

Welcome to the introduction
to computational cognitive
modelling workshop!

Part 2: Introduction to artificial neural networks

Part 2: **Introduction to artificial neural networks**

Olivia Guest

Chris Brand

Nick Sexton

Nicole Cruz De Echeverria Loebell

What is a neural network?

A mathematical model

- Inspired by the nervous system

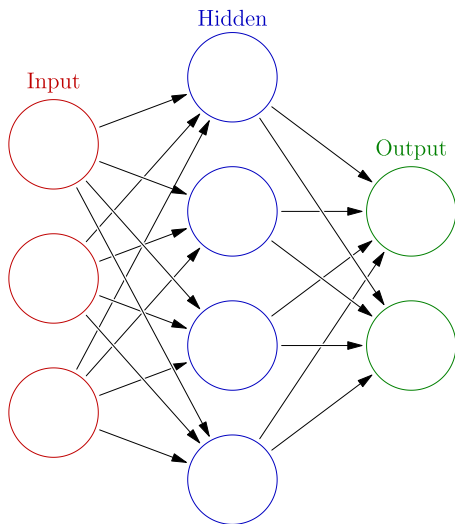


Figure: Glosser.ca / CC-BY-SA-3.0

What is a neural network?

A mathematical model

- ▶ Inspired by the nervous system
- ▶ A set of *units*, connected by *weights*

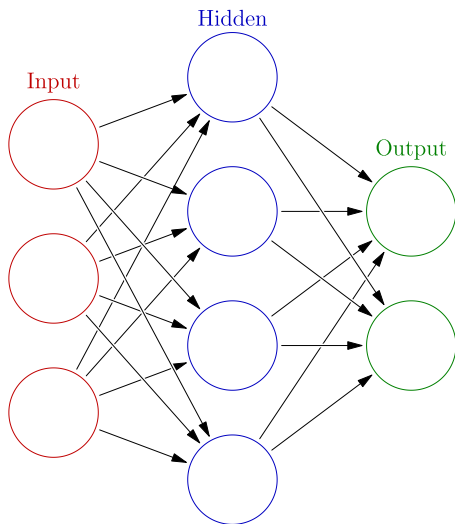


Figure: Glosser.ca / CC-BY-SA-3.0

What is a neural network?

A mathematical model

- ▶ Inspired by the nervous system
- ▶ A set of *units*, connected by *weights*
- ▶ The network *runs* by passing *activations* from the *input* (to the *hidden*) to the *output* units

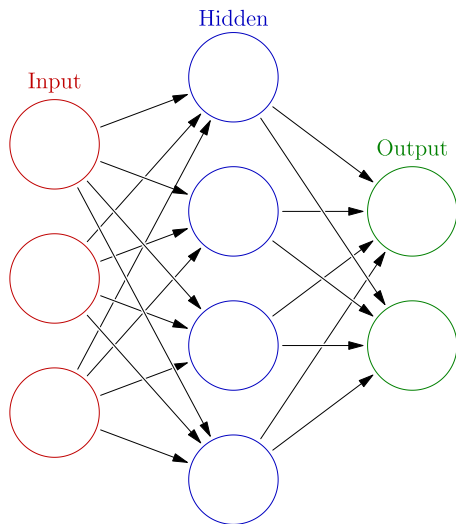


Figure: Glosser.ca / CC-BY-SA-3.0

Why use artificial neural networks for modelling?

Some aspects of their behaviour are like their namesake!

- ▶ Learn pretty much any input-output data

Why use artificial neural networks for modelling?

Some aspects of their behaviour are like their namesake!

- ▶ Learn pretty much any input-output data
- ▶ Uncover rules on their own about data

Why use artificial neural networks for modelling?

Some aspects of their behaviour are like their namesake!

- ▶ Learn pretty much any input-output data
- ▶ Uncover rules on their own about data
- ▶ Generalise from what they have learnt

Why use artificial neural networks for modelling?

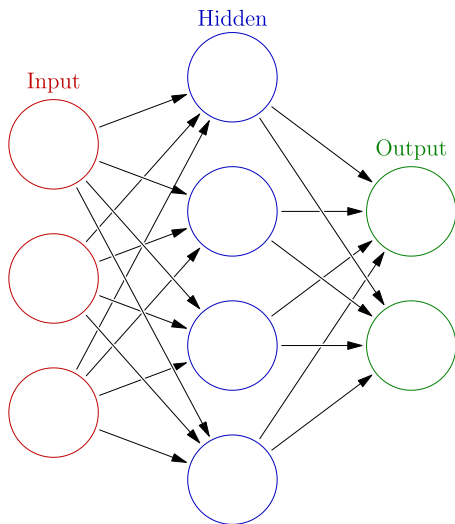
Some aspects of their behaviour are like their namesake!

- ▶ Learn pretty much any input-output data
- ▶ Uncover rules on their own about data
- ▶ Generalise from what they have learnt
- ▶ Cope with noise and damage

How does an artificial neural network run?

By using maths, predictably!

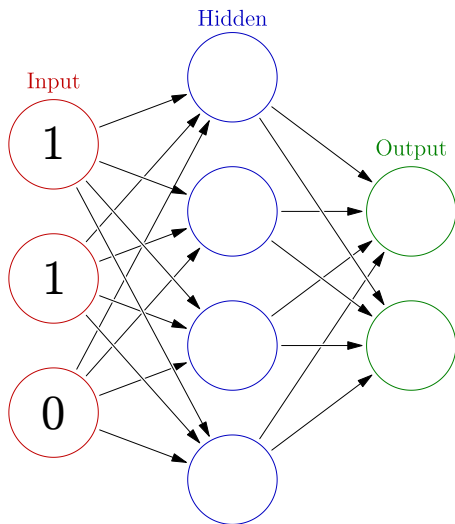
1. **Input units** are set to a *pattern*



How does an artificial neural network run?

By using maths, predictably!

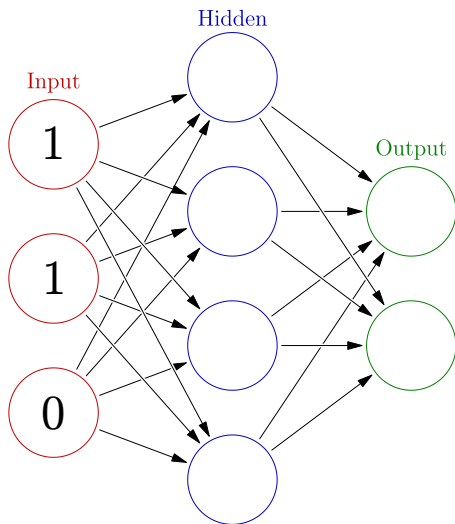
1. **Input units** are set to a *pattern*



How does an artificial neural network run?

By using maths, predictably!

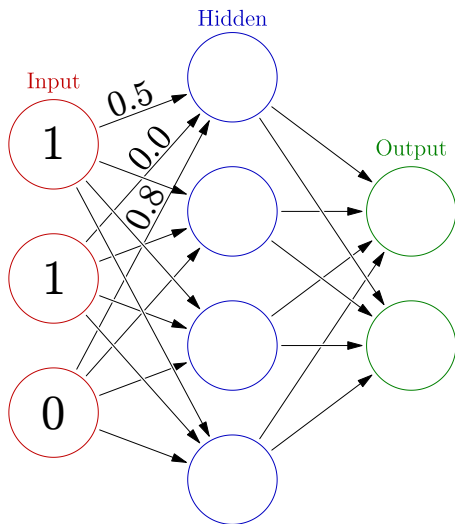
1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states



How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states

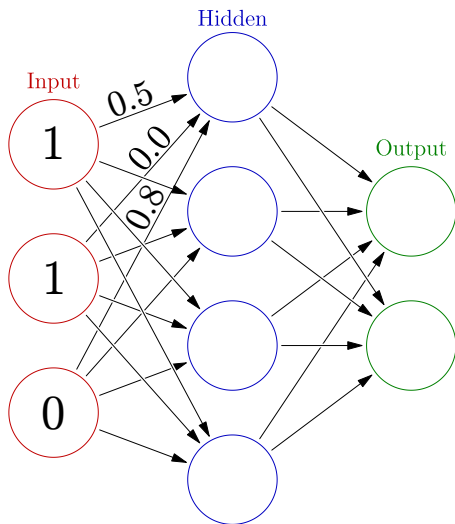


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states:

$$1 \times 0.5 = 0.5$$



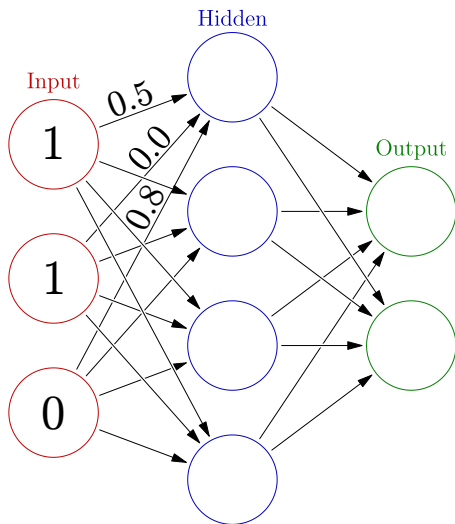
How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states:

$$1 \times 0.5 = 0.5$$

$$1 \times 0.0 = 0.0$$



How does an artificial neural network run?

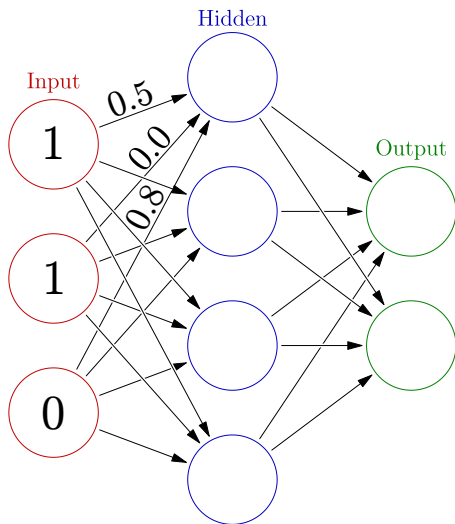
By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states:

$$1 \times 0.5 = 0.5$$

$$1 \times 0.0 = 0.0$$

$$0 \times 0.8 = 0.0$$

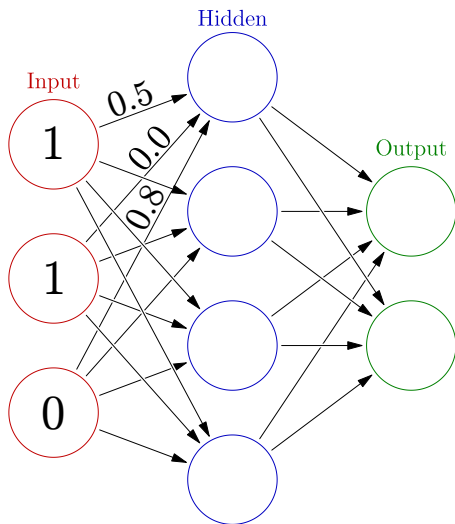


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states:

$$\begin{array}{rcl} 1 \times 0.5 & = & 0.5 \\ 1 \times 0.0 & = & 0.0 \\ 0 \times 0.8 & = & 0.0 \quad + \\ \hline \end{array}$$

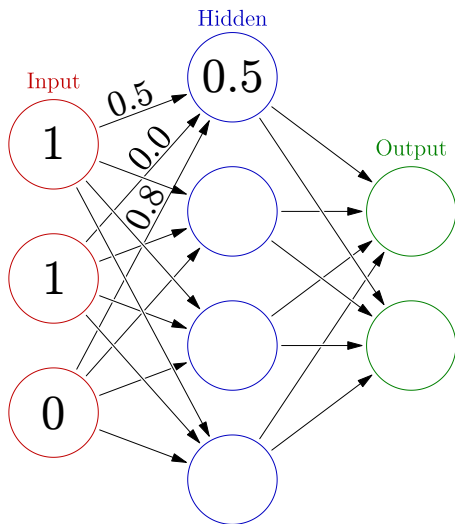


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states:

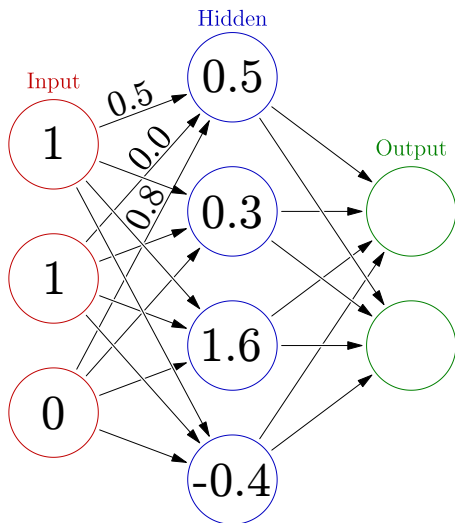
$$\begin{array}{rclcl} 1 \times 0.5 & = & 0.5 & & \\ 1 \times 0.0 & = & 0.0 & & \\ 0 \times 0.8 & = & 0.0 & + & \\ \hline & & 0.5 & & \end{array}$$



How does an artificial neural network run?

By using maths, predictably!

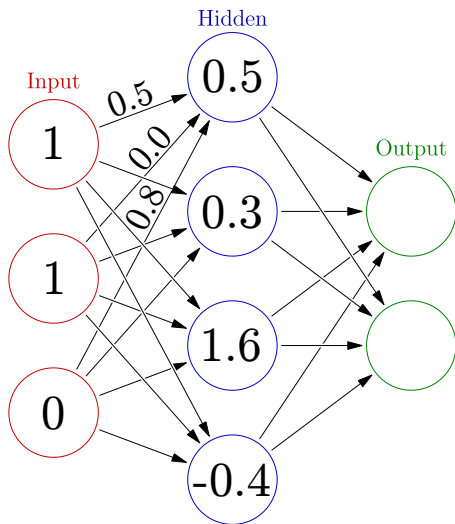
1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states



How does an artificial neural network run?

By using maths, predictably!

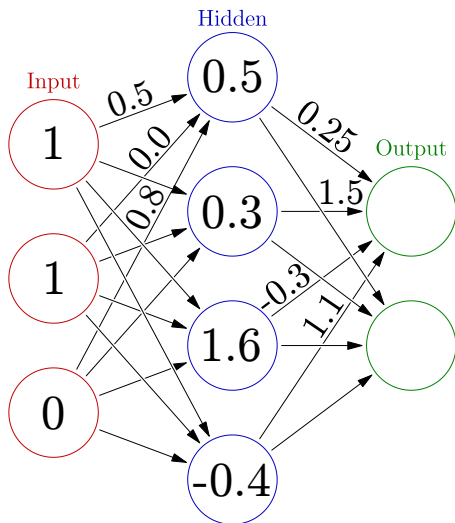
1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**



How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**

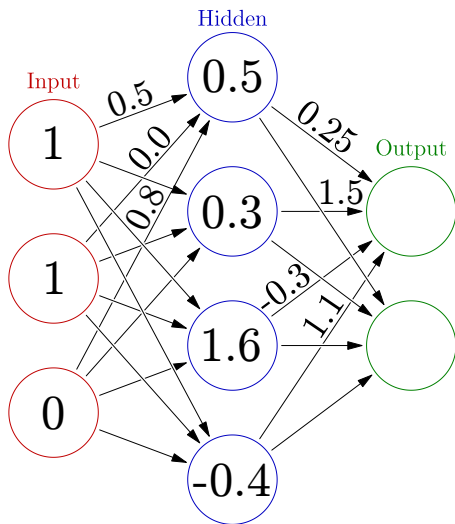


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

$$0.5 \times 0.25 = 0.125$$

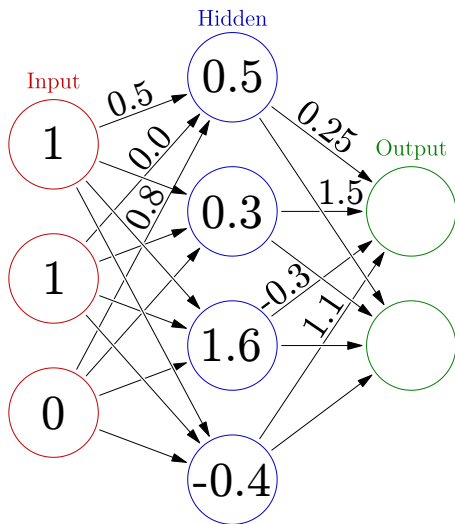


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

$$\begin{aligned} 0.5 \times 0.25 &= 0.125 \\ 0.3 \times 1.5 &= 0.45 \end{aligned}$$

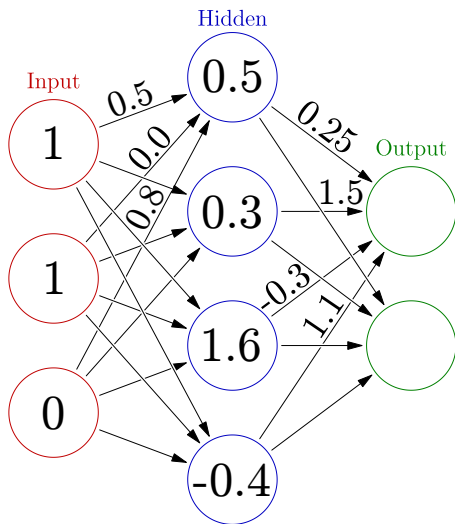


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

$$\begin{aligned}0.5 \times 0.25 &= 0.125 \\0.3 \times 1.5 &= 0.45 \\1.6 \times -0.3 &= -0.48\end{aligned}$$

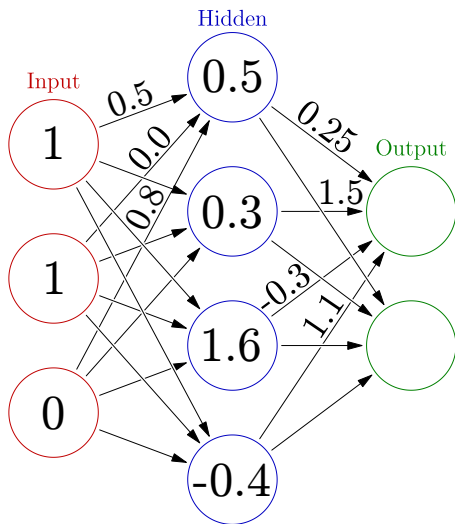


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

$$\begin{aligned} 0.5 \times 0.25 &= 0.125 \\ 0.3 \times 1.5 &= 0.45 \\ 1.6 \times -0.3 &= -0.48 \\ -0.4 \times 1.1 &= -0.44 \end{aligned}$$

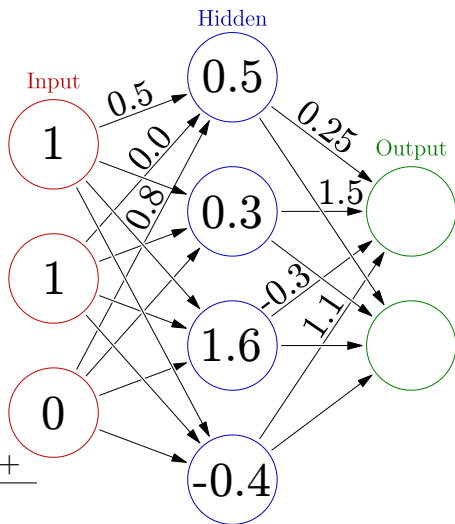


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

$$\begin{array}{rcl} 0.5 \times 0.25 & = & 0.125 \\ 0.3 \times 1.5 & = & 0.45 \\ 1.6 \times -0.3 & = & -0.48 \\ -0.4 \times 1.1 & = & -0.44 \quad + \\ \hline & & -0.345 \end{array}$$

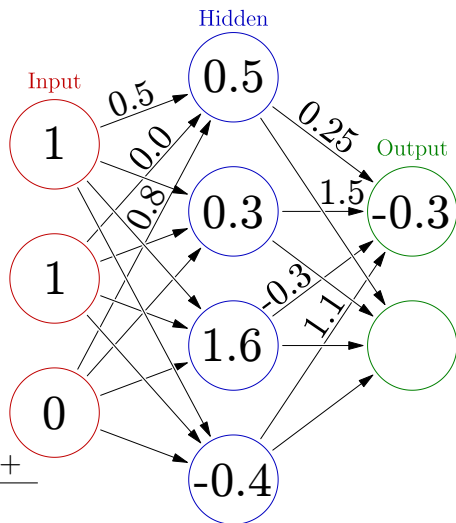


How does an artificial neural network run?

By using maths, predictably!

1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**:

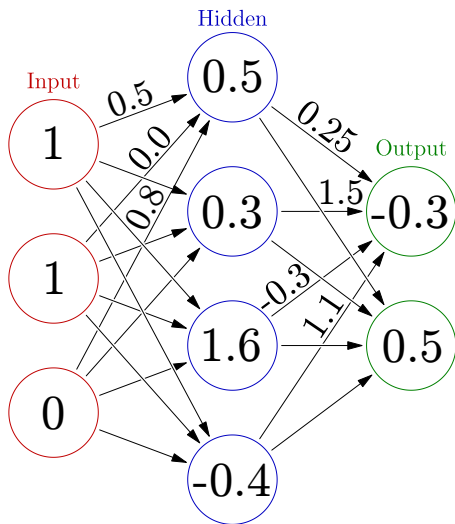
$$\begin{array}{rcl} 0.5 \times 0.25 & = & 0.125 \\ 0.3 \times 1.5 & = & 0.45 \\ 1.6 \times -0.3 & = & -0.48 \\ -0.4 \times 1.1 & = & -0.44 \quad + \\ \hline & & -0.345 \end{array}$$



How does an artificial neural network run?

By using maths, predictably!

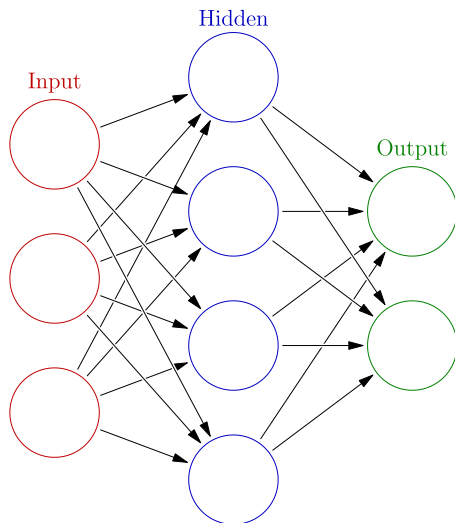
1. **Input units** are set to a *pattern*
2. Calculate **hidden units'** states
3. Same for **output units**



How does an artificial neural network run?

By using maths, predictably!

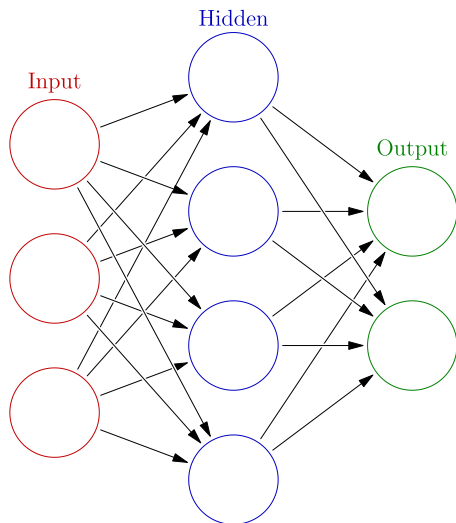
- ▶ But programmers are *lazy*!



How does an artificial neural network run?

By using maths, predictably!

- General names save time

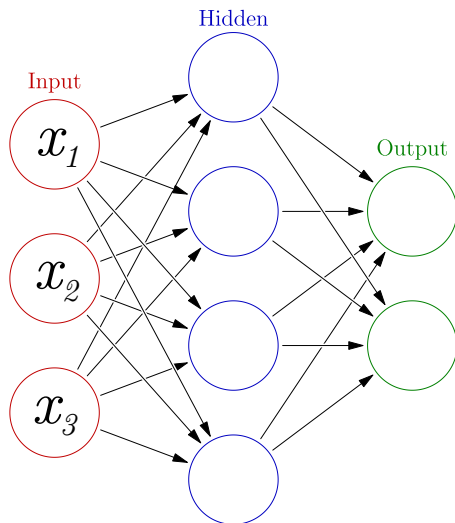


How does an artificial neural network run?

By using maths, predictably!

- ▶ General names save time

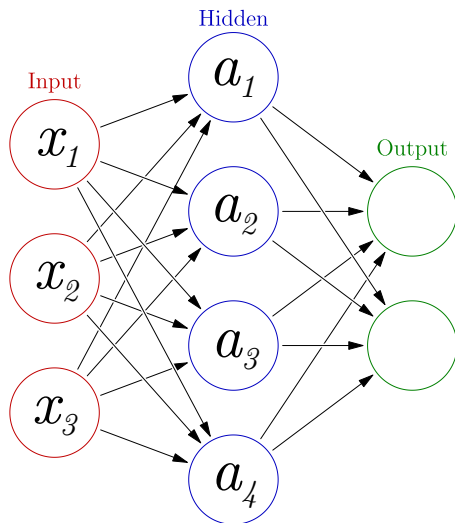
- ▶ **input units:** x_i



How does an artificial neural network run?

By using maths, predictably!

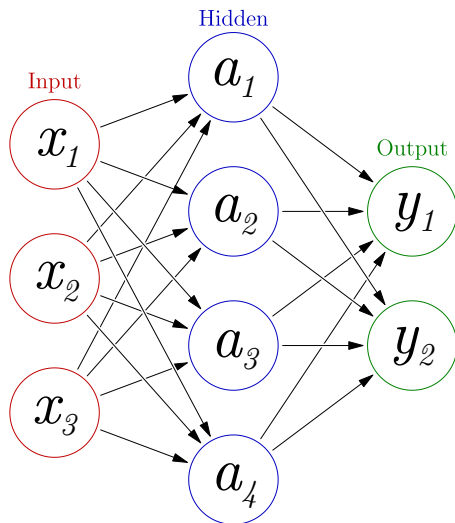
- ▶ General names save time
- ▶ **input units:** x_i
- ▶ **hidden units:** a_j



How does an artificial neural network run?

By using maths, predictably!

- ▶ General names save time
- ▶ **input units:** x_i
- ▶ **hidden units:** a_j
- ▶ **output units:** y_k



How does an artificial neural network run?

By using maths, predictably!

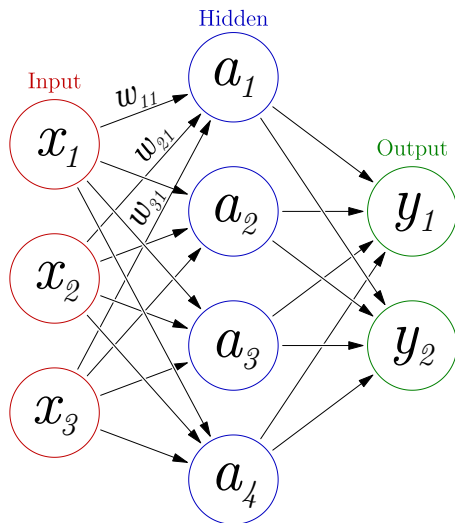
- ▶ General names save time

- ▶ **input units:** x_i

- ▶ **hidden units:** a_j

- ▶ **output units:** y_k

- ▶ connection weights: w_{ij}



How does an artificial neural network run?

By using maths, predictably!

- ▶ General names save time

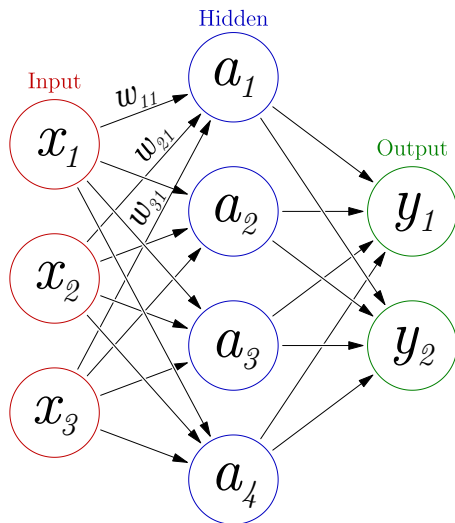
- ▶ **input units:** x_i

- ▶ **hidden units:** a_j

- ▶ **output units:** y_k

- ▶ connection weights: w_{ij}

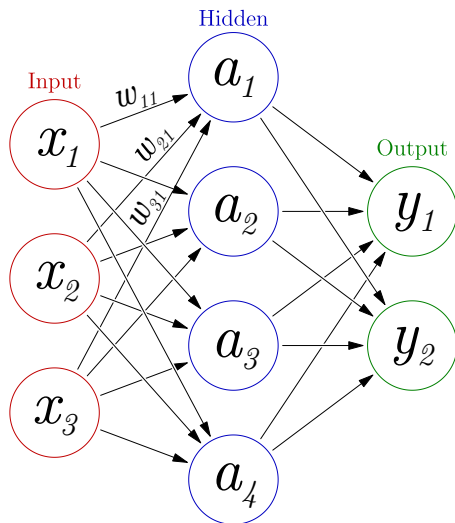
- ▶ subscripts
general: $ijklm\dots$
specific: 12345...



How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

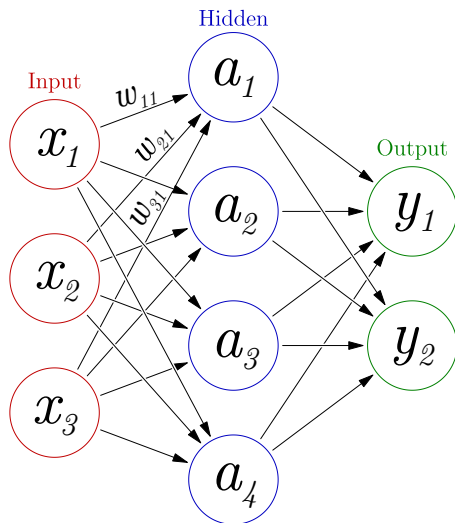


How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

$$a_i =$$

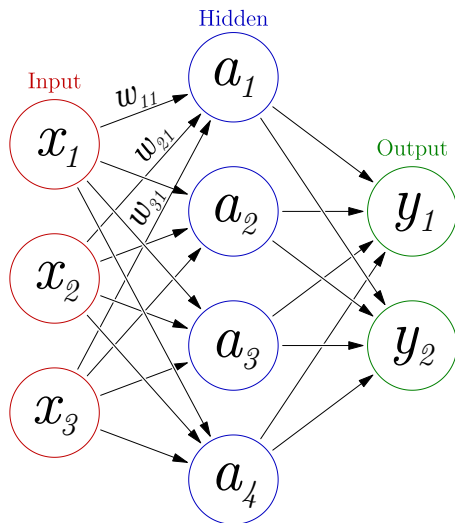


How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

$$a_i = x_j \times w_{ji}$$

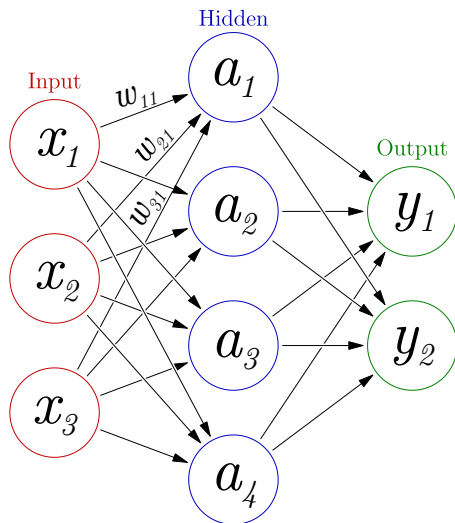


How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

$$a_i = \sum_{j=1}^N x_j \times w_{ji}$$

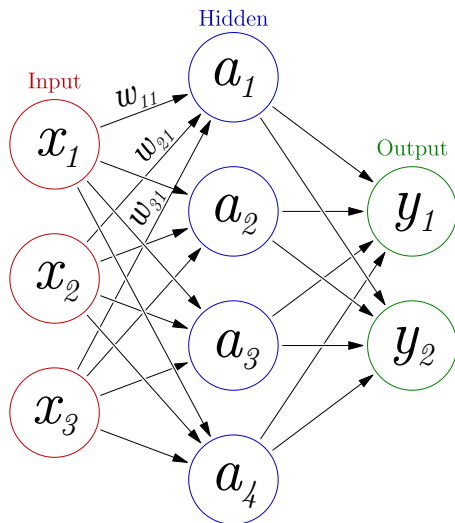


How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$



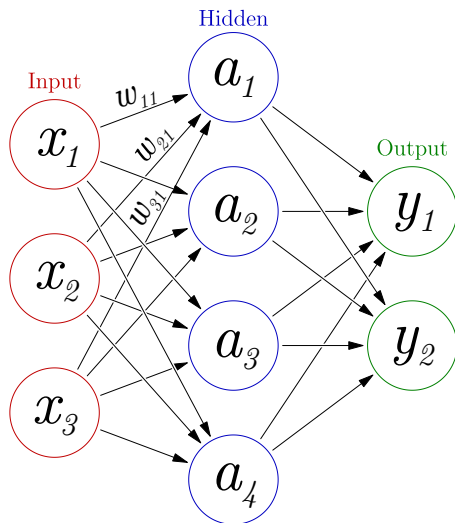
How does an artificial neural network run?

By using maths, predictably!

We use general names to write a general equation:

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

where a_i is the unit whose state we want to calculate, N is the number of units on the previous layer, w_{ji} is the weight on the connection between i and j , and f is a function that the unit applies.

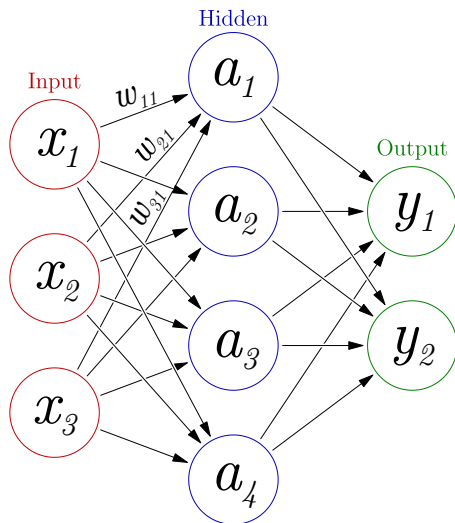


How does an artificial neural network run?

By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$



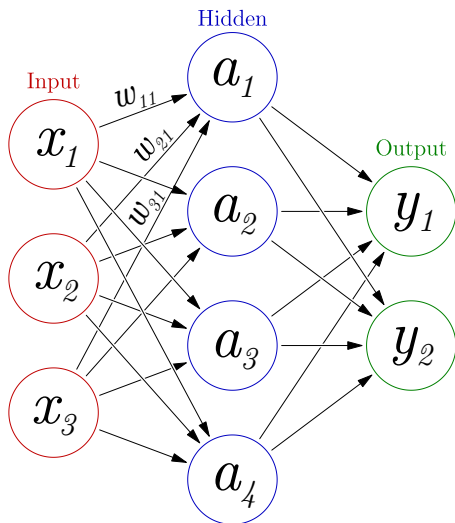
How does an artificial neural network run?

By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\mathbf{1}} = f \left(\sum_{j=1}^N x_j \times w_{j\mathbf{1}} \right)$$



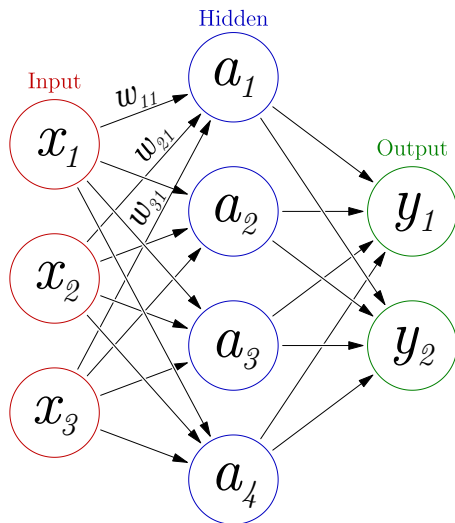
How does an artificial neural network run?

By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{1}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{1}} \right)$$



How does an artificial neural network run?

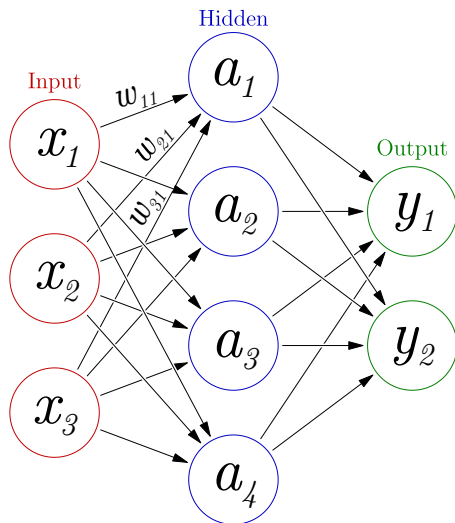
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{1}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{1}} \right)$$

$$x_{\textcolor{red}{1}} \times w_{\textcolor{blue}{1}\textcolor{blue}{1}}$$



How does an artificial neural network run?

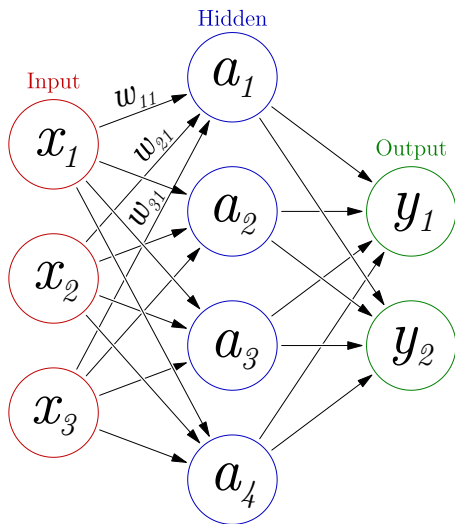
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{1}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{1}} \right)$$

$$x_{\textcolor{red}{1}} \times w_{\textcolor{blue}{1}\textcolor{red}{1}} + x_{\textcolor{red}{2}} \times w_{\textcolor{blue}{2}\textcolor{red}{1}}$$



How does an artificial neural network run?

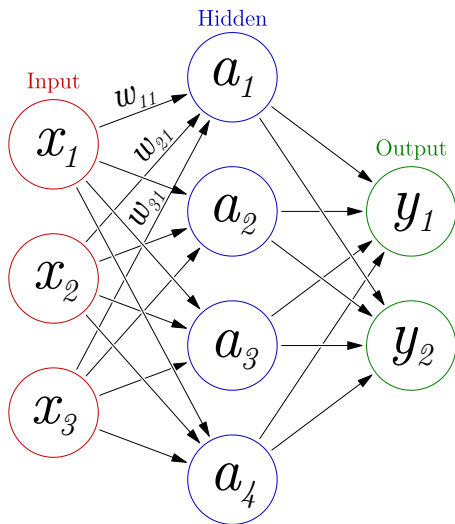
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_1 = f \left(\sum_{j=1}^3 x_j \times w_{j1} \right)$$

$$x_1 \times w_{11} + x_2 \times w_{21} + x_3 \times w_{31}$$



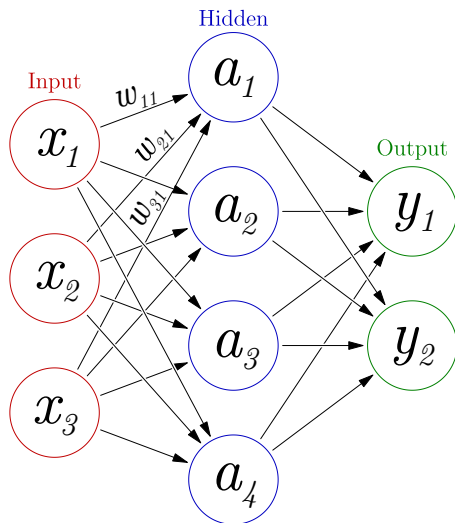
How does an artificial neural network run?

By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{2}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{2}} \right)$$



How does an artificial neural network run?

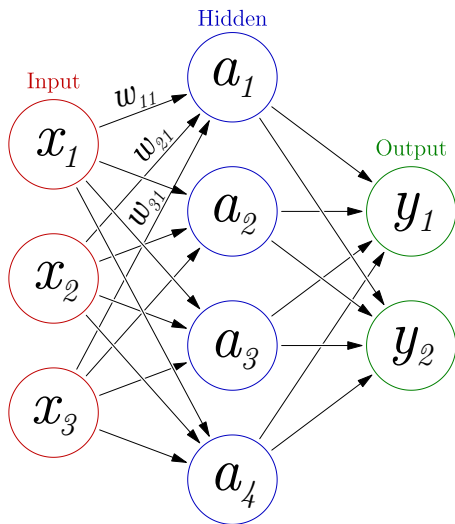
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{2}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{2}} \right)$$

$$x_{\textcolor{red}{1}} \times w_{\textcolor{blue}{1}\textcolor{blue}{2}}$$



How does an artificial neural network run?

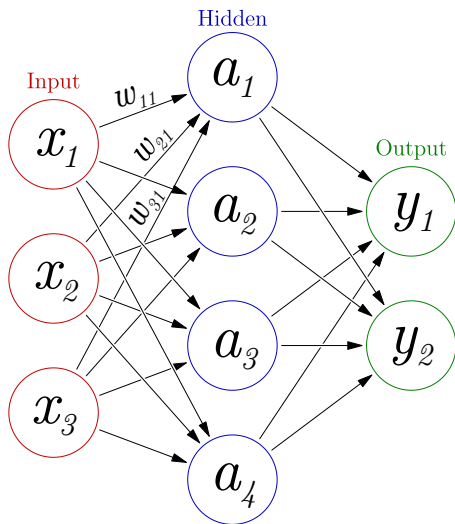
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{2}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{2}} \right)$$

$$x_{\textcolor{red}{1}} \times w_{\textcolor{blue}{1}\textcolor{blue}{2}} + x_{\textcolor{red}{2}} \times w_{\textcolor{blue}{2}\textcolor{blue}{2}}$$



How does an artificial neural network run?

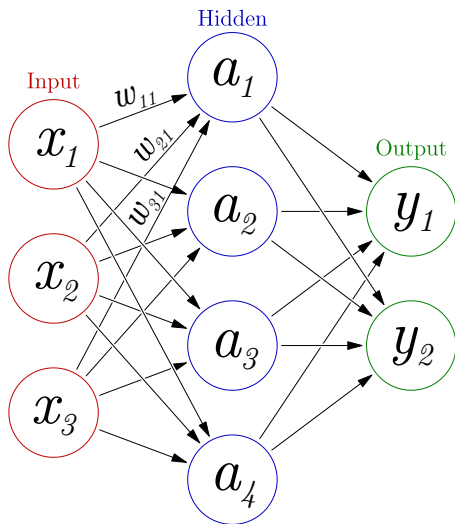
By using maths, predictably!

We use this equation by replacing *iterators* i and j :

$$a_i = f \left(\sum_{j=1}^N x_j \times w_{ji} \right)$$

$$a_{\textcolor{blue}{2}} = f \left(\sum_{j=1}^{\textcolor{red}{3}} x_j \times w_{j\textcolor{blue}{2}} \right)$$

$$x_{\textcolor{red}{1}} \times w_{\textcolor{blue}{1}\textcolor{blue}{2}} + x_{\textcolor{red}{2}} \times w_{\textcolor{blue}{2}\textcolor{blue}{2}} + x_{\textcolor{red}{3}} \times w_{\textcolor{blue}{3}\textcolor{blue}{2}}$$



How do networks learn?

Cunning!

- ▶ Many options: Hebbian learning, back-propagation of error, Boltzmann machine learning, self-organising map algorithm, etc.

How do networks learn?

Cunning!

- ▶ Many options: Hebbian learning, back-propagation of error, Boltzmann machine learning, self-organising map algorithm, etc.
- ▶ All learning algorithms work by changing the connection weights

How do networks learn?

Cunning!

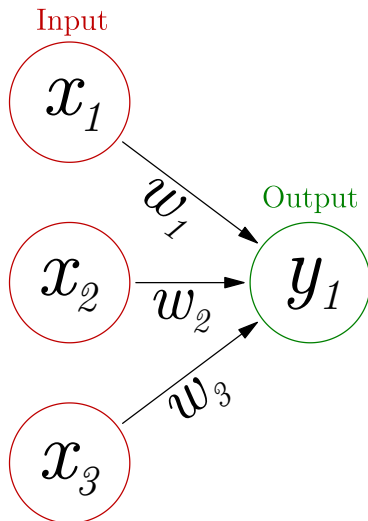
- ▶ Many options: Hebbian learning, back-propagation of error, Boltzmann machine learning, self-organising map algorithm, etc.
- ▶ All learning algorithms work by changing the connection weights
- ▶ Learning can be divided into *supervised*, *unsupervised*, and *reinforcement*

Hebbian learning

A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz



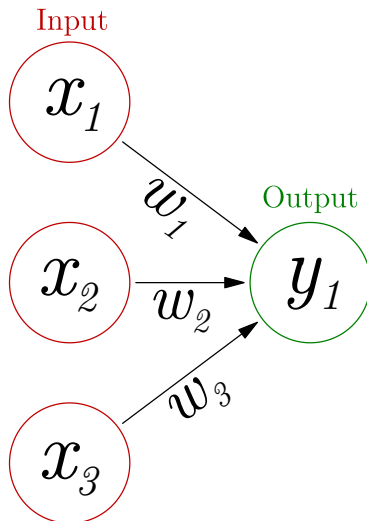
Hebbian learning

A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz

$$w_i =$$



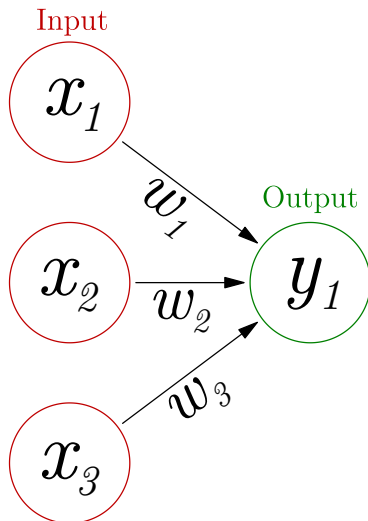
Hebbian learning

A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz

$$w_i = x_i \times y_j$$



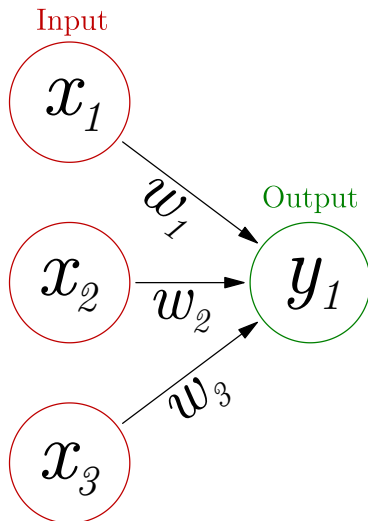
Hebbian learning

A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz

$$w_i = \eta \times x_i \times y_j$$



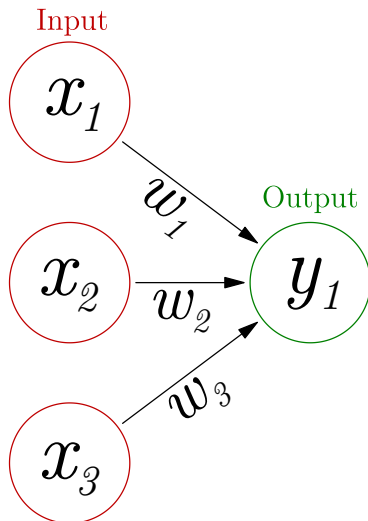
Hebbian learning

A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz

$$\Delta w_i = \eta \times x_i \times y_j$$



Hebbian learning

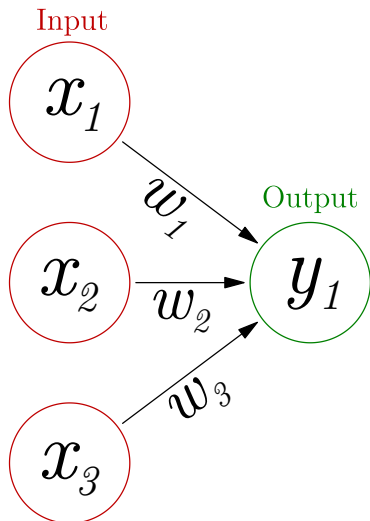
A very simple learning rule

“Cells that fire together, wire together”

— Carla Shatz

$$\Delta w_i = \eta \times \textcolor{red}{x}_i \times \textcolor{green}{y}_j$$

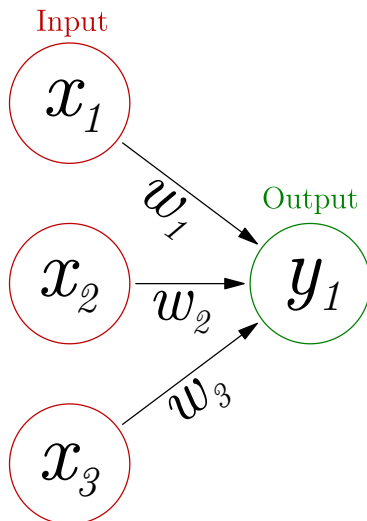
which means each weight is changed by a small in/decrement for every pattern



Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but very *unstable*!

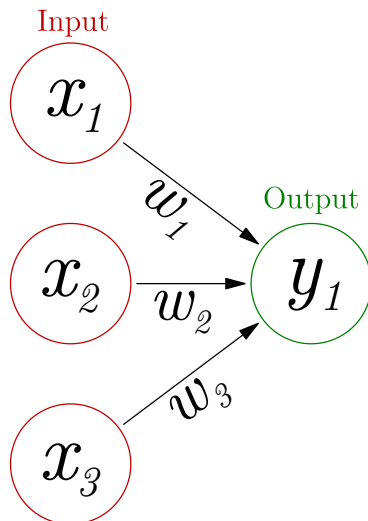


Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$



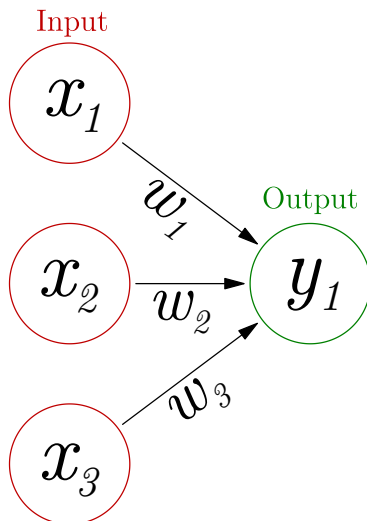
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = \eta \times x_i \times y_j$$



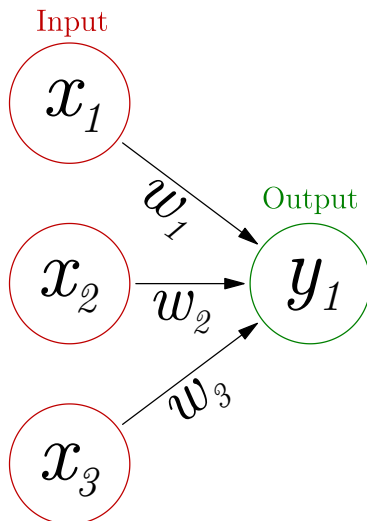
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.5 \times x_i \times y_j$$



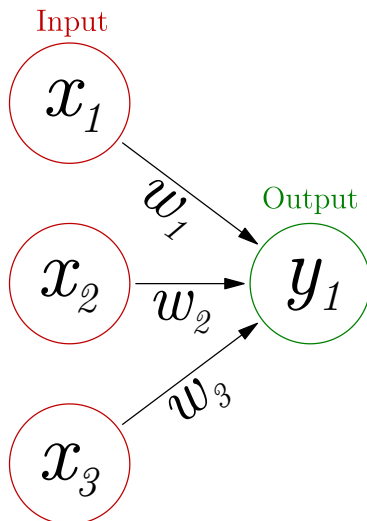
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.5 \times x_1 \times y_j$$



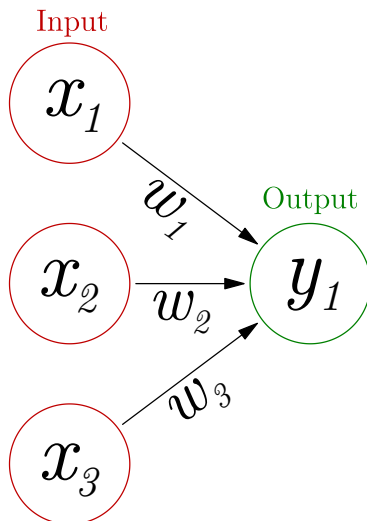
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.5 \times x_1 \times y_1$$



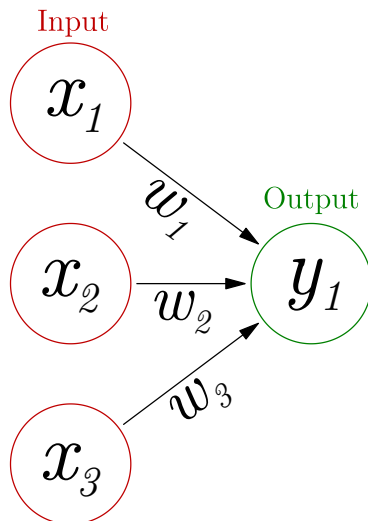
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.5 \times 1.0 \times y_1$$



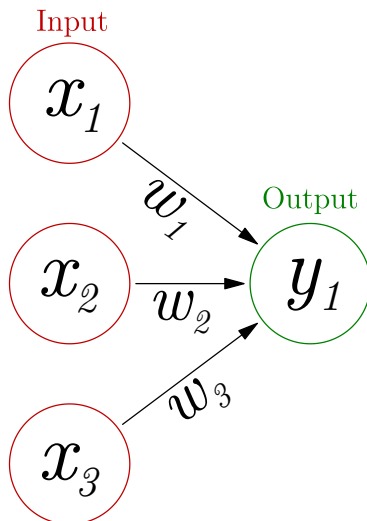
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.5 \times 1.0 \times 0.3$$



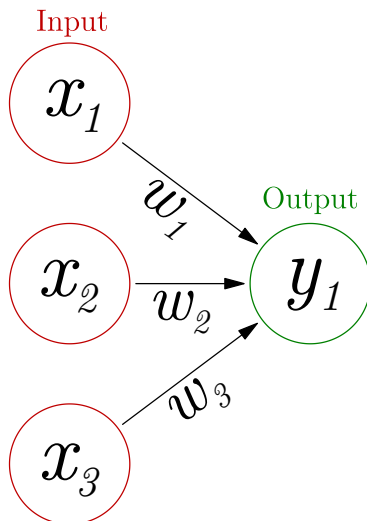
Hebbian learning

“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$



Hebbian learning

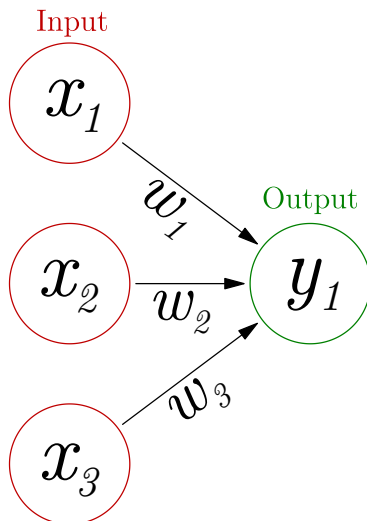
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$\mathbf{new} \ w_1 = \mathbf{old} \ w_1 + \Delta w_1$$



Hebbian learning

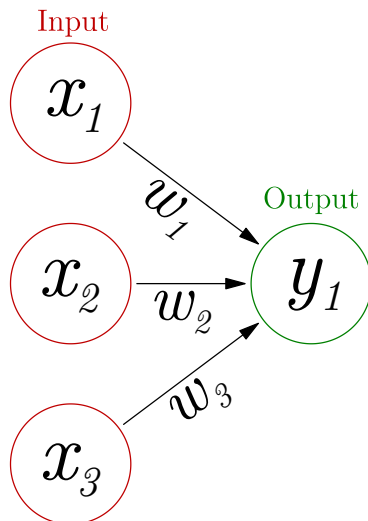
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$\mathbf{new} \ w_1 = 0.0 + \Delta w_1$$



Hebbian learning

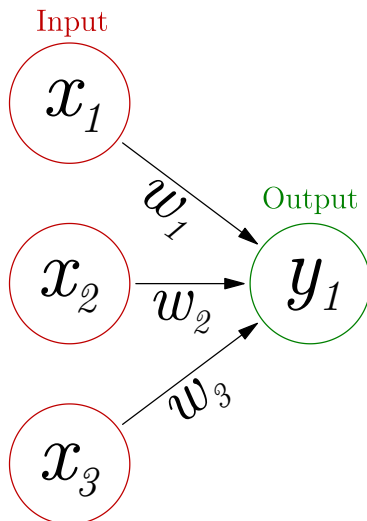
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$\text{new } w_1 = 0.0 + 0.15$$



Hebbian learning

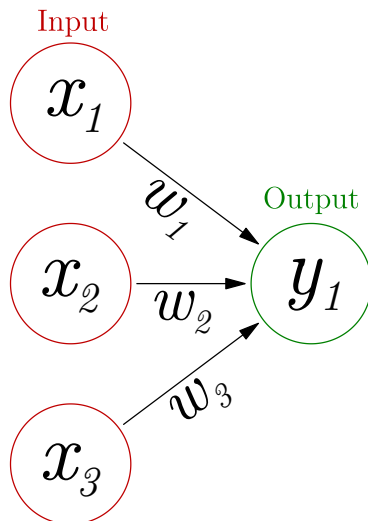
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$\text{new } w_1 = 0.15$$



Hebbian learning

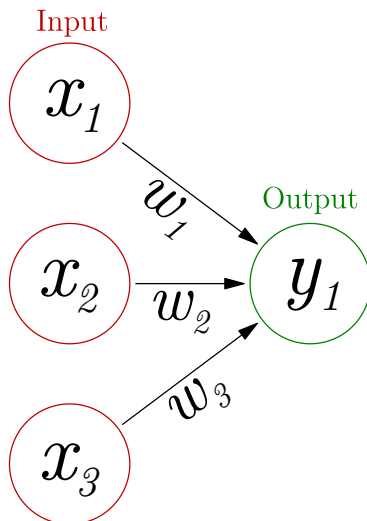
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$w_1 = 0.15$$



Hebbian learning

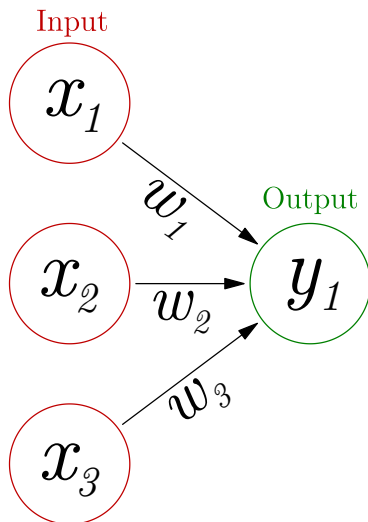
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$$w_1 = 0.15 + \text{something positive}$$



Hebbian learning

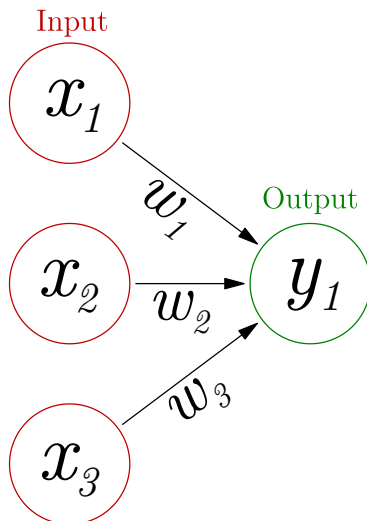
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

$$\Delta w_1 = 0.15$$

$w_1 = 0.15 + \text{something}$
positive + something else
positive +



Hebbian learning

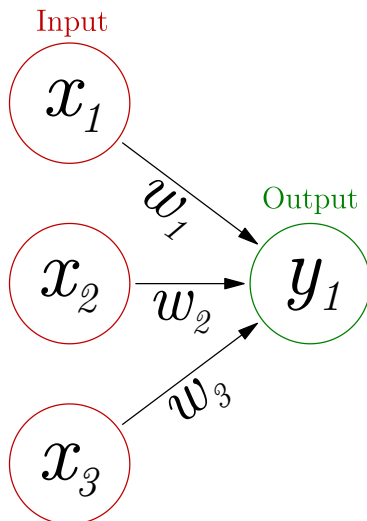
“Cells that fire together, wire together” — Carla Shatz

Hebb's rule is simple, but *very unstable!*

$$\Delta w_i = \eta \times x_i \times y_j$$

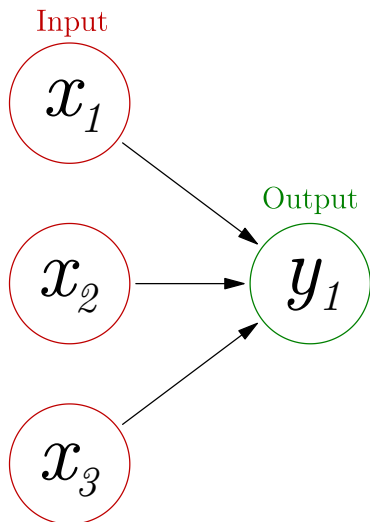
$$\Delta w_1 = 0.15$$

$w_1 = 0.15 + \text{something}$
positive + something else
positive + another positive
value + ...



The perceptron

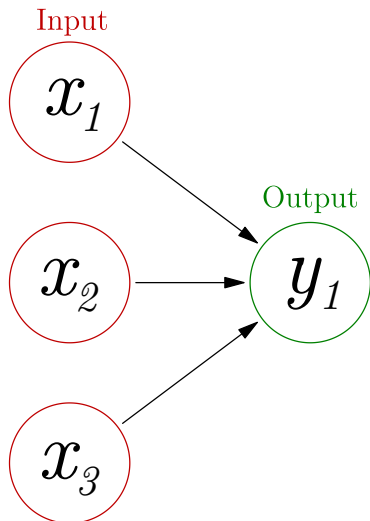
A simple classifier



The perceptron

A simple classifier

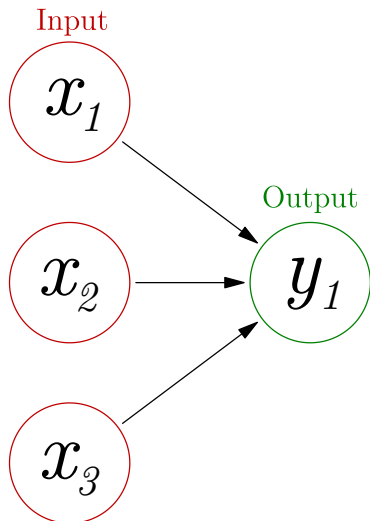
- Created in 1957 at the Cornell Aeronautical Laboratory by Frank Rosenblatt



The perceptron

A simple classifier

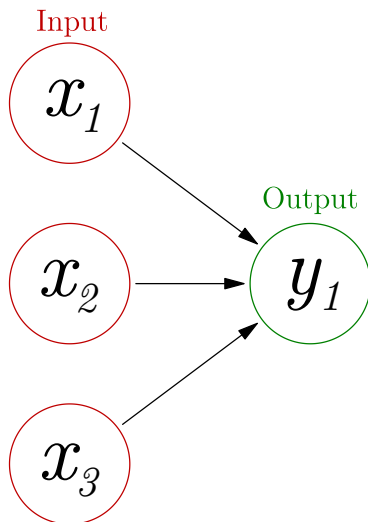
- ▶ Created in 1957 at the Cornell Aeronautical Laboratory by Frank Rosenblatt
- ▶ Linear classifier



The perceptron

A simple classifier

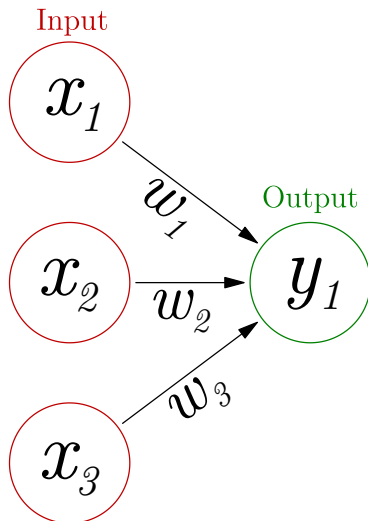
- ▶ Created in 1957 at the Cornell Aeronautical Laboratory by Frank Rosenblatt
- ▶ Linear classifier
- ▶ Simplest form of feedforward network



How does the perceptron learn?

Maths again!

1. Initialise weights



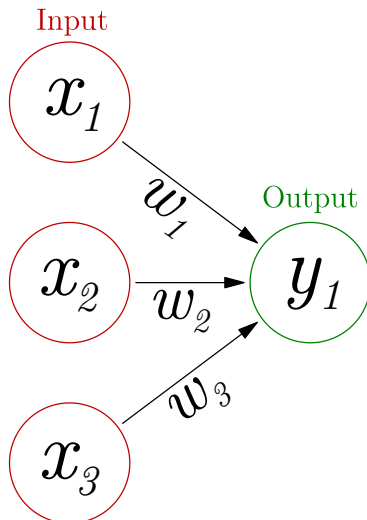
How does the perceptron learn?

Maths again!

1. Initialise weights
2. Run network using:

$$y_j = f\left(\sum_1^N w_i \times x_i\right)$$

same as always!

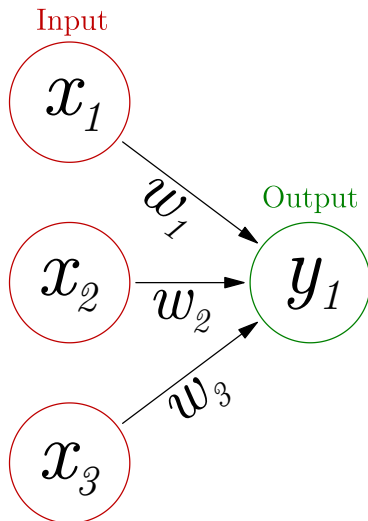


How does the perceptron learn?

Maths again!

1. Initialise weights
2. Run network
3. Update weights using:

$$\Delta w_i = \eta \quad y_j \times x_i$$

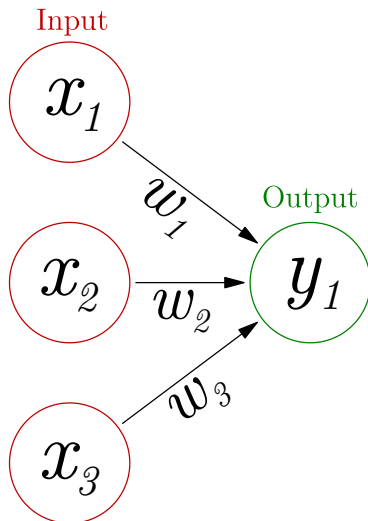


How does the perceptron learn?

Maths again!

1. Initialise weights
2. Run network
3. Update weights using:

$$\Delta w_i = \eta (d_j - y_j) \times x_i$$



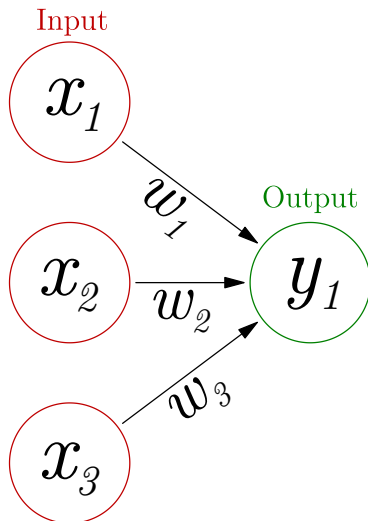
How does the perceptron learn?

Maths again!

1. Initialise weights
2. Run network
3. Update weights using:

$$\Delta w_i = \eta (d_j - y_j) \times x_i$$

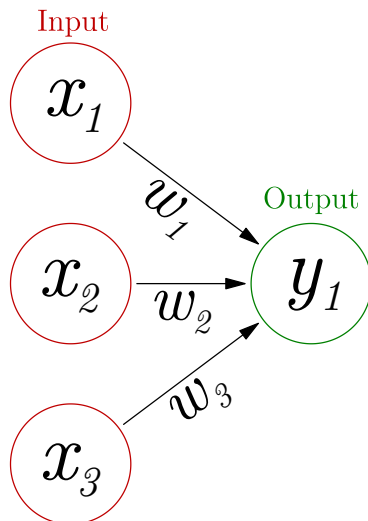
where d is what we want y to be given x , and η is the learning rate.



How does the perceptron learn?

Maths again!

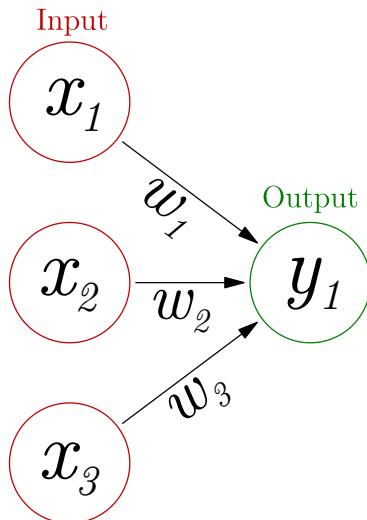
1. Initialise weights
2. Run network
3. Update weights
4. Repeat 2 and 3



How does the perceptron learn?

Maths again!

1. Initialise weights
2. Run network
3. Update weights
4. Repeat 2 and 3
5. When do we stop?



Time to program a perceptron!

Oh, and join our mailing list so we can send you stuff:

<https://groups.google.com/d/forum/introcompcog>

Training the network

The basic algorithm!

```
def Train(self):
```

Training the network

The basic algorithm!

```
def Train(self):
```

```
    x[i] = self.patterns[p][i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
  
        y += x[i] * w[i]  
    y = f(y)  
    error = d[p][0] - y  
    for i in range(N+1):  
        w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
        y = 0  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
        y = 0  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```


Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
        y = 0  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
        y = 0  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for i in range(N):  
        x[i] = self.patterns[p][i]  
        y = 0  
        for i in range(N+1):  
            y += x[i] * w[i]  
        y = f(y)  
        error = d[p][0] - y  
        for i in range(N+1):  
            w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
  
    for p in range(P):  
        for i in range(N):  
            x[i] = self.patterns[p][i]  
            y = 0  
            for i in range(N+1):  
                y += x[i] * w[i]  
            y = f(y)  
            error = d[p][0] - y  
            for i in range(N+1):  
                w[i] += h * error * x[i]
```

Training the network

The basic algorithm!

```
def Train(self):  
    for t in range(100):  
        for p in range(P):  
            for i in range(N):  
                x[i] = self.patterns[p][i]  
            y = 0  
            for i in range(N+1):  
                y += x[i] * w[i]  
            y = f(y)  
            error = d[p][0] - y  
            for i in range(N+1):  
                w[i] += h * error * x[i]
```

Training the network

Defining some patterns!

```
Patterns =  
    [#colour, shape, taste  
     #red-yellow, big-small, sweet-sour  
     [0.1, 0.0, 0.2], #loquat  
     [0.0, 0.2, 0.0], #lemon  
     [1.0, 0.5, 0.8], #red apple  
     [1.0, 0.0, 0.9], #strawberry  
    ]
```

Training the network

Defining some patterns!

```
Patterns =  
    [#colour, shape, taste  
    #red-yellow, big-small, sweet-sour  
    [0.1, 0.0, 0.2], #loquat  
    [0.0, 0.2, 0.0], #lemon  
    [1.0, 0.5, 0.8], #red apple  
    [1.0, 0.0, 0.9], #strawberry  
]  
  
Targets = [  
    [1.0], #first target  
    [1.0], #targets indicate  
    [0.0], #which class  
    [0.0], #a pattern  
] #belongs to
```