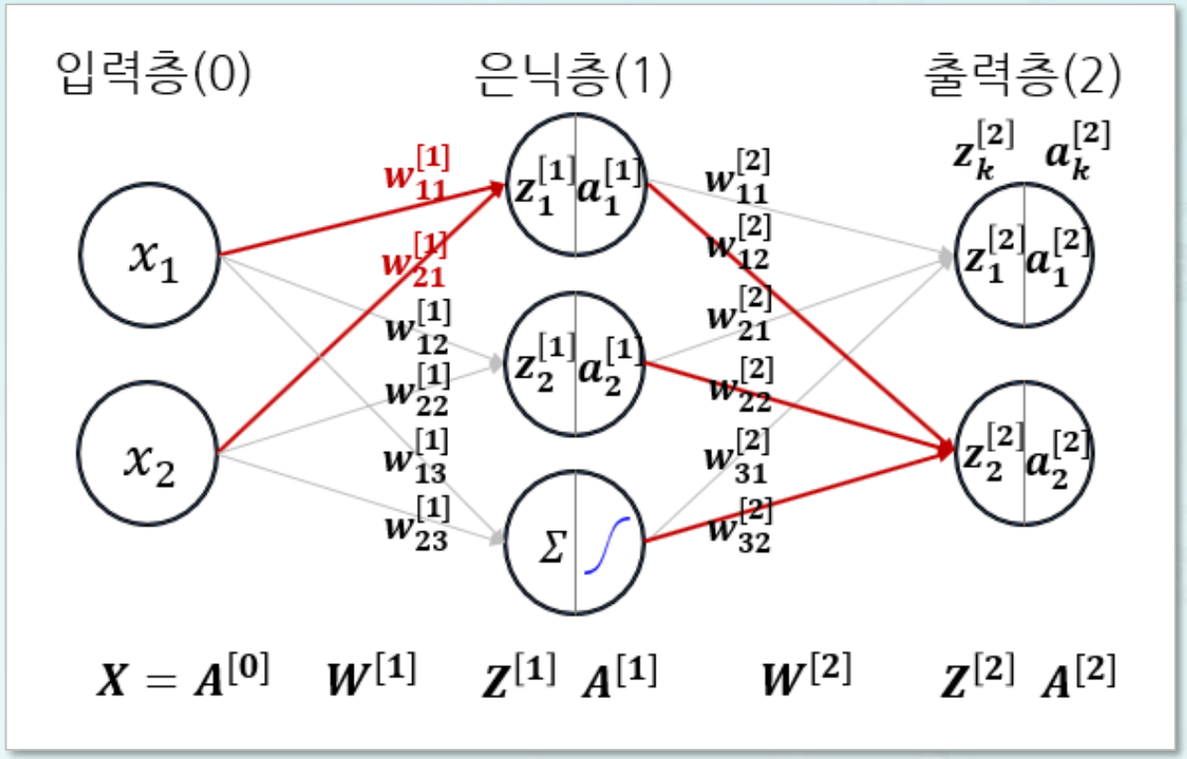


$$Z^{[l]} = W^{[l]} A^{[l-1]}$$

$$Z^{[1]} = W^{[1]} A^{[0]}$$

$$Z^{[l]} = W^{[l]} A^{[l-1]}$$

2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)

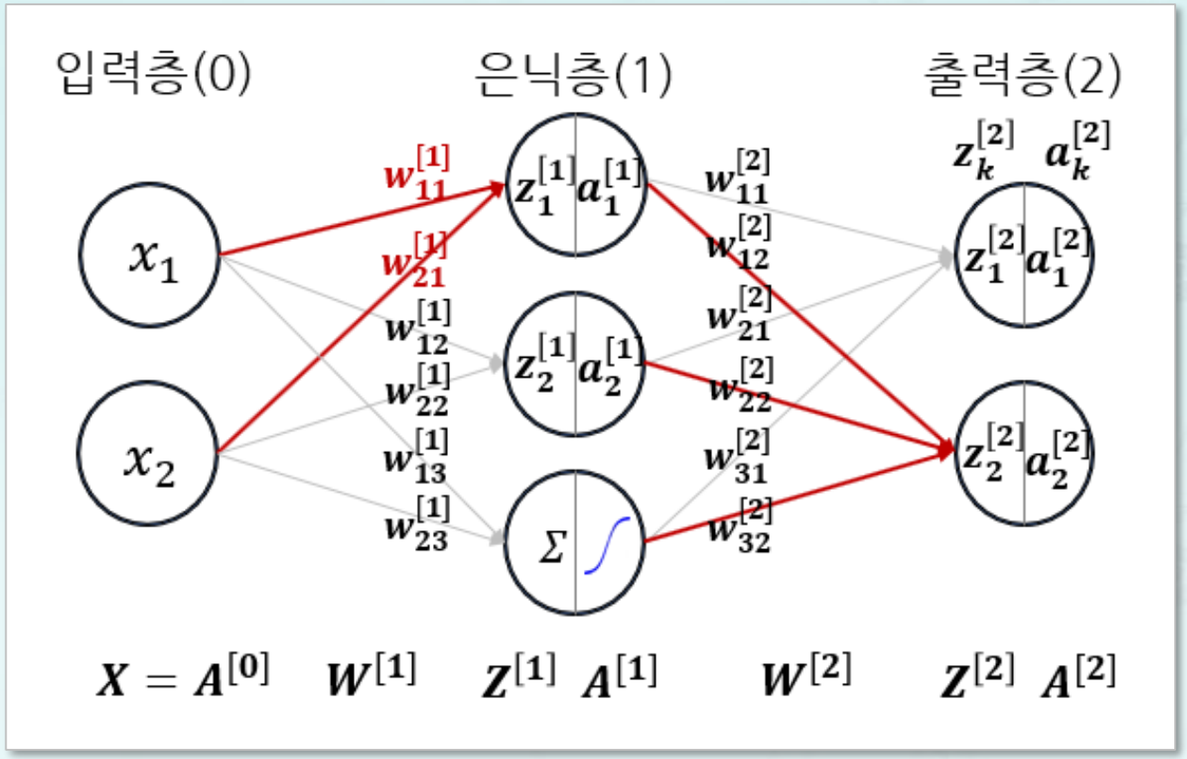


$$Z^{[l]} = W^{[l]} A^{[l-1]}$$

$$Z^{[1]} = W^{[1]} A^{[0]}$$

$$= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)



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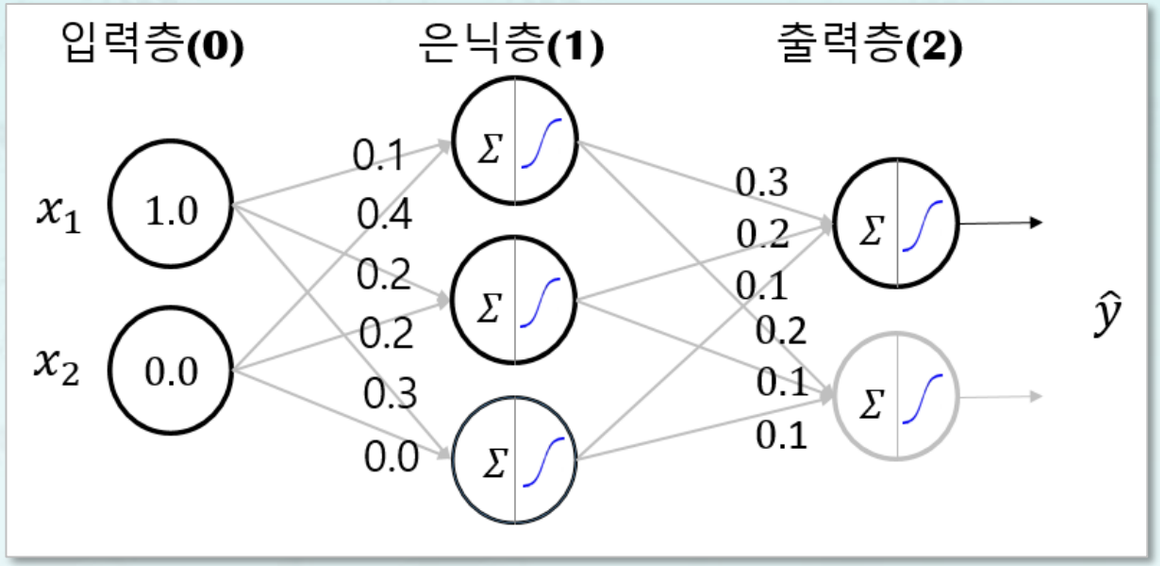
$$= \begin{pmatrix} z_1^{(1)} \\ z_2^{(1)} \\ z_3^{(1)} \end{pmatrix}$$

2. Weights Notation: W_{ij}^{T} Style(or W_{ji}Style)

- W_{ij} 와 W_{ij}^{T} **Notations**

3. Feed-forward NN Example: W_{ij}^T Notations

- W_{ij} 와 W_{ij}^T **Notations**



3. Feed-forward NN Example: Input Data Prep

n개 특성을 가진
Input자료 **m** 개

$$\mathbf{X} \in \mathbb{R}^{nxm}$$

$$\mathbf{X} = \begin{pmatrix} x_1^{(1)} & x_1^{(2)} & \cdots & x_1^{(m)} \\ x_2^{(1)} & x_2^{(2)} & \cdots & x_2^{(m)} \\ \vdots & \vdots & \vdots & \vdots \\ x_n^{(1)} & x_n^{(2)} & \cdots & x_n^{(m)} \end{pmatrix}$$

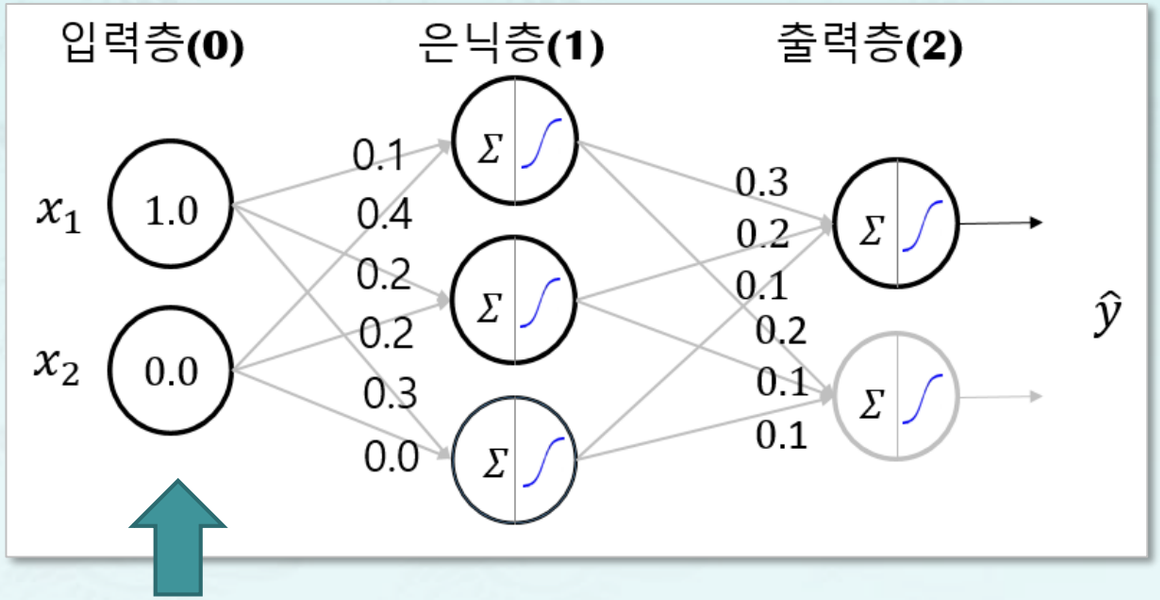
n개 특성을 가진
첫번째
Input자료

3. Feed-forward NN Example: Input Data Prep

- **Input X: m = 1, n = 2**

$$\mathbf{X} \in \mathbb{R}^{nxm}$$

$$\mathbf{X} = \begin{pmatrix} x_1^{(1)} & x_1^{(2)} & \cdots & x_1^{(m)} \\ x_2^{(1)} & x_2^{(2)} & \cdots & x_2^{(m)} \\ \vdots & \vdots & \vdots & \vdots \\ x_n^{(1)} & x_n^{(2)} & \cdots & x_n^{(m)} \end{pmatrix}$$



3. Feed-forward NN Example: Input Data Prep

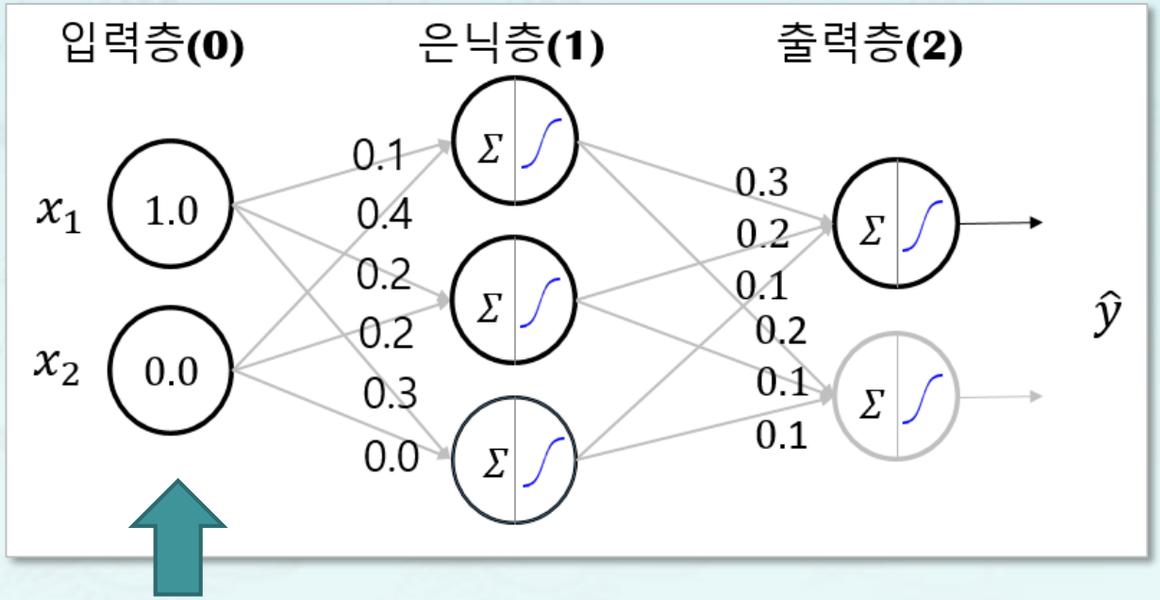
- **Input X: m = 1, n = 2**

$$\mathbf{X} \in \mathbb{R}^{nxm}$$

$$\mathbf{X} = \begin{pmatrix} x_1^{(1)} & x_1^{(2)} & \cdots & x_1^{(m)} \\ x_2^{(1)} & x_2^{(2)} & \cdots & x_2^{(m)} \\ \vdots & \vdots & \vdots & \vdots \\ x_n^{(1)} & x_n^{(2)} & \cdots & x_n^{(m)} \end{pmatrix}$$

$$\mathbf{x}^{(1)} = \begin{pmatrix} x_1^{(1)} \\ x_2^{(1)} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

- **Weights Initialization**



3. Feed-forward NN Example: Input Data Prep

- **Input X: m = 1, n = 2**

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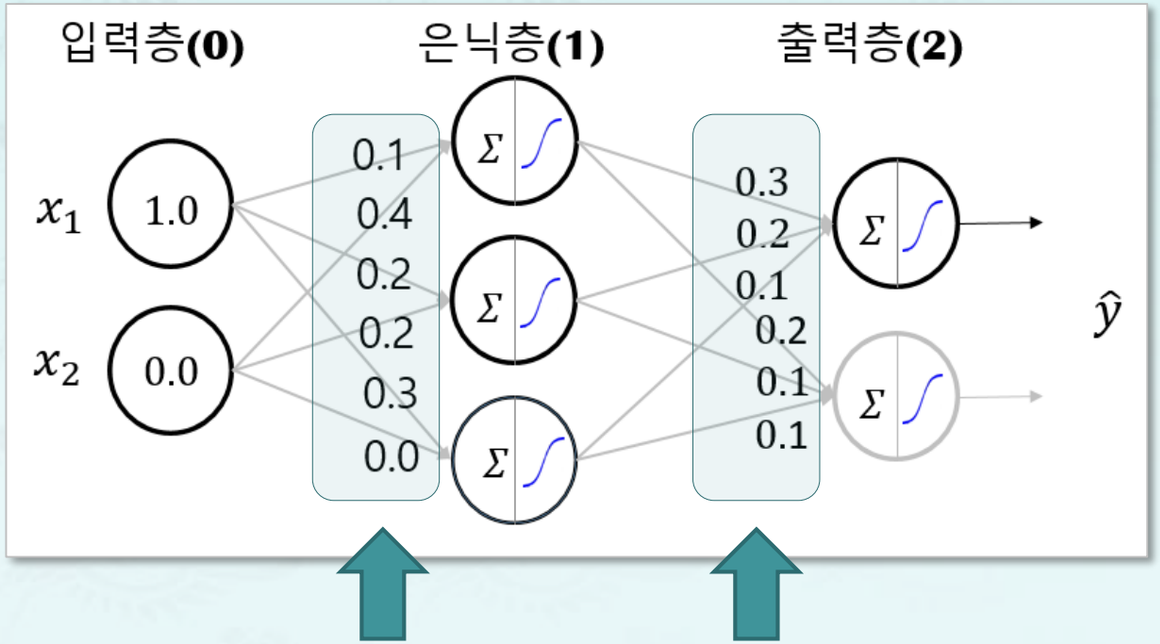
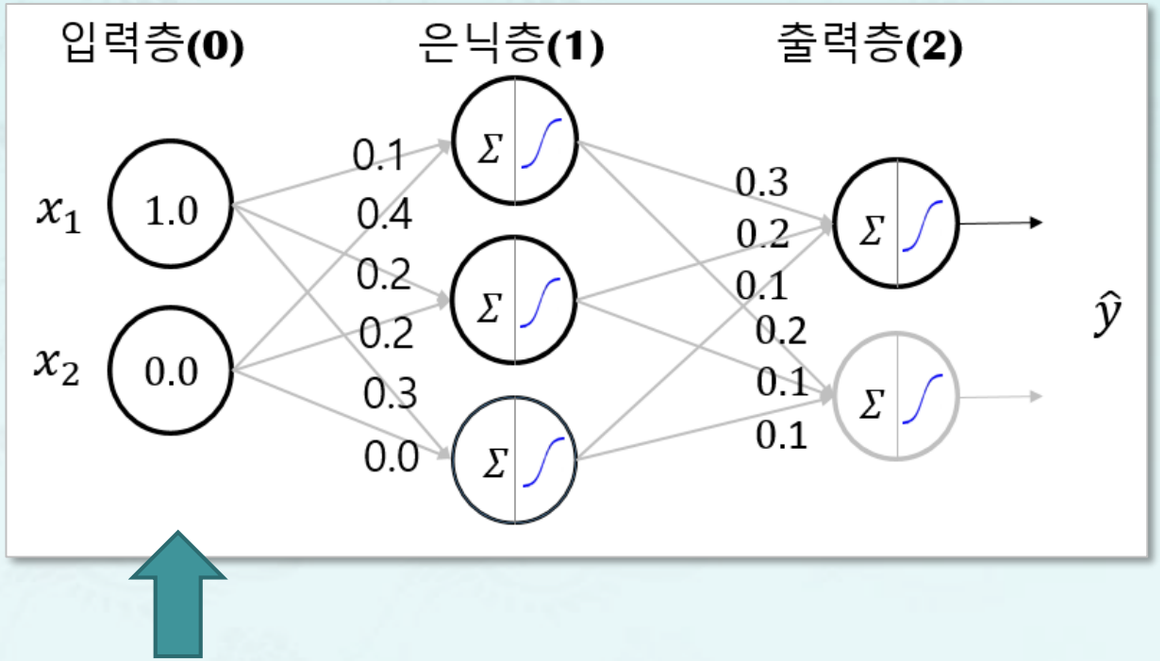
- **Weights Initialization**



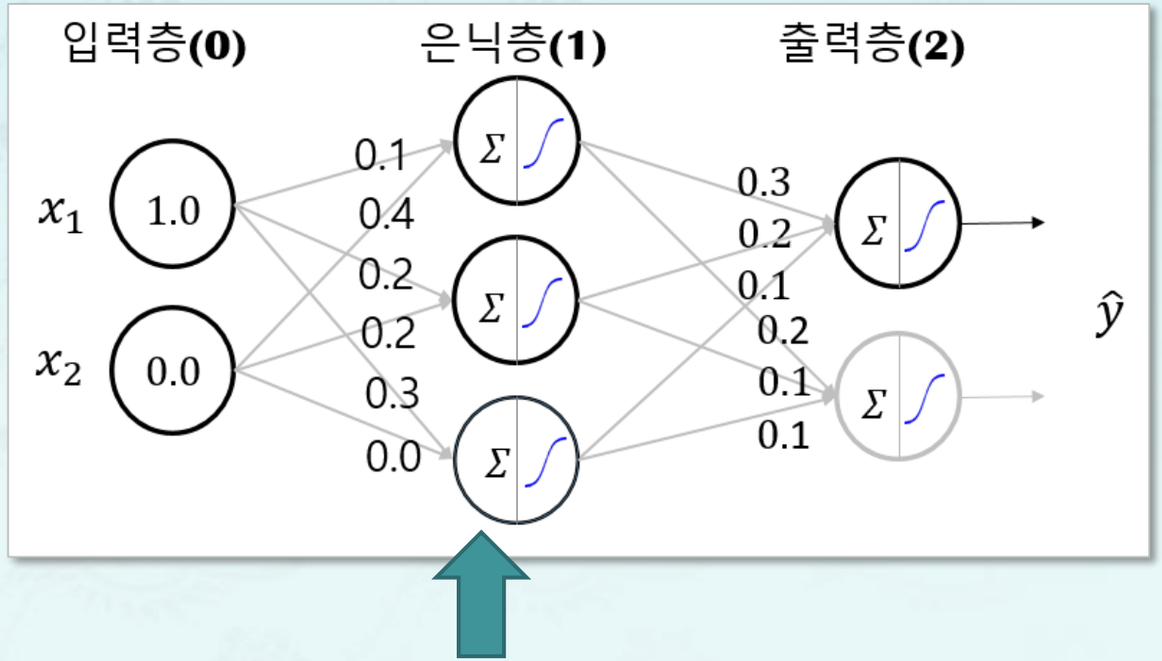
4. Feed-forward NN Computation: Input층

- $A^{[0]} = X$



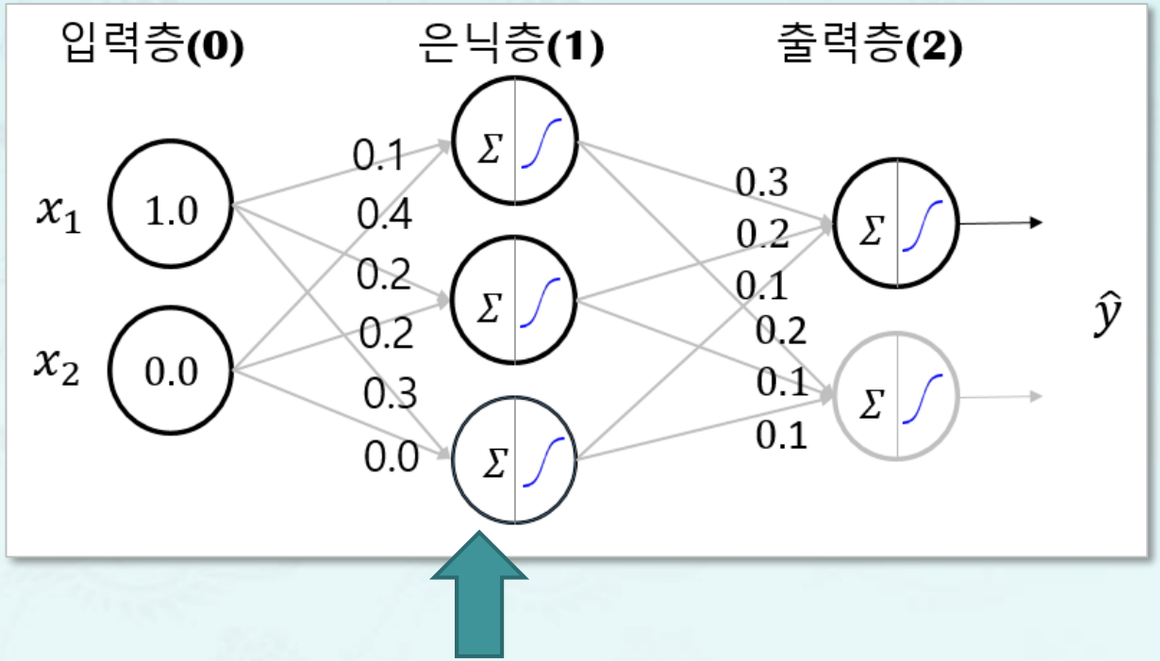
4. Feed-forward NN Computation: Hidden Layer

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



4. Feed-forward NN Computation: Hidden Layer

$$
\begin{aligned}
\mathbf{Z}^{[1]} &= W^{[1]}A^{[0]} = W^{[1]}X \\
&= \begin{pmatrix} w_{11}^{(1)} & w_{21}^{(1)} \\ w_{12}^{(1)} & w_{22}^{(1)} \\ w_{13}^{(1)} & w_{23}^{(1)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\
&= \begin{pmatrix} 0.1 & 0.4 \\ 0.2 & 0.2 \\ 0.3 & 0.0 \end{pmatrix} \begin{pmatrix} 1.0 \\ 0.0 \end{pmatrix} \\
&= \begin{pmatrix} 0.1 \\ 0.2 \\ 0.3 \end{pmatrix}
\end{aligned}
$$

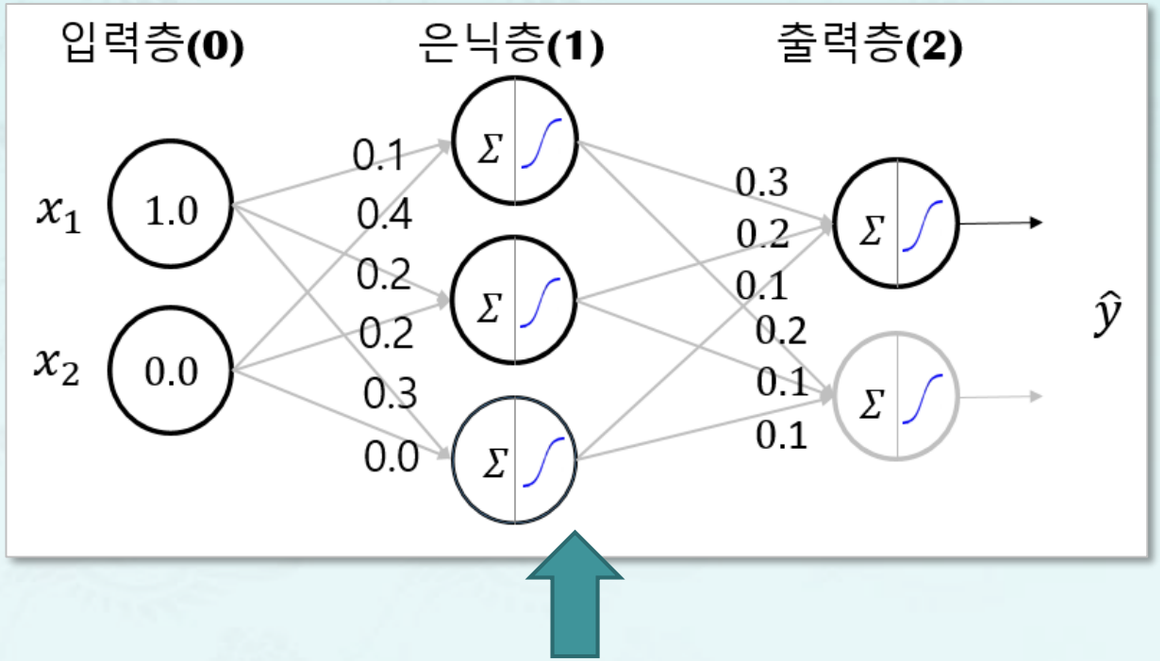


4. Feed-forward NN Computation: Hidden Layer

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

$$= sigmoid\left(\begin{pmatrix} 0.1 \\ 0.2 \\ 0.3 \end{pmatrix}\right) = \left(\begin{pmatrix} \frac{1}{1+e^{-0.1}} \\ \frac{1}{1+e^{-0.2}} \\ \frac{1}{1+e^{-0.3}} \end{pmatrix}\right)$$

$$= \begin{pmatrix} 0.525 \\ 0.500 \\ 0.574 \end{pmatrix}$$



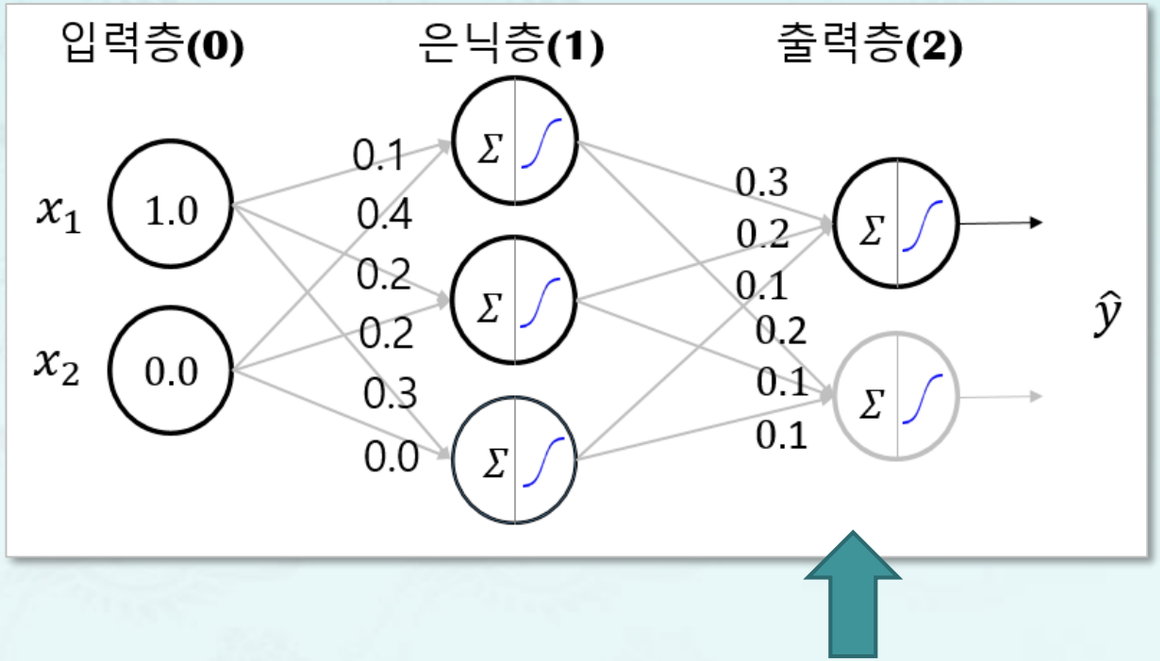
4. Feed-forward NN Computation: Output Layer

$$\mathbf{Z}^{[2]} = W^{[2]} A^{[1]}$$

$$= \begin{pmatrix} w_{11}^{(2)} & w_{21}^{(2)} & w_{31}^{(2)} \\ w_{12}^{(2)} & w_{22}^{(2)} & w_{32}^{(2)} \end{pmatrix} \begin{pmatrix} a_1^{(1)} \\ a_2^{(1)} \\ a_3^{(1)} \end{pmatrix}$$

$$= \begin{pmatrix} 0.3 & 0.2 & 0.1 \\ 0.2 & 0.1 & 0.1 \end{pmatrix} \begin{pmatrix} 0.525 \\ 0.500 \\ 0.574 \end{pmatrix}$$

$$= \begin{pmatrix} 0.325 \\ 0.217 \end{pmatrix}$$

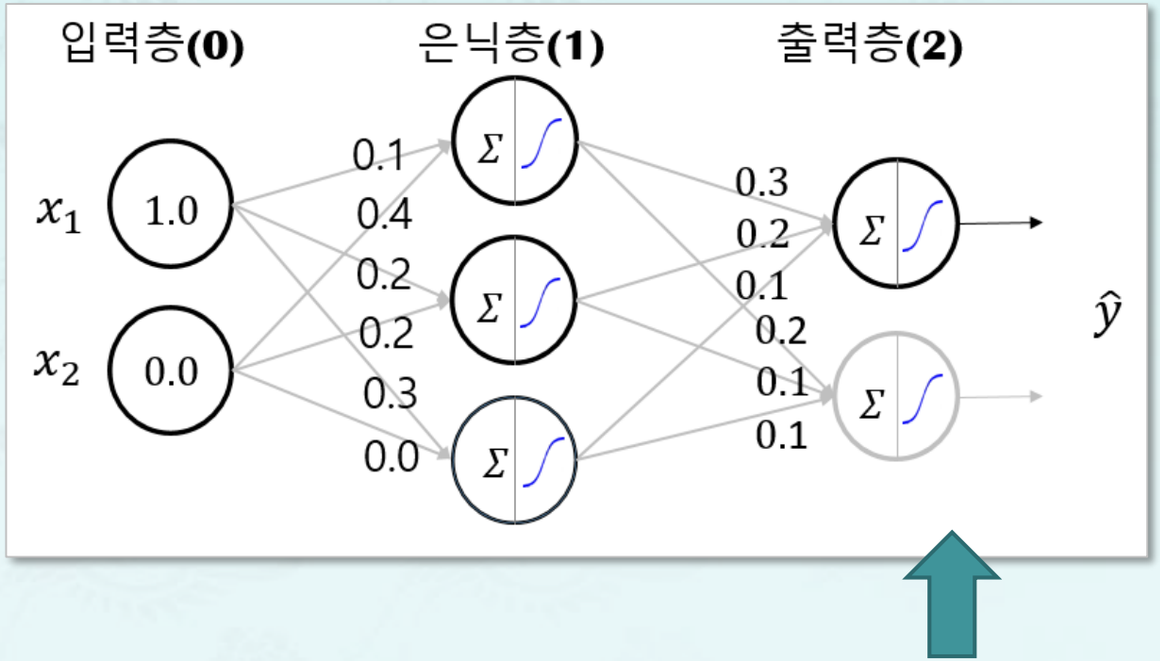


4. Feed-forward NN Computation: Output Layer

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

$$= sigmoid\left(\begin{pmatrix} 0.325 \\ 0.217 \end{pmatrix}\right) = \begin{pmatrix} \frac{1}{1+e^{-0.325}} \\ \frac{1}{1+e^{-0.217}} \end{pmatrix}$$

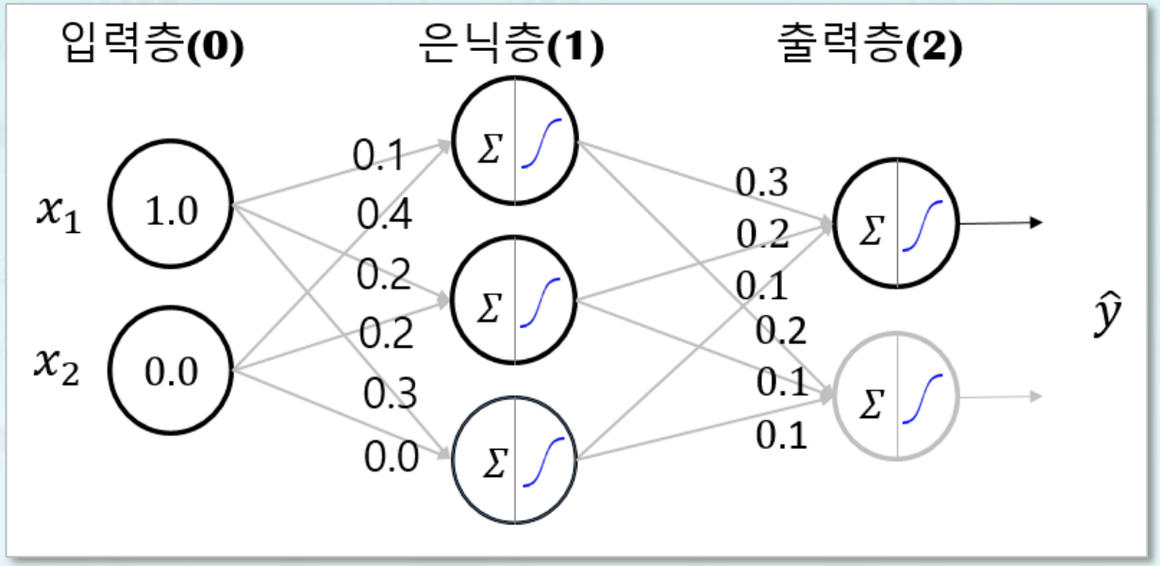
$$= \begin{pmatrix} 0.581 \\ 0.554 \end{pmatrix}$$



4. Feed-forward NN Computation: Output Layer

- **Output Layer(2)**

$$\mathbf{A}^{[2]} = g(\mathbf{Z}^{[2]})$$
$$= sigmoid\left(\begin{pmatrix} 0.325 \\ 0.217 \end{pmatrix}\right) = \begin{pmatrix} \frac{1}{1+e^{-0.325}} \\ \frac{1}{1+e^{-0.217}} \end{pmatrix}$$
$$= \begin{pmatrix} 0.581 \\ 0.554 \end{pmatrix}$$



$$\hat{y} = \begin{pmatrix} \hat{y}_1 \\ \hat{y}_2 \end{pmatrix} = \begin{pmatrix} 0.581 \\ 0.554 \end{pmatrix}$$

Feed-forward Neural Network

- **Summary**
  - **Feed-forward NN Notation**
  - **Feed-forward NN Processing**
  - **Weights W_{iJ} and W_{ij}^{T} Notation Styles**
  - **Feed-forward NN Example**

- **7-2 Feed-forward NN Example**

Week 7(1/3)

Feed-forward NN

Machine Learning with Python

Handong Global University
Prof. Youngsup Kim
idebtor@gmail.com

여러분 곁에 항상 열려 있는 K-MOOC 강의실에서 만나 뵙기를 바랍니다.