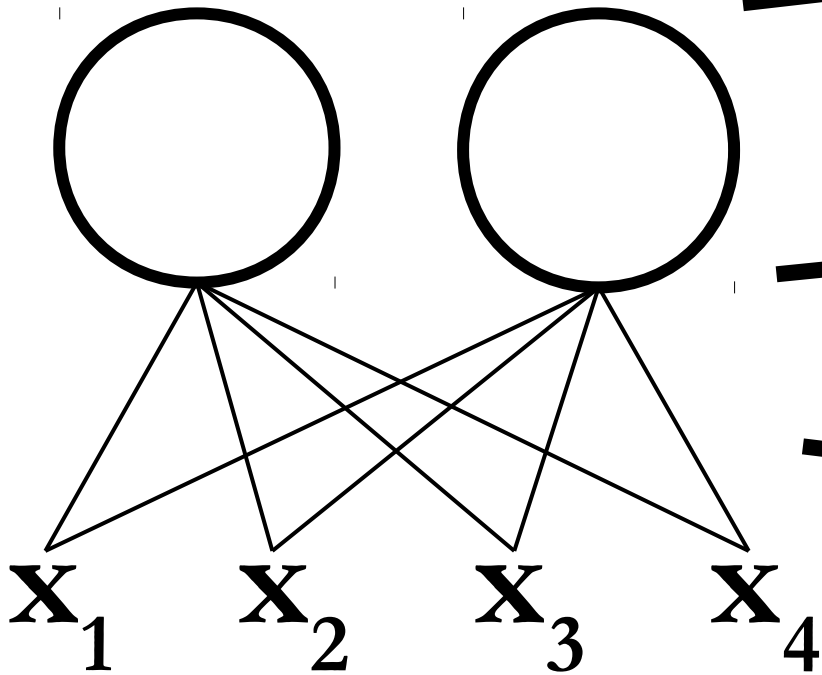


$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$

$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$

$$\begin{bmatrix} [0.9 & 0.8 & -1.0 & -1.0] \\ [-0.5 & -0.5 & 1.5 & 1.0] \end{bmatrix}$$

$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}$$

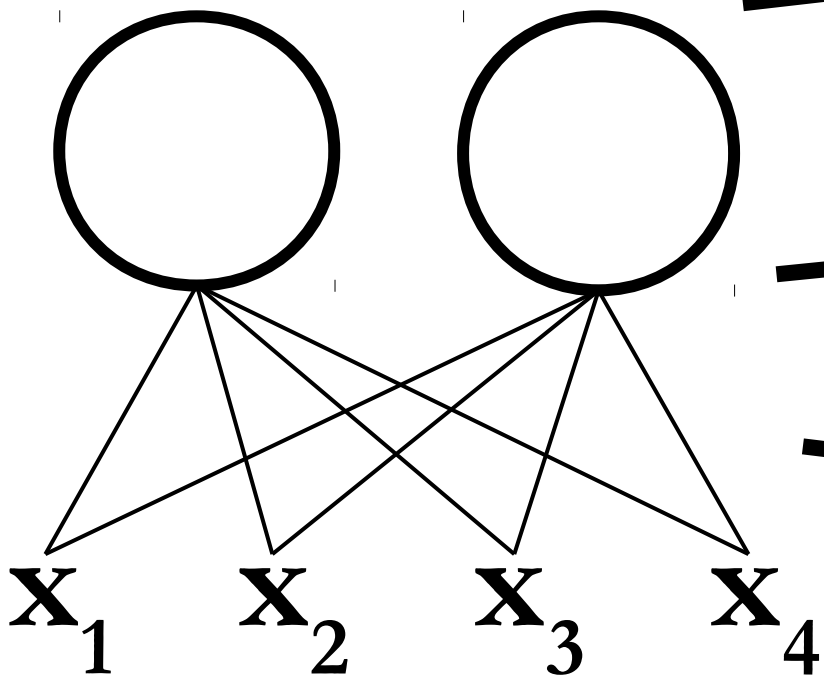


$\begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix}$

$\begin{bmatrix} 5.21 & -1.65 \\ 2.32 & 3.45 \\ 0.38 & 5.30 \end{bmatrix}$

$\begin{bmatrix} 0.9 & 0.8 & -1.0 & -1.0 \\ -0.5 & -0.5 & 1.5 & 1.0 \end{bmatrix}$

$\begin{bmatrix} 4.9 & 3.0 & 1.4 & 0.2 \\ 6.4 & 3.2 & 4.5 & 1.5 \\ 5.8 & 2.7 & 5.1 & 1.9 \end{bmatrix}$ ²

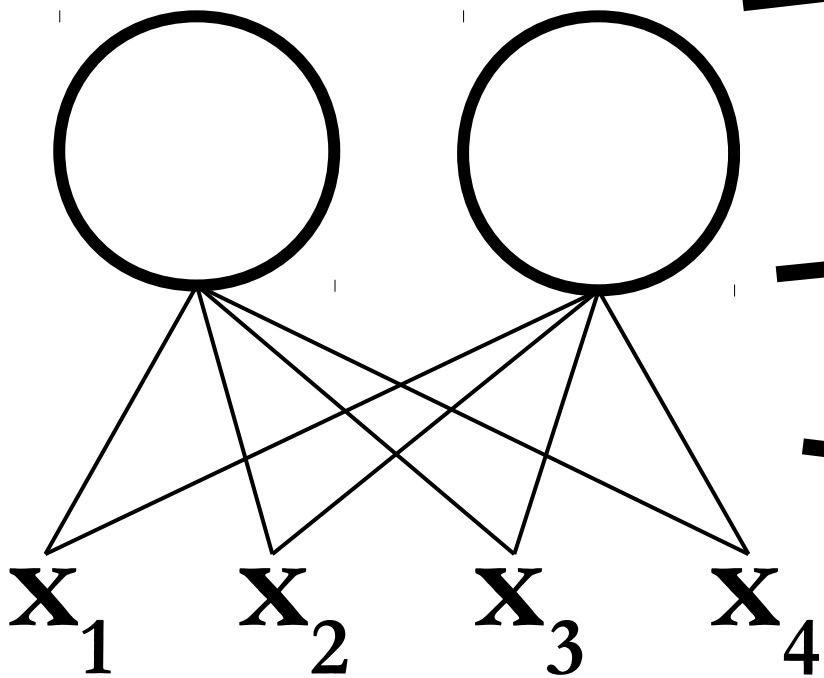


$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$

$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$

$$\begin{bmatrix} [0.9 & 0.8 & -1.0 & -1.0] \\ [-0.5 & -0.5 & 1.5 & 1.0] \end{bmatrix}$$

$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}$$



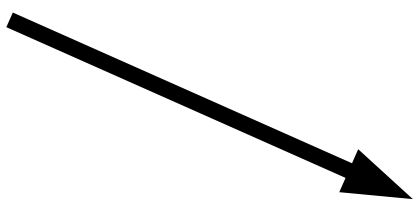
$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$



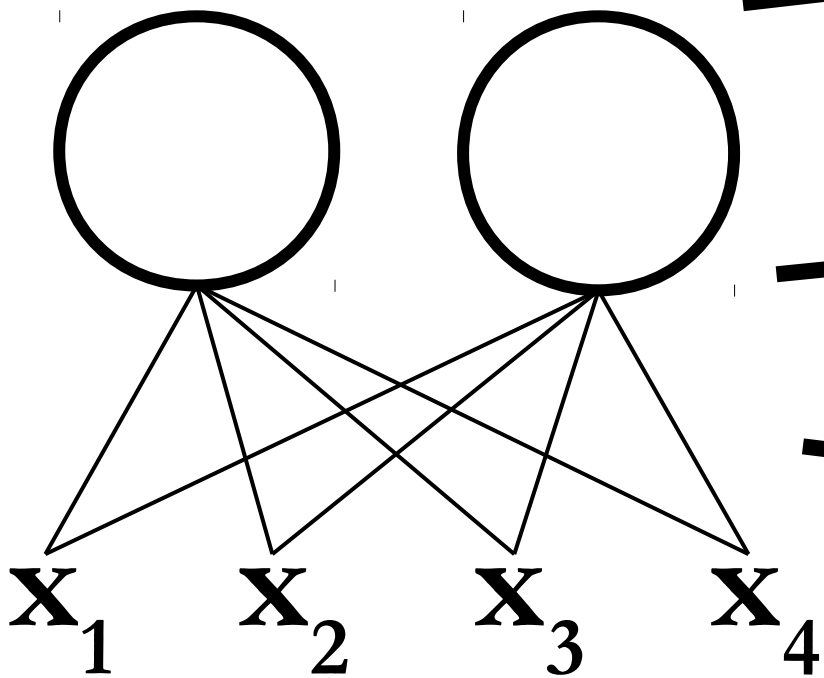
$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$



$$\begin{bmatrix} [0.9 & 0.8 & -1.0 & -1.0] \\ [-0.5 & -0.5 & 1.5 & 1.0] \end{bmatrix}$$



$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}$$



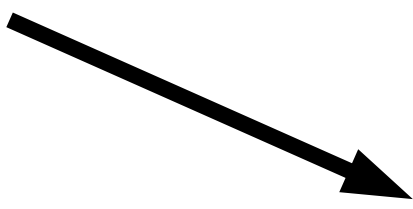
$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$



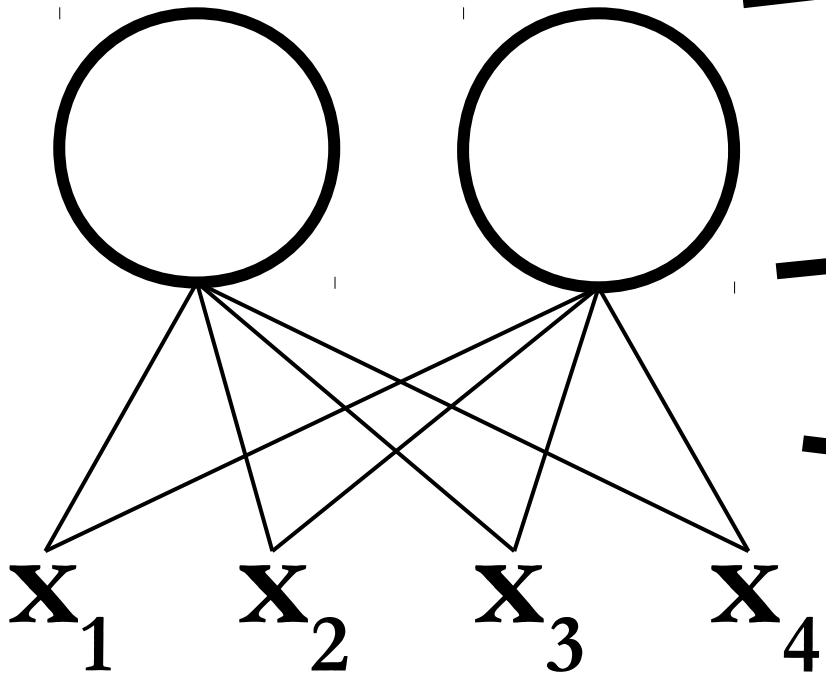
$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$



$$\begin{bmatrix} [0.9 & 0.8 & -1.0 & -1.0] \\ [-0.5 & -0.5 & 1.5 & 1.0] \end{bmatrix}$$



$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}$$



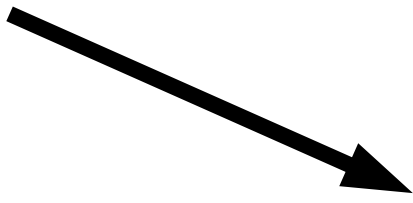
$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$



$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$



$$\begin{bmatrix} [0.9 & 0.8 & -1.0 & -1.0] \\ [-0.5 & -0.5 & 1.5 & 1.0] \end{bmatrix}$$



$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}$$

Inputs

Weights

Result

determine_layer_outputs():

[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]]

[[5.21 **-1.65]**
[2.32 3.45]
[0.38 5.30]]

Matrix Multiplication:

[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[[0.9 **-0.5]**
[0.8 **-0.5]**
[-1.0 **1.5]**
[-1.0 **1.0]**]

[[5.21 **-1.65]**
[2.32 3.45]
[0.38 5.30]]

Inputs

Weights

Result

determine_layer_outputs():

1 [4.9 3.0 1.4 0.2]
2 [6.4 3.2 4.5 1.5]
3 [5.8 2.7 5.1 1.9]

1 [0.9 0.8 -1.0 -1.0]
2 [-0.5 -0.5 1.5 1.0]

1 [5.21 -1.65]
2 [2.32 3.45]
3 [0.38 5.30]

Matrix Multiplication:

1 [4.9 3.0 1.4 0.2]
2 [6.4 3.2 4.5 1.5]
3 [5.8 2.7 5.1 1.9]

1 2
[[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]

1 2
1 [5.21 -1.65]
2 [2.32 3.45]
3 [0.38 5.30]

Inputs

Weights

Result

determine_layer_outputs():

1 [[4.9 3.0 1.4 0.2]
2 [6.4 3.2 4.5 1.5]
3 [5.8 2.7 5.1 1.9]]

1 [0.9 0.8 -1.0 -1.0]
2 [-0.5 -0.5 1.5 1.0]]

1 2
1 [[5.21 -1.65]
2 [2.32 3.45]
3 [0.38 5.30]]

Matrix Multiplication:

1 [[4.9 3.0 1.4 0.2]
2 [6.4 3.2 4.5 1.5]
3 [5.8 2.7 5.1 1.9]]

1 2
[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]]

1 2
1 [[5.21 -1.65]
2 [2.32 3.45]
3 [0.38 5.30]]

Inputs

Weights

Result

determine_layer_outputs():

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

Matrix Multiplication:

[[4.9 3.0 1.4 0.2 0.8]
[6.4 3.2 4.5 1.5 4.7]
[5.8 2.7 5.1 1.9 6.2]]

[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]

Inputs

Weights

Result

determine_layer_outputs():

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

Matrix Multiplication:

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

3 x 4

4 x 2

Inputs

Weights

Result

determine_layer_outputs():

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

Matrix Multiplication:

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

3 x 4

4 x 2

Inputs

Weights

Result

determine_layer_outputs():

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

Matrix Multiplication:

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

3 x 4

4 x 2

3 x 2

Inputs

Weights

Result

determine_layer_outputs():

[[4.9 3.0 1.4 0.2]
[6.4 3.2 4.5 1.5]
[5.8 2.7 5.1 1.9]]

[0.9 0.8 -1.0 -1.0]
[-0.5 -0.5 1.5 1.0]

[[5.21 -1.65]
[2.32 3.45]
[0.38 5.30]]

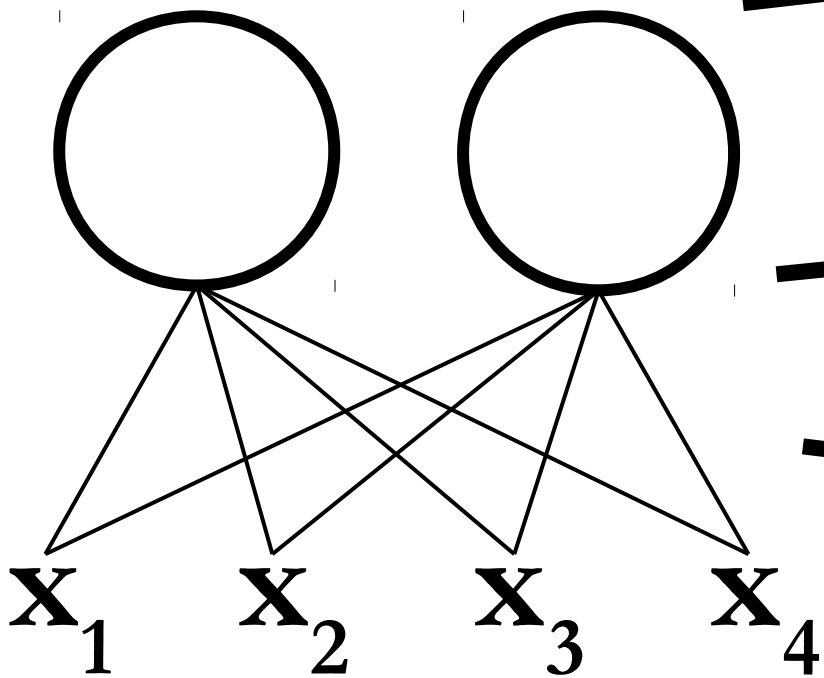
Matrix Multiplication:

[[4.9 3.0 1.4 0.2 0.8]
[6.4 3.2 4.5 1.5 4.7]
[5.8 2.7 5.1 1.9 6.2]]

[0.9 -0.5]
[0.8 -0.5]
[-1.0 1.5]
[-1.0 1.0]

3 x **5**

4 x 2

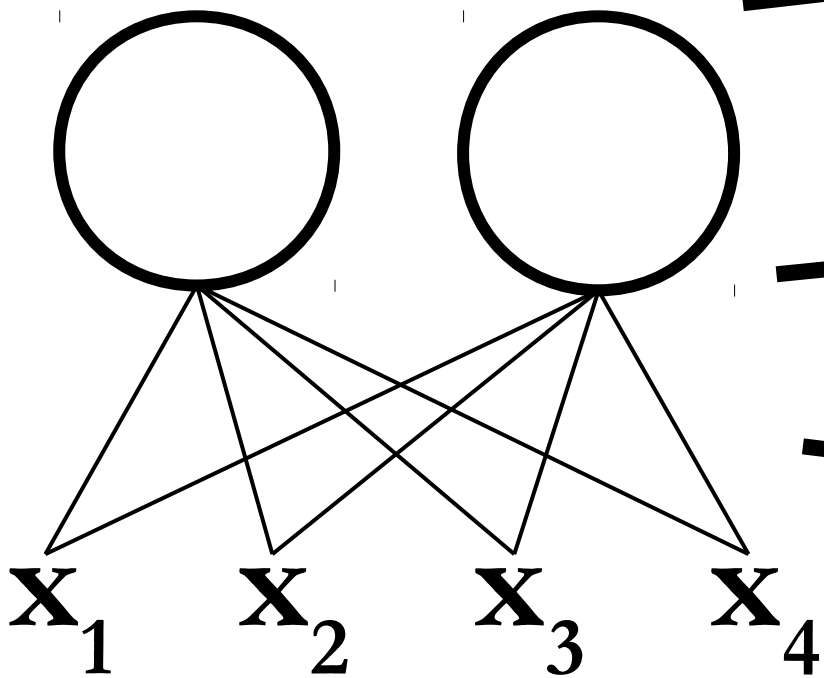


$\begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix}$

$\begin{bmatrix} 5.21 & -1.65 \\ 2.32 & 3.45 \\ 0.38 & 5.30 \end{bmatrix}$

$\begin{bmatrix} 0.9 & 0.8 & -1.0 & -1.0 \\ -0.5 & -0.5 & 1.5 & 1.0 \end{bmatrix}$

$\begin{bmatrix} 4.9 & 3.0 & 1.4 & 0.2 \\ 6.4 & 3.2 & 4.5 & 1.5 \\ 5.8 & 2.7 & 5.1 & 1.9 \end{bmatrix}^{15}$



$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$



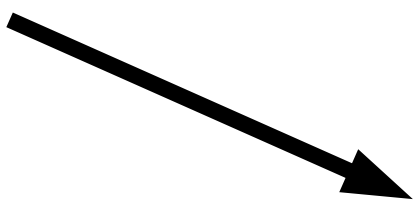
$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$



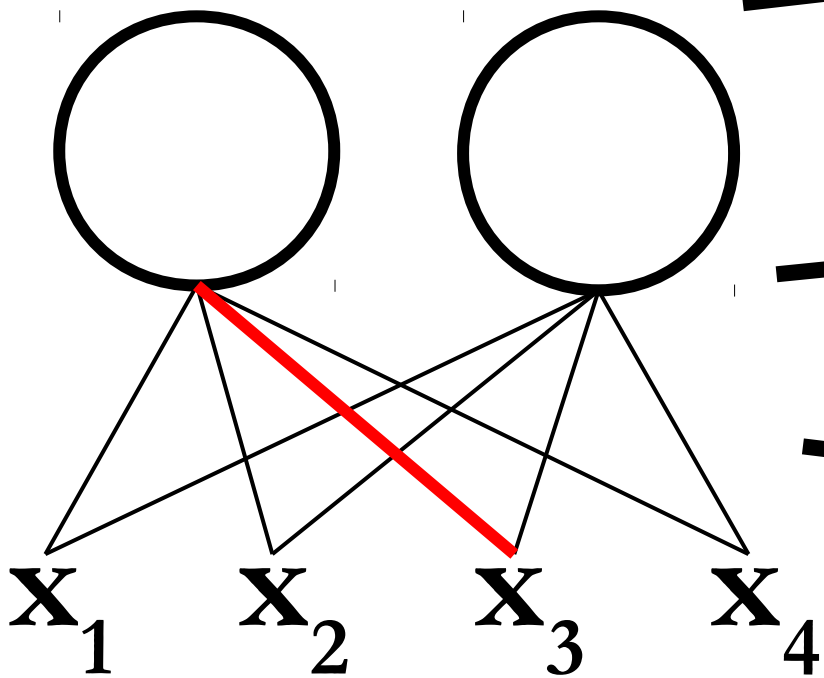
to

$$\begin{bmatrix} [0.9 & -0.5] \\ [0.8 & -0.5] \\ [-1.0 & 1.5] \\ [-1.0 & 1.0] \end{bmatrix}$$

from



$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}^{16}$$



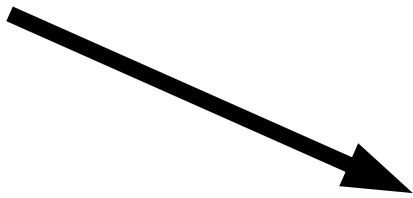
$\begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix}$



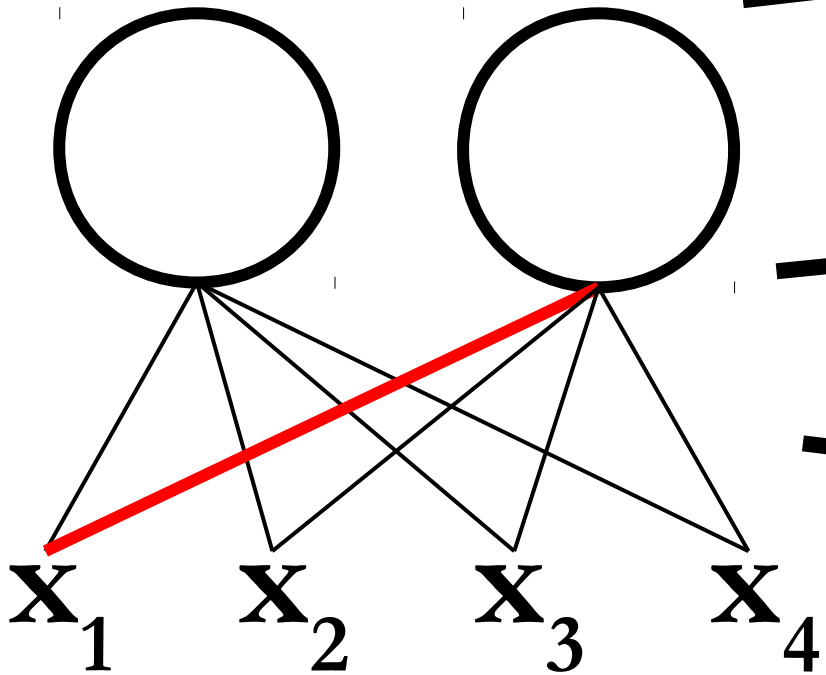
$\begin{bmatrix} 5.21 & -1.65 \\ 2.32 & 3.45 \\ 0.38 & 5.30 \end{bmatrix}$



to
 $\begin{bmatrix} 0.9 & -0.5 \\ 0.8 & -0.5 \\ -1.0 & 1.5 \\ -1.0 & 1.0 \end{bmatrix}$
from



$\begin{bmatrix} 4.9 & 3.0 & 1.4 & 0.2 \\ 6.4 & 3.2 & 4.5 & 1.5 \\ 5.8 & 2.7 & 5.1 & 1.9 \end{bmatrix}^{17}$



$$\begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix}$$



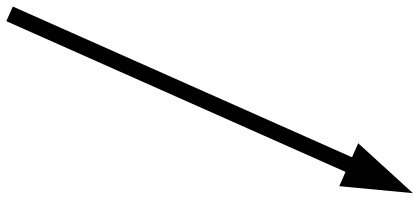
$$\begin{bmatrix} 5.21 & -1.65 \\ 2.32 & 3.45 \\ 0.38 & 5.30 \end{bmatrix}$$



to

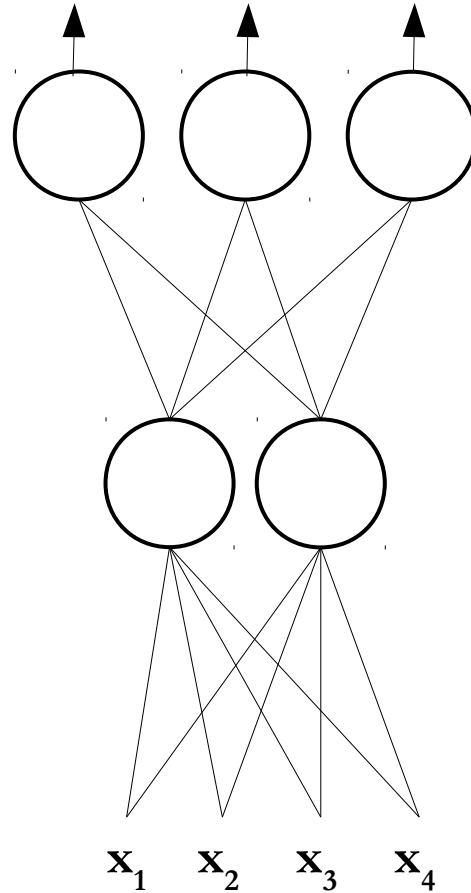
$$\begin{bmatrix} 0.9 & -0.5 \\ 0.8 & -0.5 \\ -1.0 & 1.5 \\ -1.0 & 1.0 \end{bmatrix}$$

from



$$\begin{bmatrix} 4.9 & 3.0 & 1.4 & 0.2 \\ 6.4 & 3.2 & 4.5 & 1.5 \\ 5.8 & 2.7 & 5.1 & 1.9 \end{bmatrix}^{18}$$

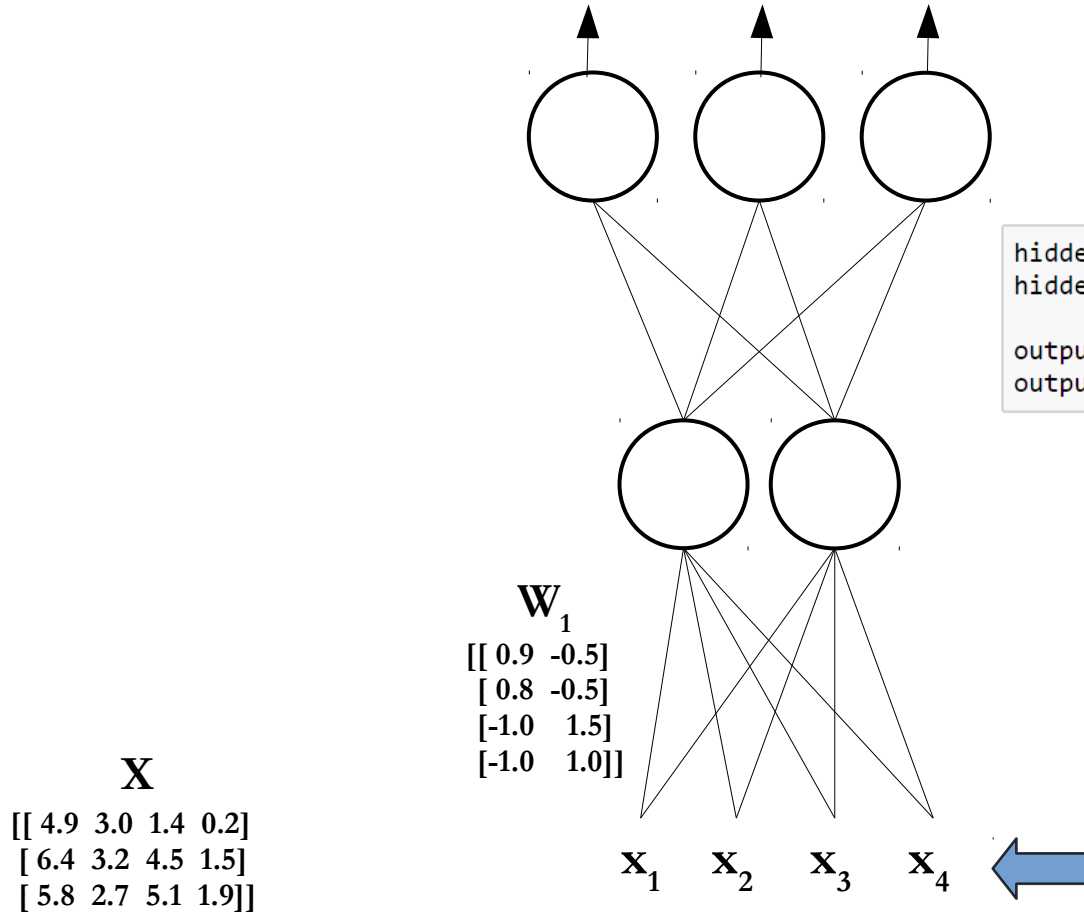
Feedforward



```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```

Feedforward



```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

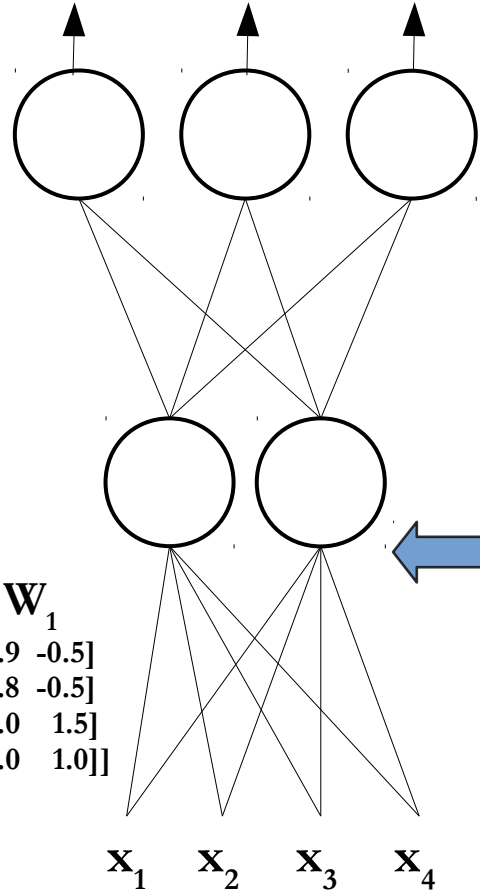
output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```

Feedforward

H_{in}
[[5.21 -1.65]
 [2.32 3.45]
 [0.38 5.30]]

X
[[4.9 3.0 1.4 0.2]
 [6.4 3.2 4.5 1.5]
 [5.8 2.7 5.1 1.9]]

W_1
[[0.9 -0.5]
 [0.8 -0.5]
 [-1.0 1.5]
 [-1.0 1.0]]



```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```

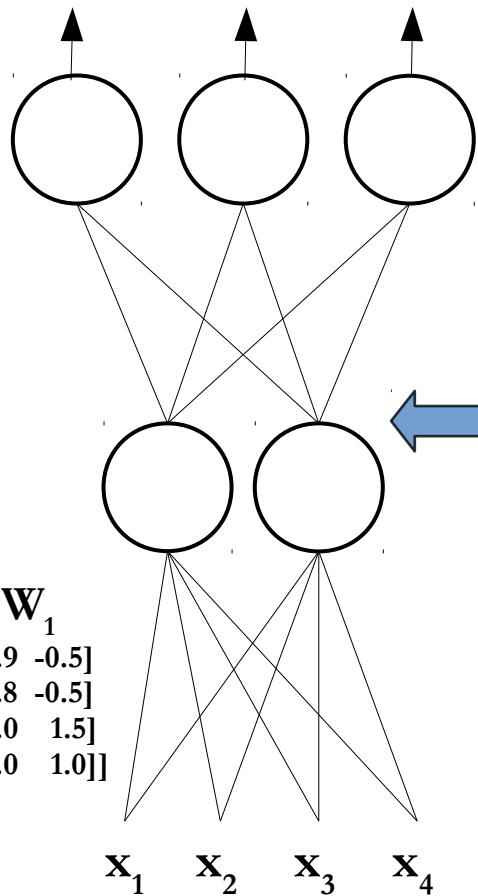
Feedforward

H_{in}
[[5.21 -1.65]
 [2.32 3.45]
 [0.38 5.30]]

H_{out}
[[1 0]
 [1 1]
 [0 1]]

X
[[4.9 3.0 1.4 0.2]
 [6.4 3.2 4.5 1.5]
 [5.8 2.7 5.1 1.9]]

W_1
[[0.9 -0.5]
 [0.8 -0.5]
 [-1.0 1.5]
 [-1.0 1.0]]



```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```

Feedforward

O_{in}

```
[[ 2  1 -1]
 [ 1  2  1]
 [-1  1  2]]
```

H_{in}

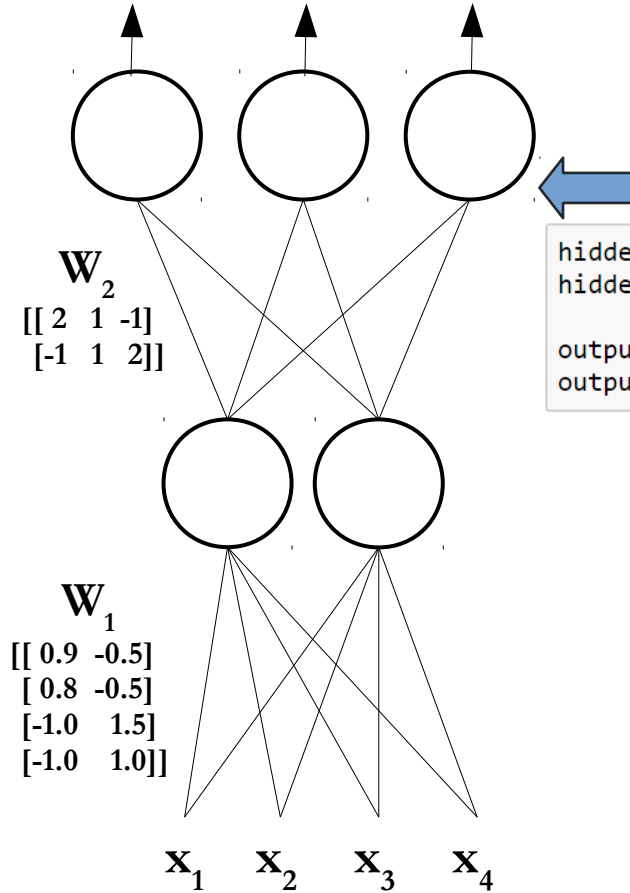
```
[[ 5.21 -1.65]
 [ 2.32  3.45]
 [ 0.38  5.30]]
```

H_{out}

```
[[1 0]
 [1 1]
 [0 1]]
```

X

```
[[ 4.9  3.0  1.4  0.2]
 [ 6.4  3.2  4.5  1.5]
 [ 5.8  2.7  5.1  1.9]]
```



W_2

```
[[ 2  1 -1]
 [-1  1  2]]
```

W_1

```
[[ 0.9 -0.5]
 [ 0.8 -0.5]
 [-1.0  1.5]
 [-1.0  1.0]]
```

```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

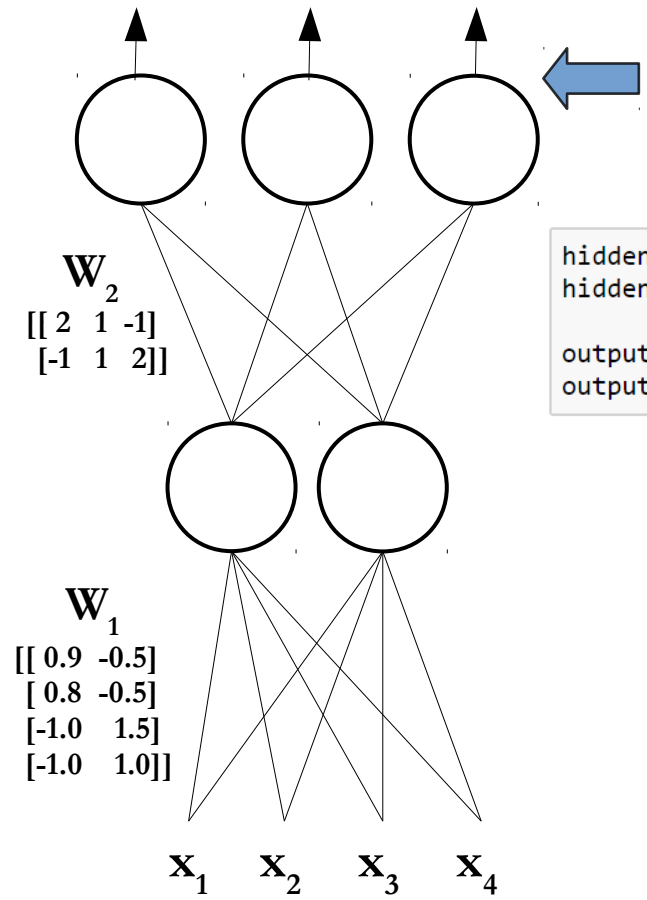
output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```

Feedforward

$$\mathbf{O}_{in} = \begin{bmatrix} 2 & 1 & -1 \\ 1 & 2 & 1 \\ -1 & 1 & 2 \end{bmatrix}$$
$$\mathbf{O}_{out} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{H}_{in} = \begin{bmatrix} 5.21 & -1.65 \\ 2.32 & 3.45 \\ 0.38 & 5.30 \end{bmatrix}$$
$$\mathbf{H}_{out} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \end{bmatrix}$$

$$\mathbf{X} = \begin{bmatrix} 4.9 & 3.0 & 1.4 & 0.2 \\ 6.4 & 3.2 & 4.5 & 1.5 \\ 5.8 & 2.7 & 5.1 & 1.9 \end{bmatrix}$$

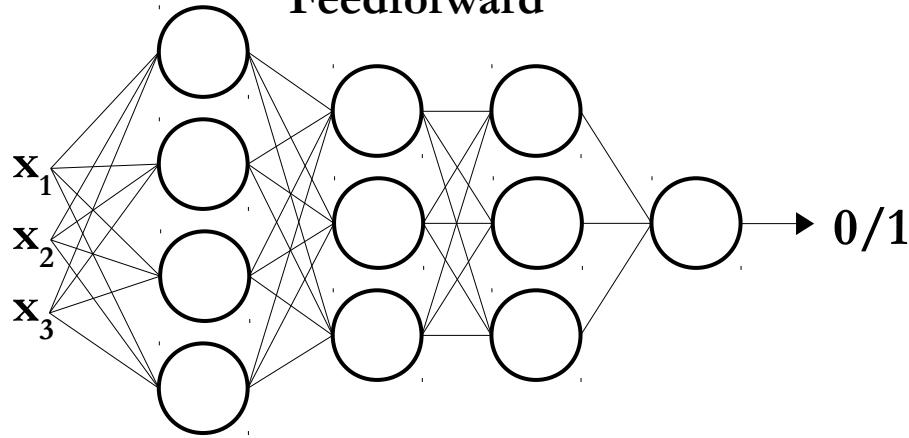


```
hidden_layer_inputs = np.dot(inputs, weights_1)
hidden_layer_outputs = step_function(hidden_layer_inputs)

output_layer_inputs = np.dot(hidden_layer_outputs, weights_2)
output_layer_outputs = step_function(output_layer_inputs)
```


Deep Learning

Feedforward

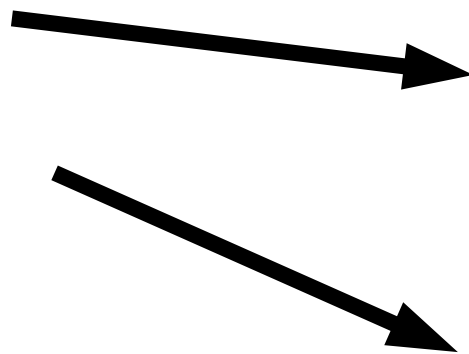
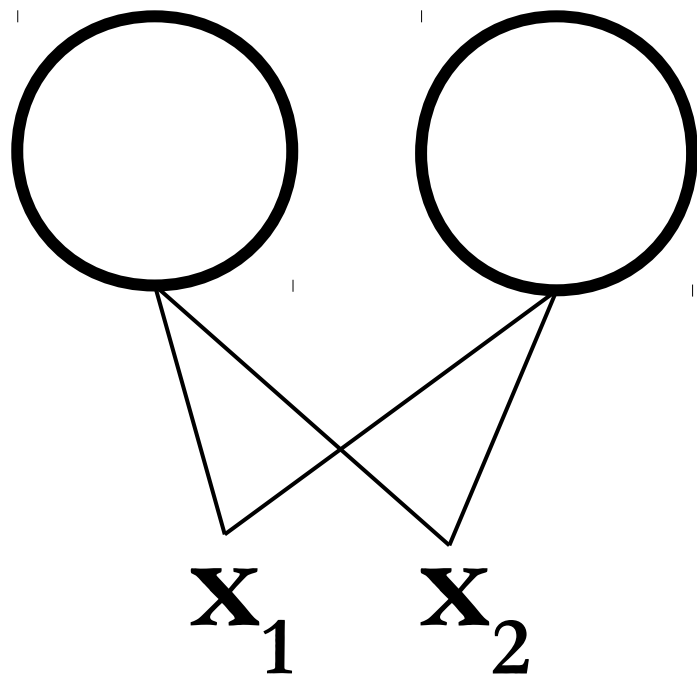


How does the algorithm make a decision?



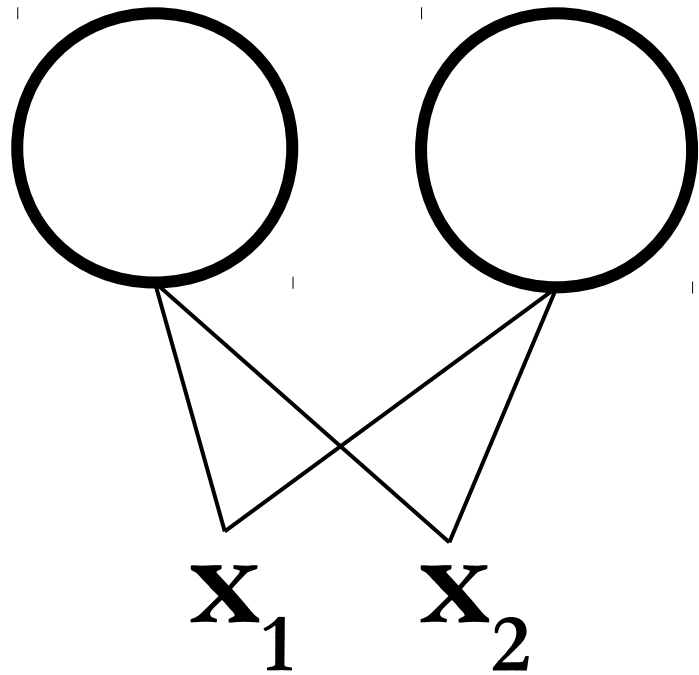
How do you determine the right parameters for the algorithm?





to
from $\begin{bmatrix} 0.9 & -0.5 \\ 0.8 & -0.5 \end{bmatrix}$

$\begin{bmatrix} 4.9 & 3.0 \\ 6.4 & 3.2 \end{bmatrix}$



$$\begin{bmatrix} 1 & 0 \\ 1 & 0 \end{bmatrix}$$

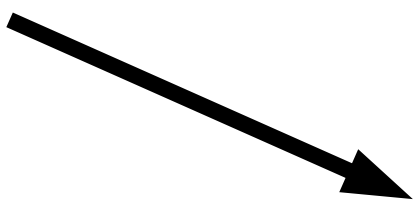


$$\begin{bmatrix} 6.81 & -3.95 \\ 8.32 & -4.80 \end{bmatrix}$$

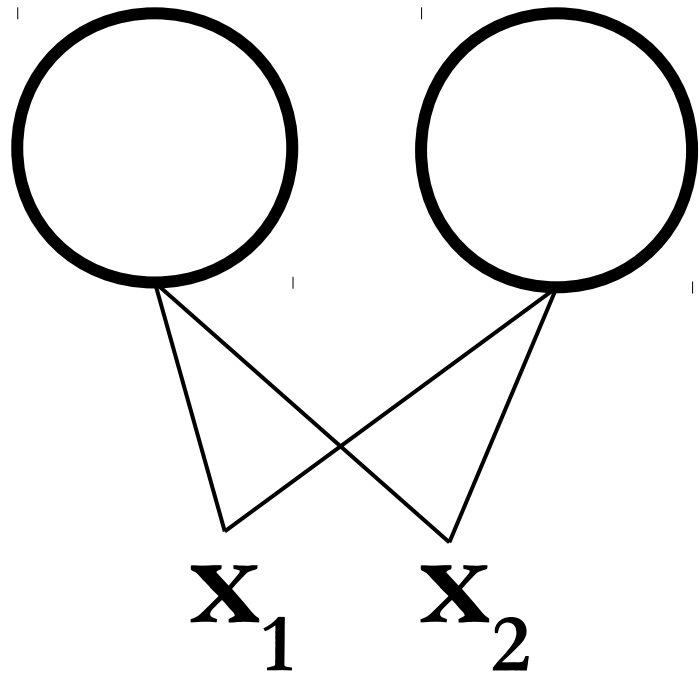


to

from $\begin{bmatrix} 0.9 & -0.5 \\ 0.8 & -0.5 \end{bmatrix}$



$$\begin{bmatrix} 4.9 & 3.0 \\ 6.4 & 3.2 \end{bmatrix}$$



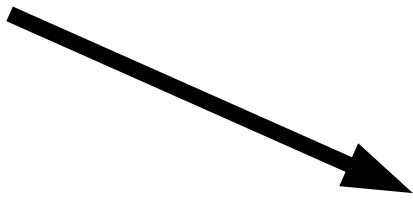
$$\begin{bmatrix} [0 & 0] \\ [0 & 0] \end{bmatrix}$$



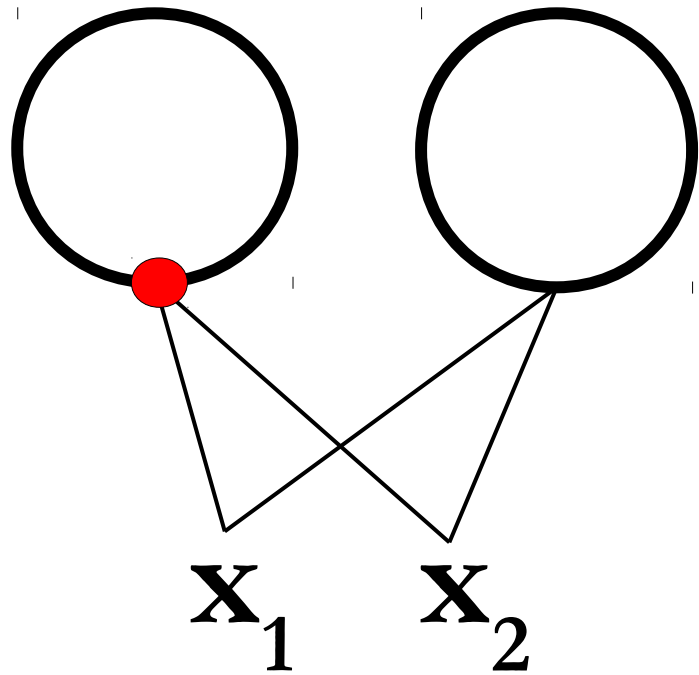
$$\begin{bmatrix} [1.21 & 1.10] \\ [0.72 & 0.80] \end{bmatrix}$$



to
from $\begin{bmatrix} [0.9 & -0.5] \\ [0.8 & -0.5] \end{bmatrix}$



$$\begin{bmatrix} [4.9 & 3.0] \\ [6.4 & 3.2] \end{bmatrix}$$

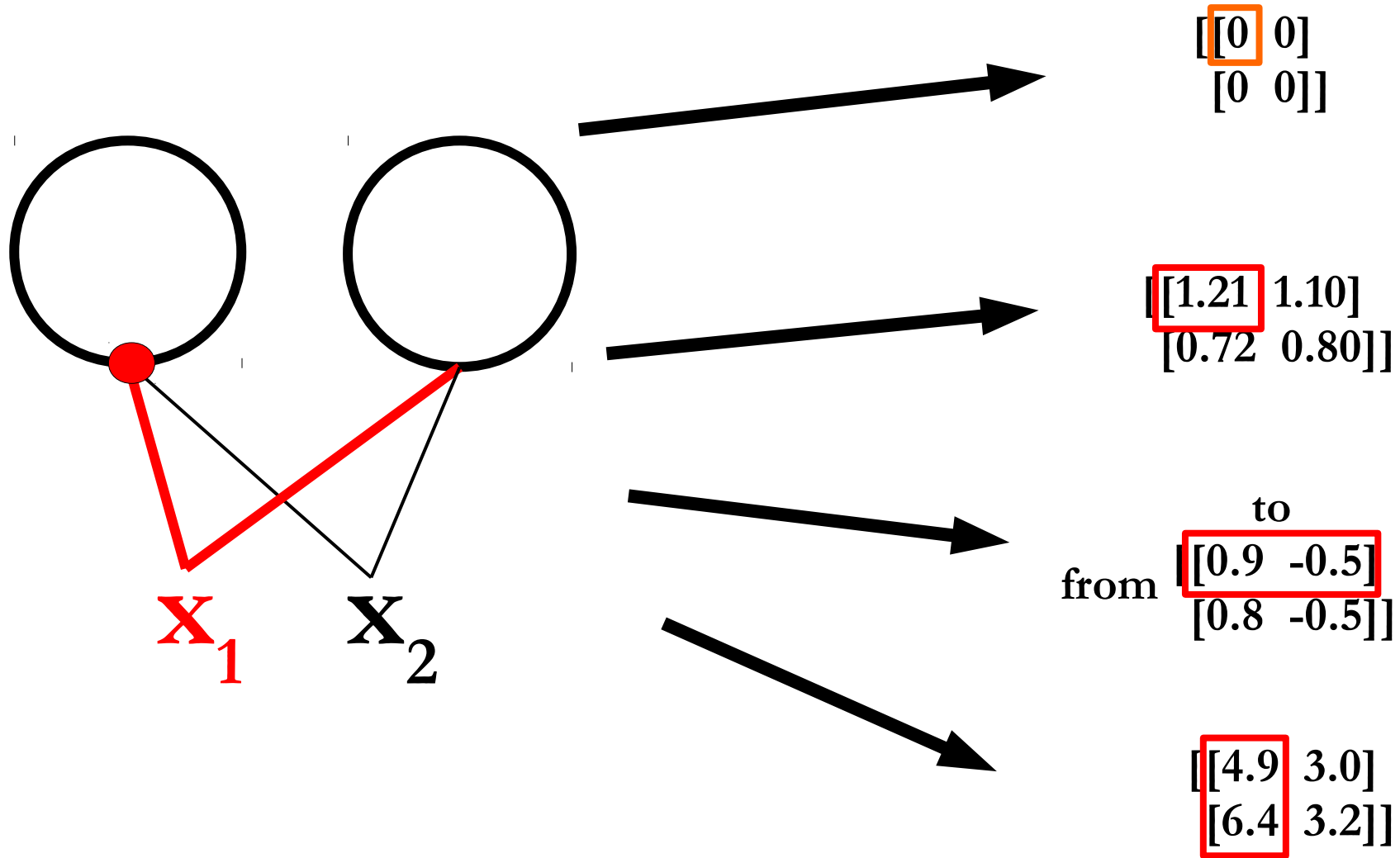


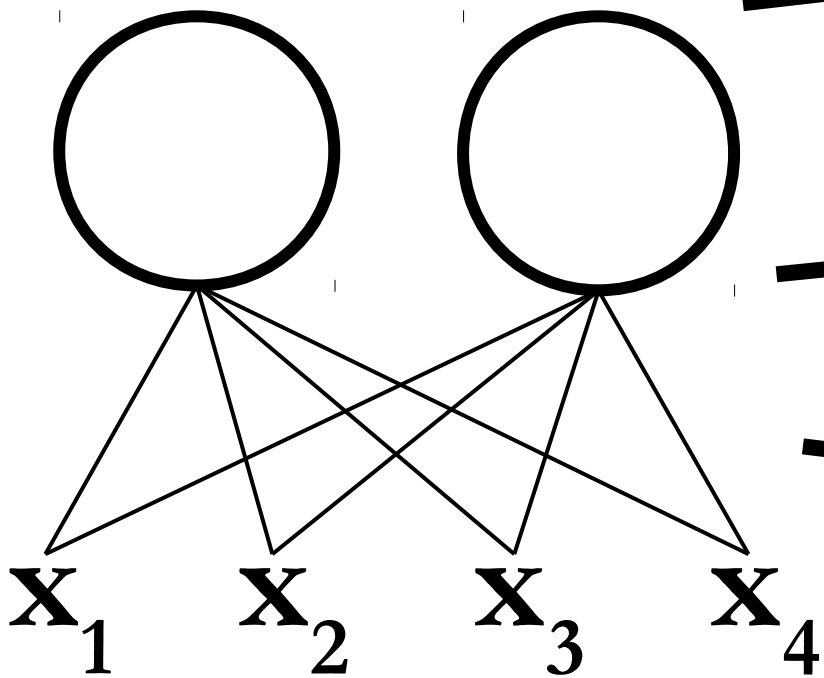
$$\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 1.21 & 1.10 \\ 0.72 & 0.80 \end{bmatrix}$$

to
from $\begin{bmatrix} 0.9 & -0.5 \\ 0.8 & -0.5 \end{bmatrix}$

$$\begin{bmatrix} 4.9 & 3.0 \\ 6.4 & 3.2 \end{bmatrix}$$





$$\begin{bmatrix} [1 & 0] \\ [1 & 1] \\ [0 & 1] \end{bmatrix}$$



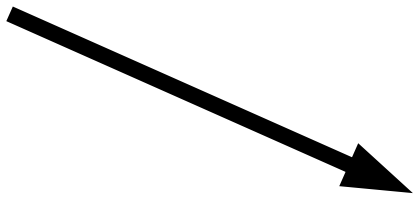
$$\begin{bmatrix} [5.21 & -1.65] \\ [2.32 & 3.45] \\ [0.38 & 5.30] \end{bmatrix}$$



to

$$\begin{bmatrix} [0.9 & -0.5] \\ [0.8 & -0.5] \\ [-1.0 & 1.5] \\ [-1.0 & 1.0] \end{bmatrix}$$

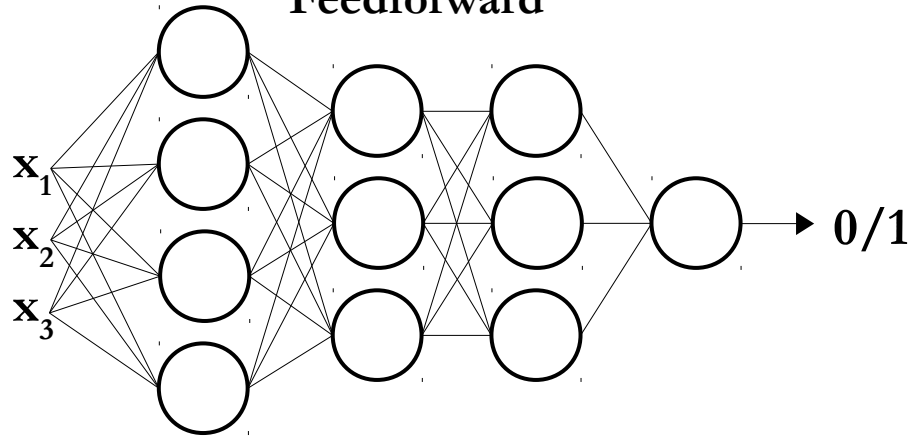
from



$$\begin{bmatrix} [4.9 & 3.0 & 1.4 & 0.2] \\ [6.4 & 3.2 & 4.5 & 1.5] \\ [5.8 & 2.7 & 5.1 & 1.9] \end{bmatrix}^{31}$$

Deep Learning

Feedforward



How does the algorithm make a decision?



How do you determine the right parameters for the algorithm?

