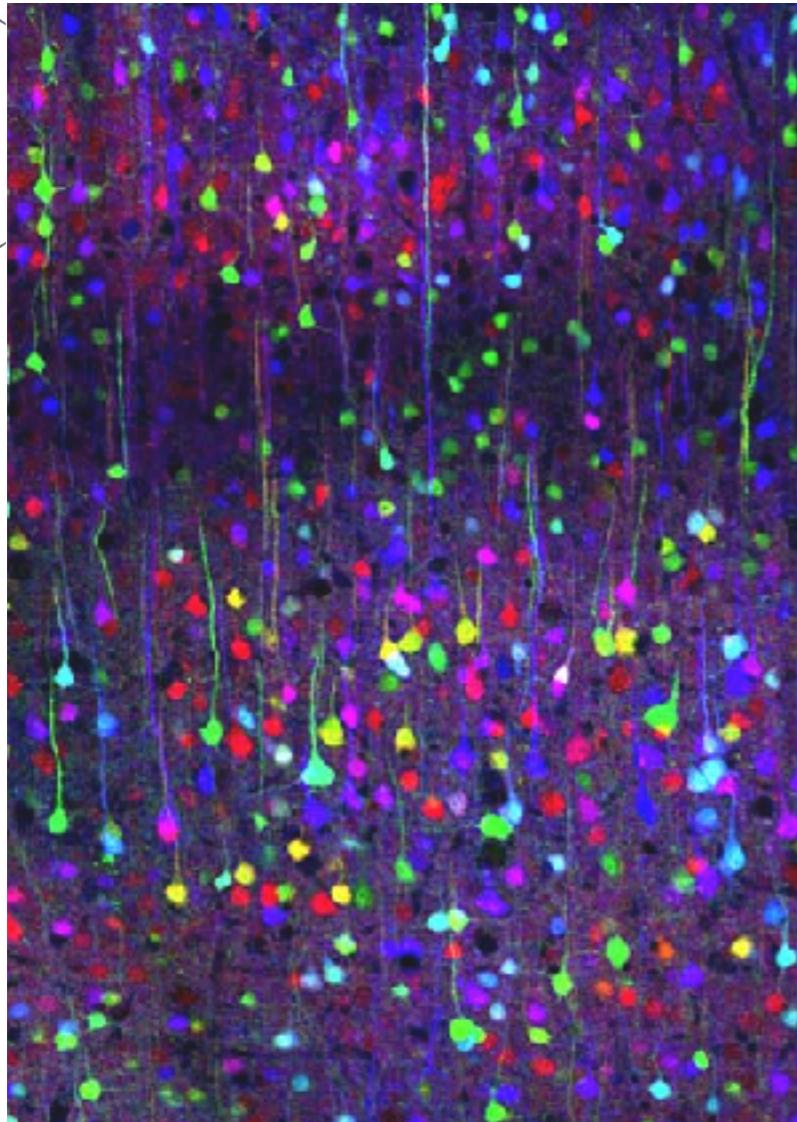


# Neural Information Processing 2018/2019



Brainbow (Litchman Lab)



## Lecture 10: Neural circuits and learning



Rui Ponte Costa

# Outline

A short overview on the credit assignment problem and the different forms of learning in the brain (and machine learning):

**Supervised learning**

**Unsupervised learning**

**Reinforcement learning**

# Given visual input how should you move?

Visual input → Prepare movement → Hit (or not) the ball



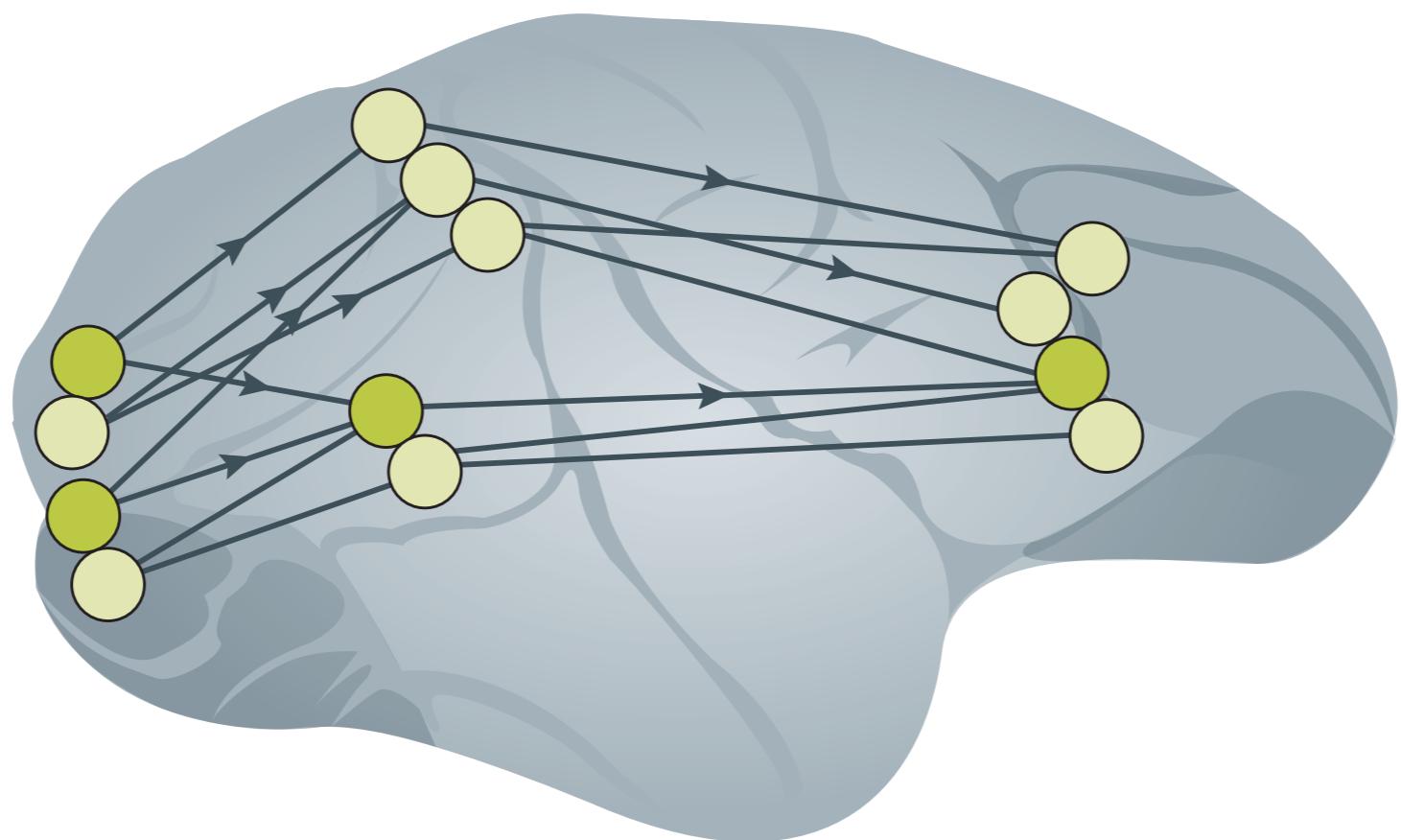
# How does the brain learn?

Visual input → Prepare movement → Hit (or not) the ball



(typically **synapses**)

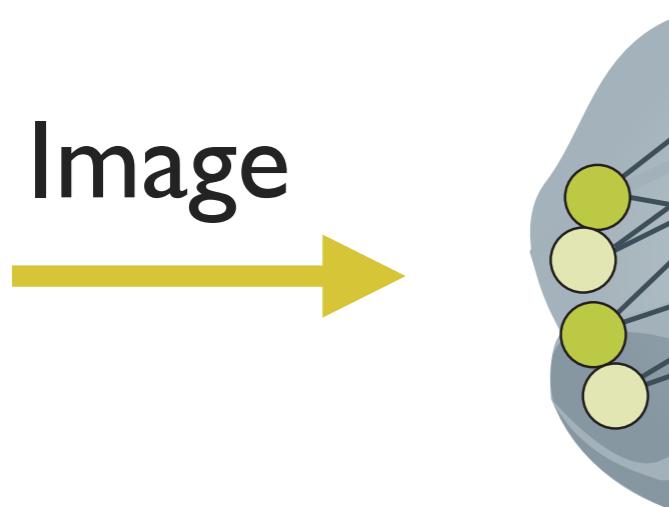
# How to assign credit to ‘parameters’ in the brain?



Roelfsema et al. Nature Neuroscience Rev 2018

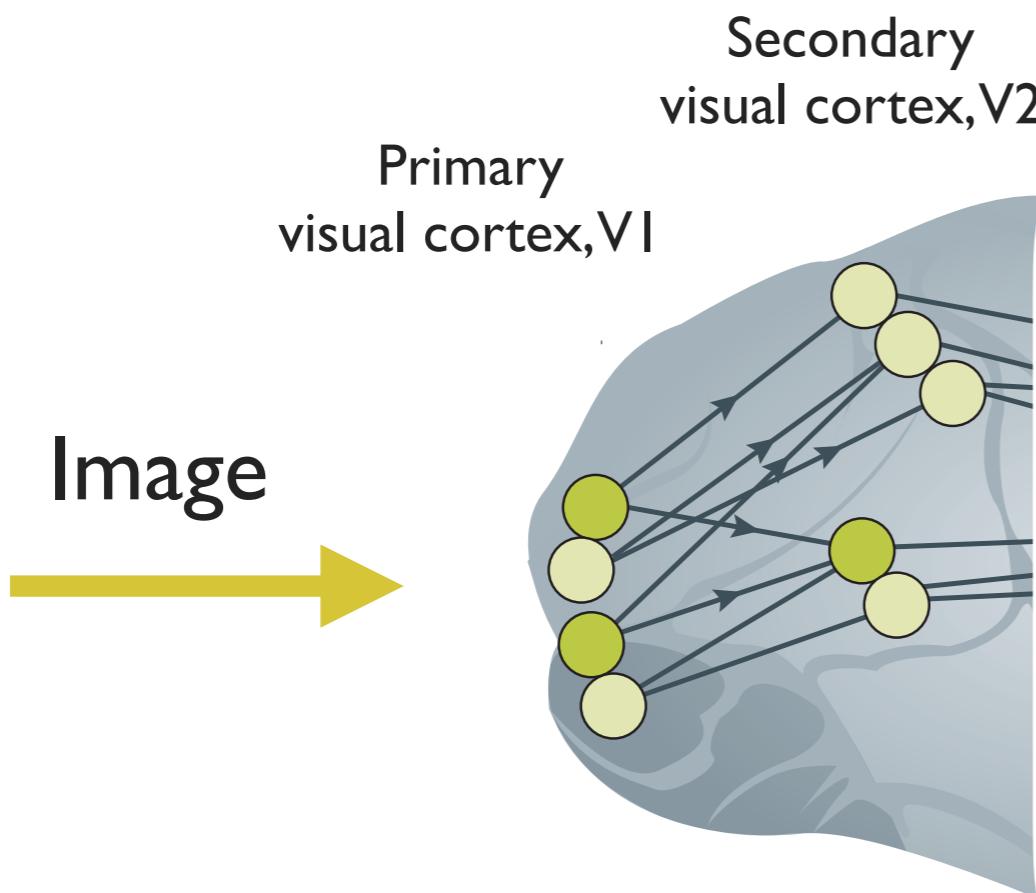
# How to assign credit in the brain?

Primary  
visual cortex, VI



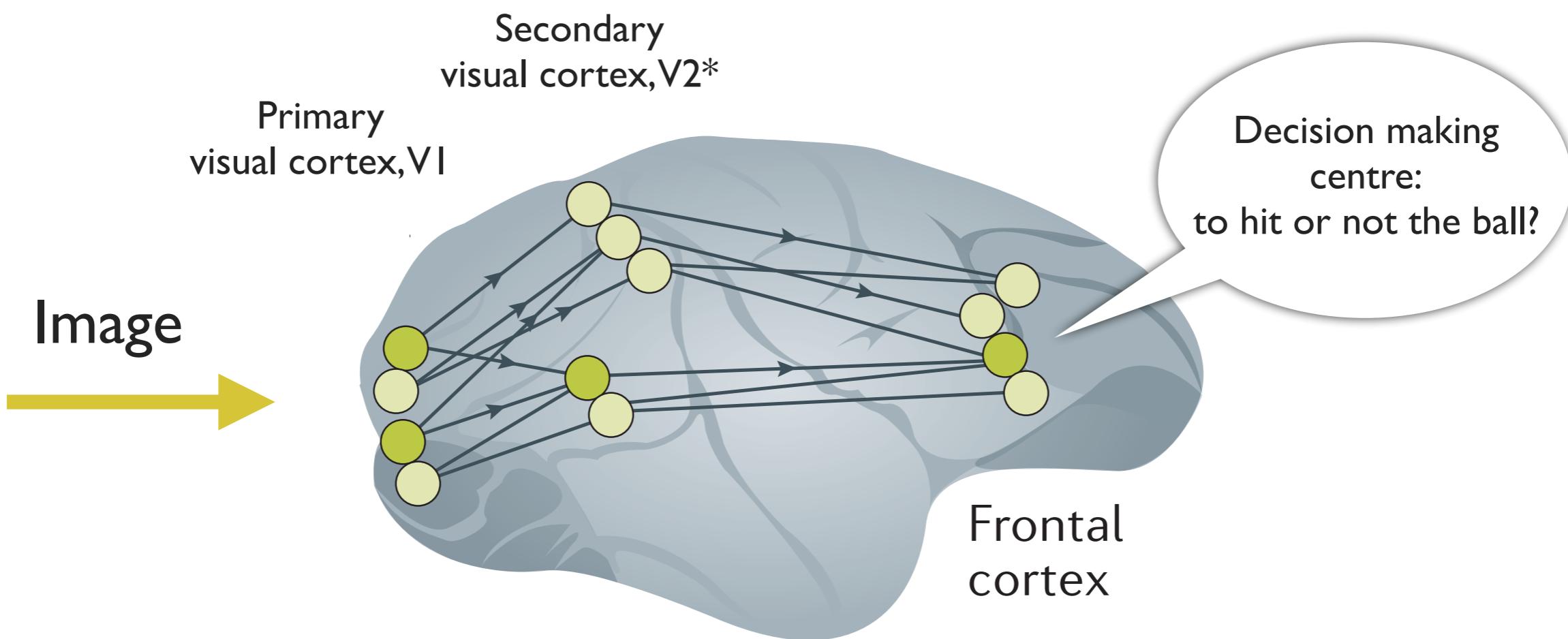
Roelfsema et al. Nature Neuroscience Rev 2018

# How to assign credit in the brain?



Roelfsema et al. Nature Neuroscience Rev 2018

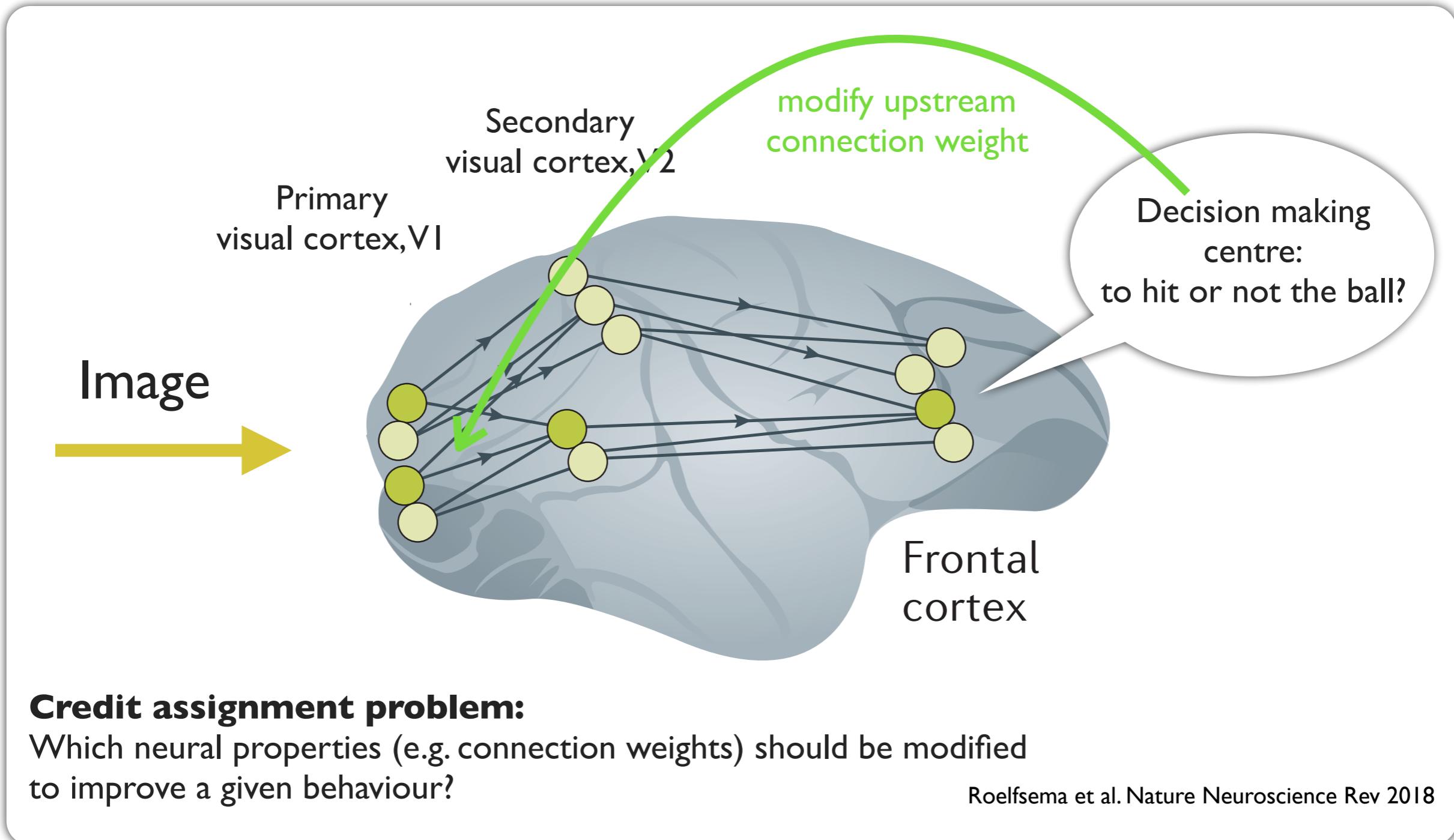
# How to assign credit in the brain?



\*: or associative cortices

Roelfsema et al. Nature Neuroscience Rev 2018

# How to assign credit in the brain?



Three forms of (direct or indirect)  
*credit assignment*

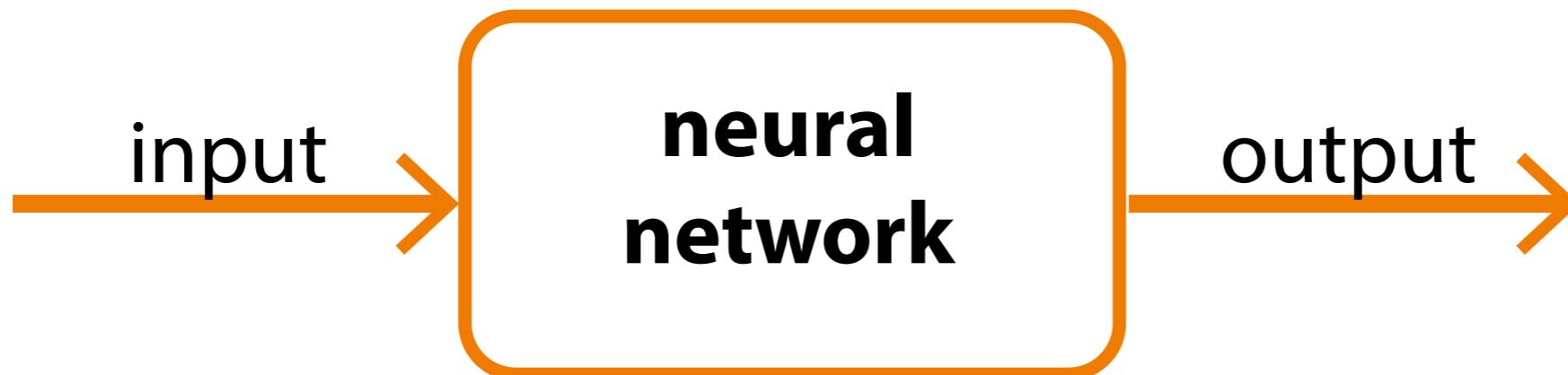
Supervised Learning

Unsupervised Learning

Reinforcement Learning

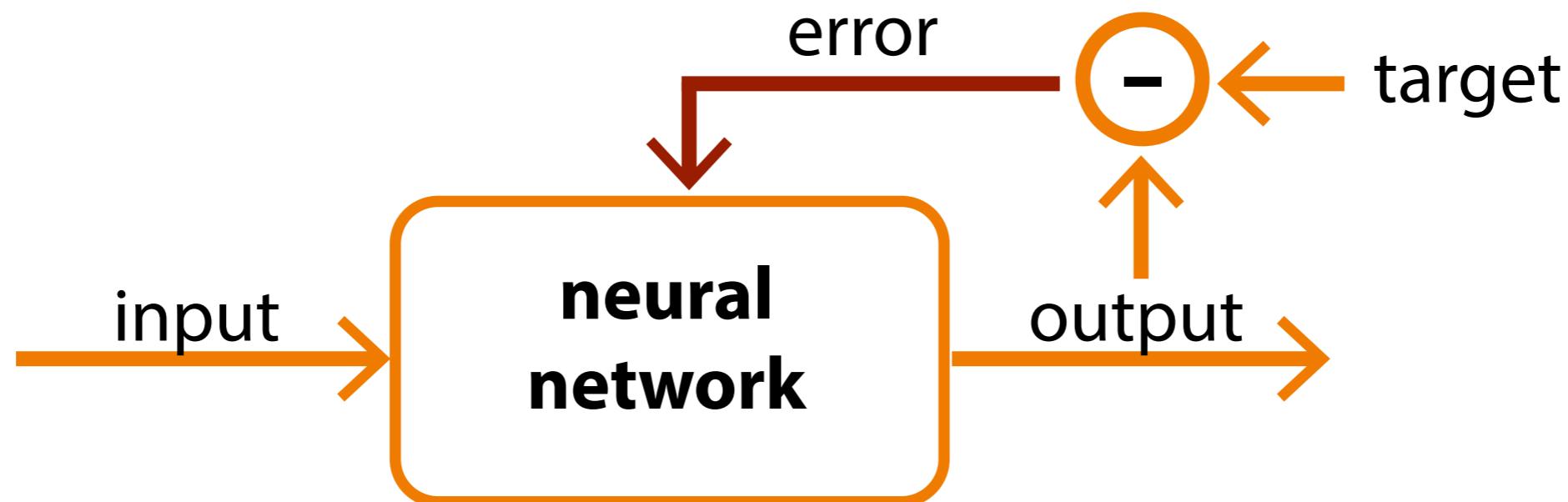
# Three forms of (direct or indirect) *credit assignment*

**Unsupervised Learning:**  
Extracts useful representations of input



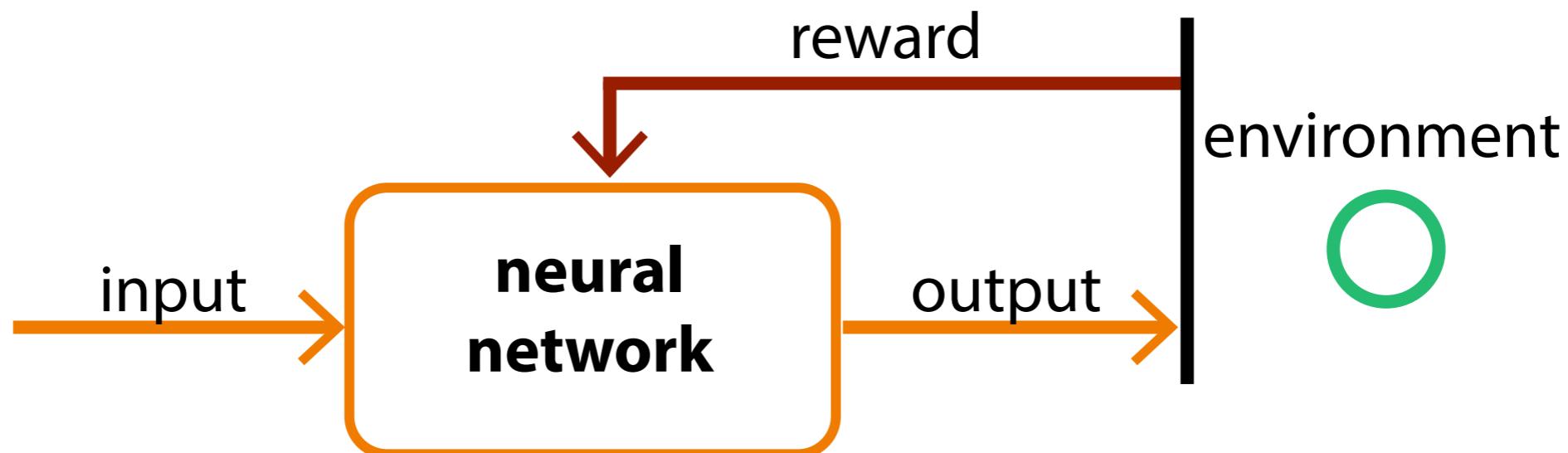
# Three forms of (direct or indirect) *credit assignment*

**Supervised Learning:**  
Relies on a teaching signal



# Three forms of (direct or indirect) *credit assignment*

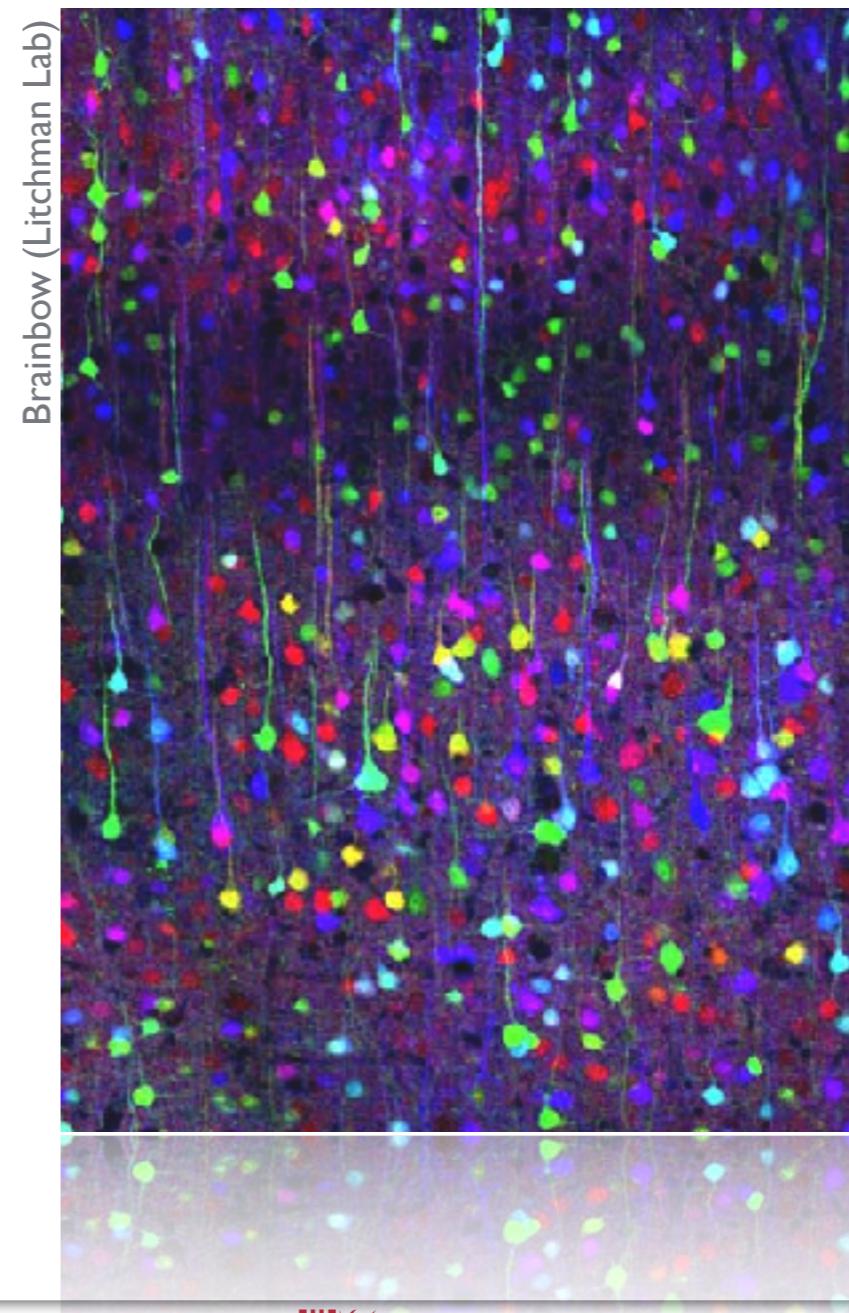
**Reinforcement Learning:**  
Learn to navigate/survive an environment



# A feedforward neural network

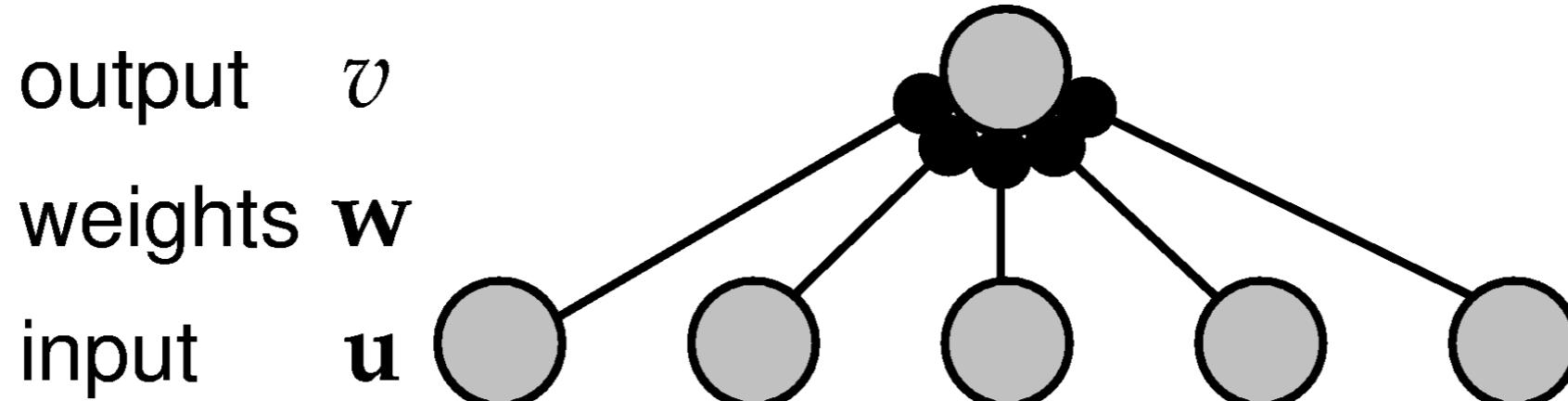
The brain is like a tropical forest!  
With many different neuron *types*  
and *architectures*..

DeFelipe et al. Nat. Neurosci. Reviews 2013



# A feedforward neural network

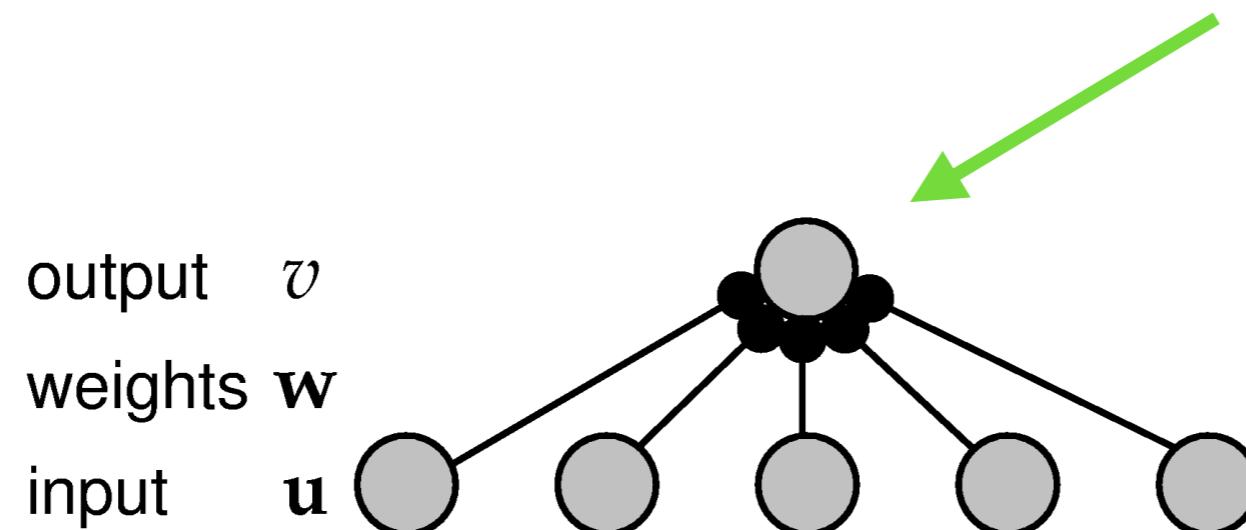
In theoretical neuroscience we need to abstract out some of this complexity to get at the principles of information processing in the brain!



# Supervised learning

**Goal:** Classify input into different categories

Teaching signal,  $y$



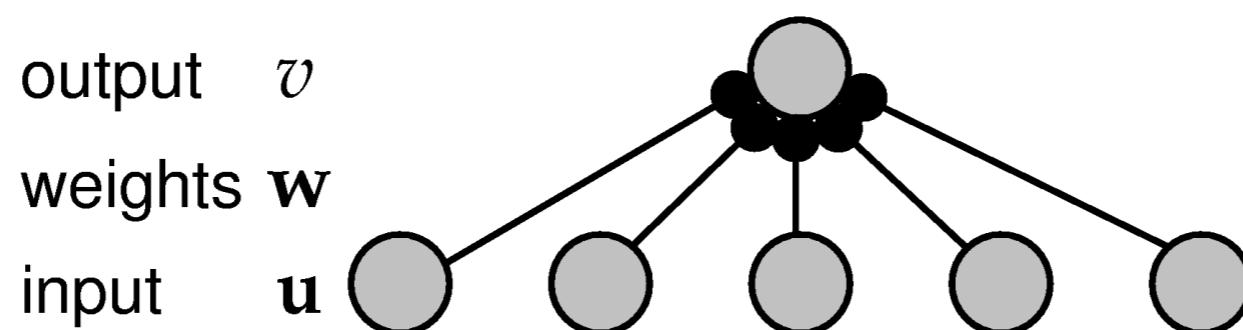
# Supervised learning

output,  $v = f(wu)$

where  $f$  is some (non)linear function

Predator, yes/no?  
 $y = \{1,0\}$

output  $v$   
weights  $w$   
input  $u$



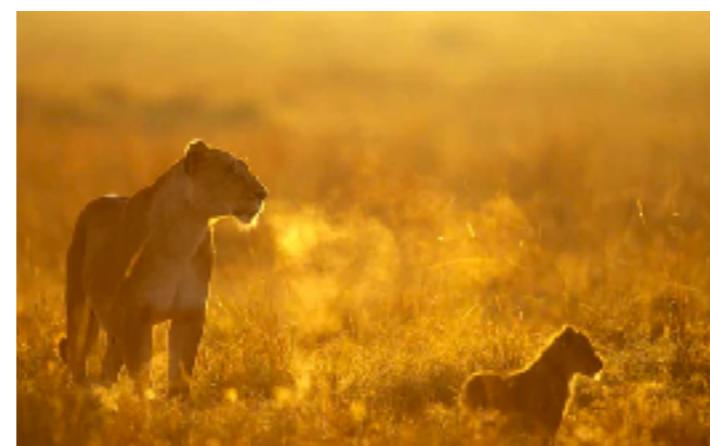
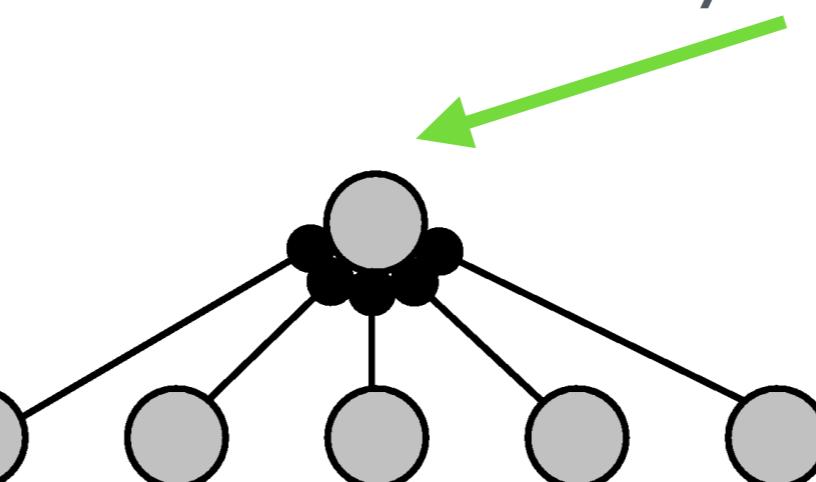
# Supervised learning

Minimise cost

$$\text{cost} = (v - y)^2$$

Predator, yes/no?  
 $y = \{1, 0\}$

output  $v$   
weights  $w$   
input  $u$



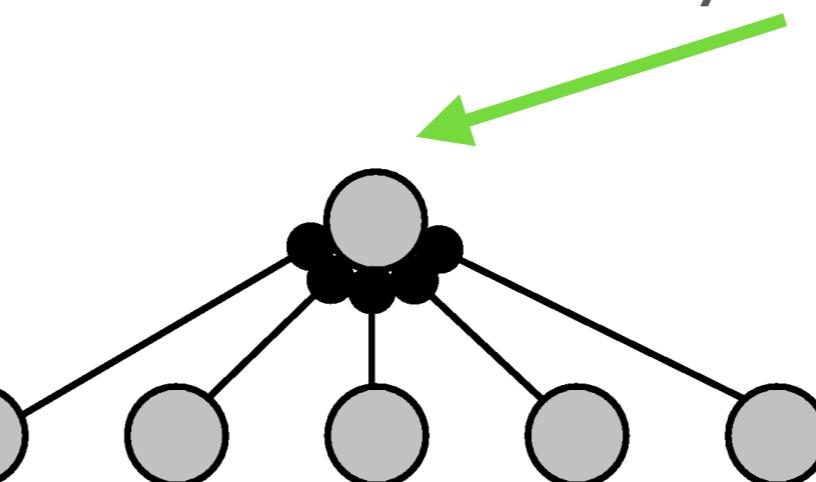
# Supervised learning

Minimise cost

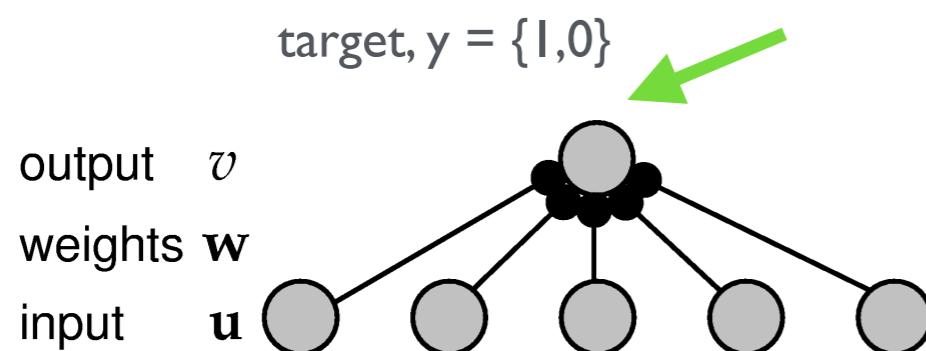
$$\text{cost} = (v - y)^2$$

Predator, yes/no?  
 $y = \{1, 0\}$

output  $v$   
weights  $w$   
input  $u$



# Supervised learning



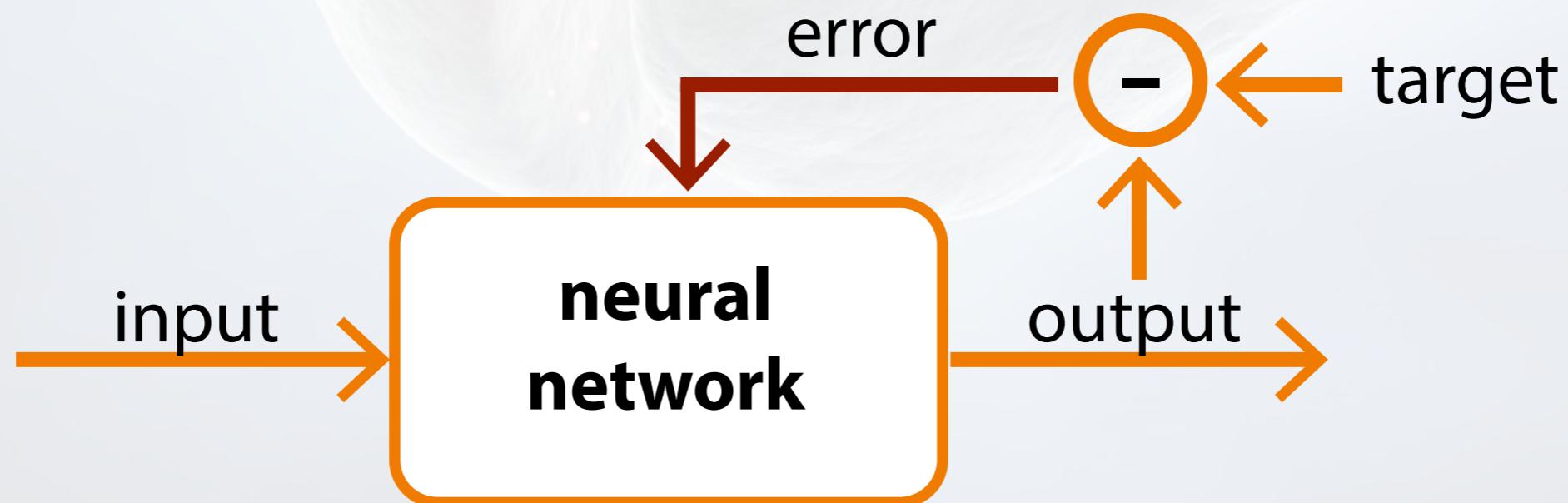
$$\text{cost} = (v - y)^2$$

- The learning rules for  $w$  can be derived from the cost (or error) function for a particular network: e.g. using the popular backpropagation algorithm
- Examples of methods that use supervised learning:
  - Convolutional neural networks
  - Recurrent neural networks
  - Deep learning methods in general
  - Animals experience some degree of supervised learning (e.g. with external teacher)

## Group discussion

groups of 2-3 (5 min)

- Can you think of examples of teaching signals that may inform the brain during learning?



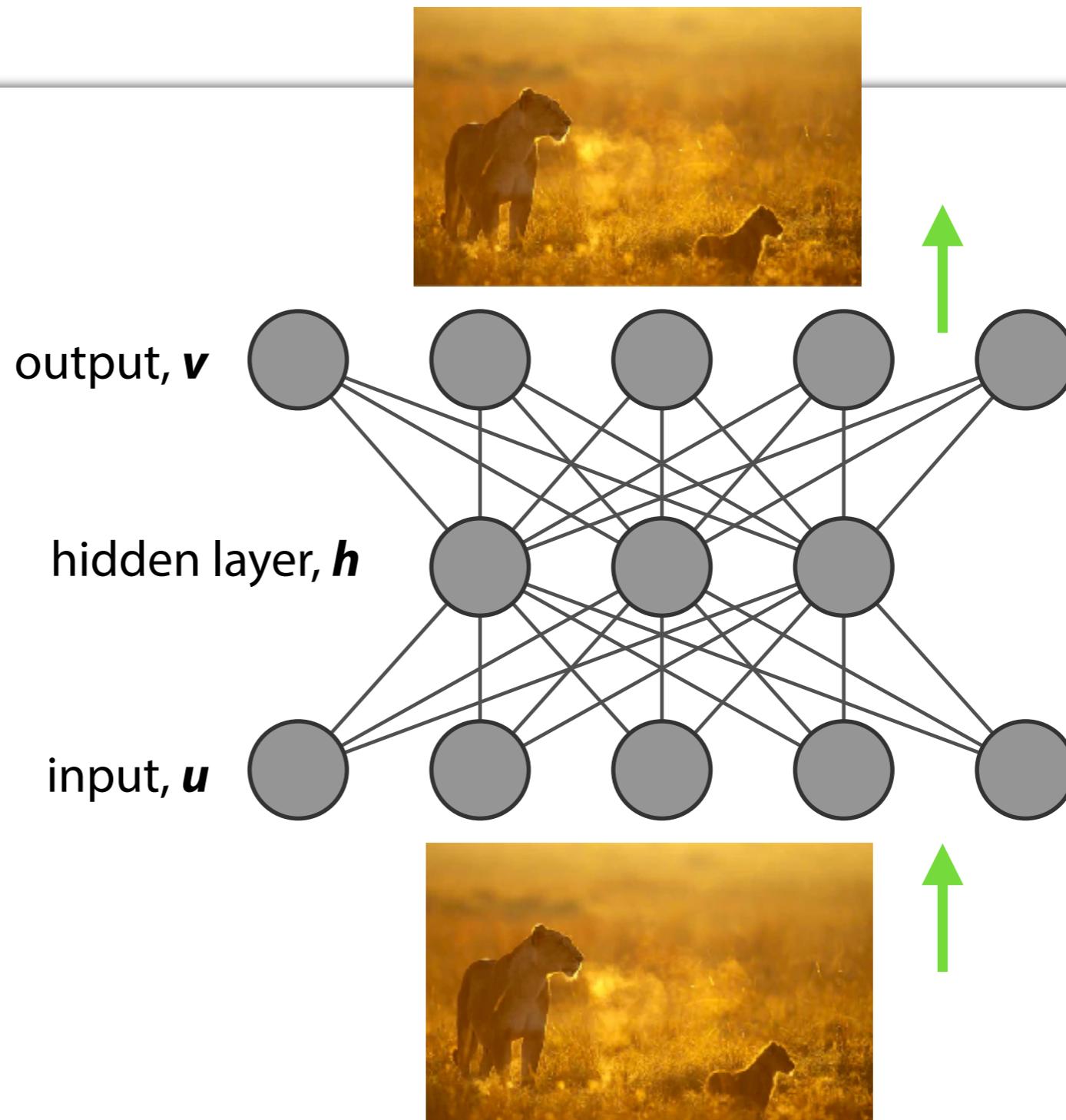
## **Group discussion**

groups of 2-3 (5 min)

- Can you think of examples of teaching signals that may inform the brain during learning?
- Hint: Think in the context of a classroom

# Unsupervised learning

**Goal:** Extract a representation of the input (dimensionality reduction)



# Unsupervised learning

$$\text{output, } v = f(wh)$$

**Learned representation** →  
(e.g. edges)

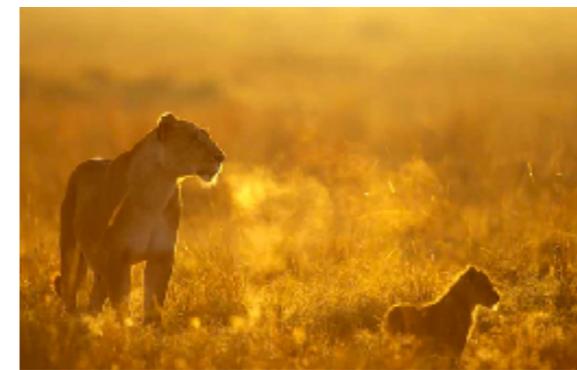
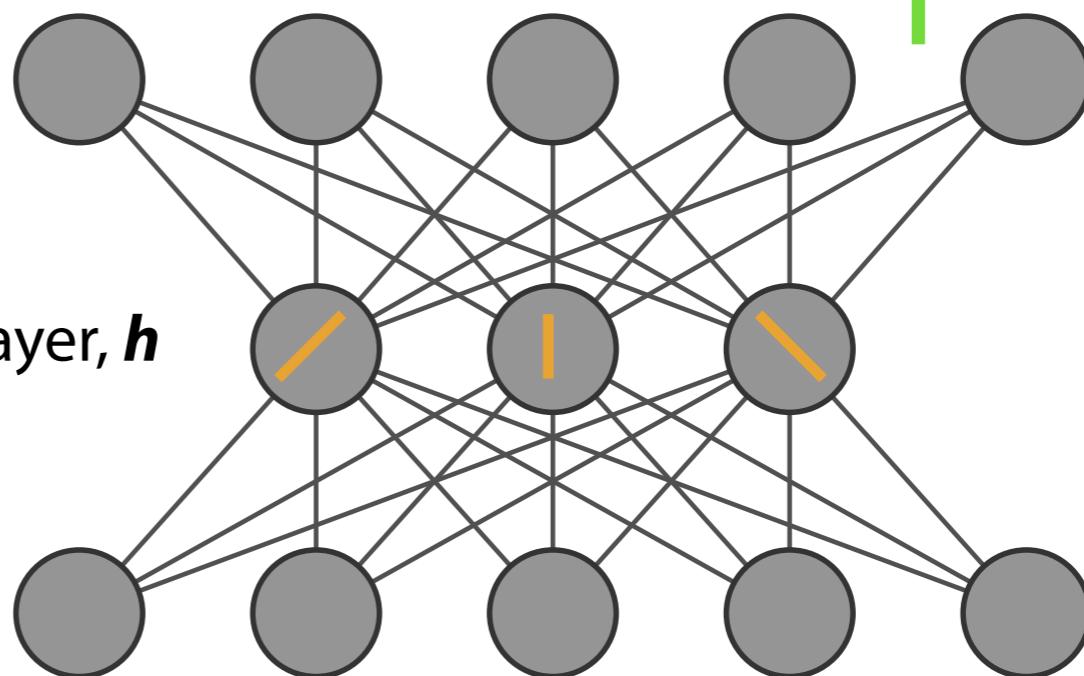
Minimise cost

$$\text{cost} = (v - f(wu))^2$$

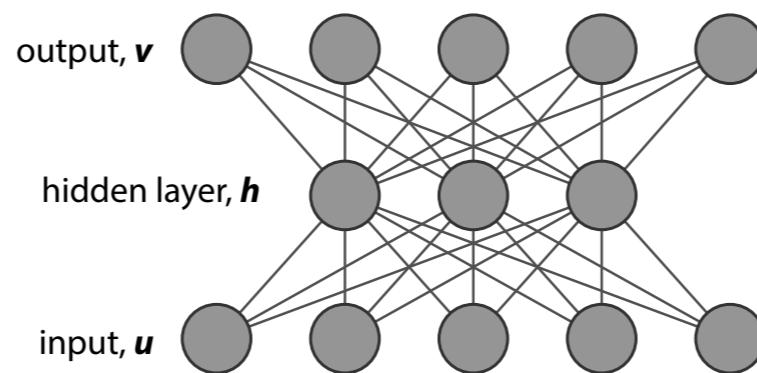
output,  $v$

hidden layer,  $h$

input,  $u$



# Unsupervised learning

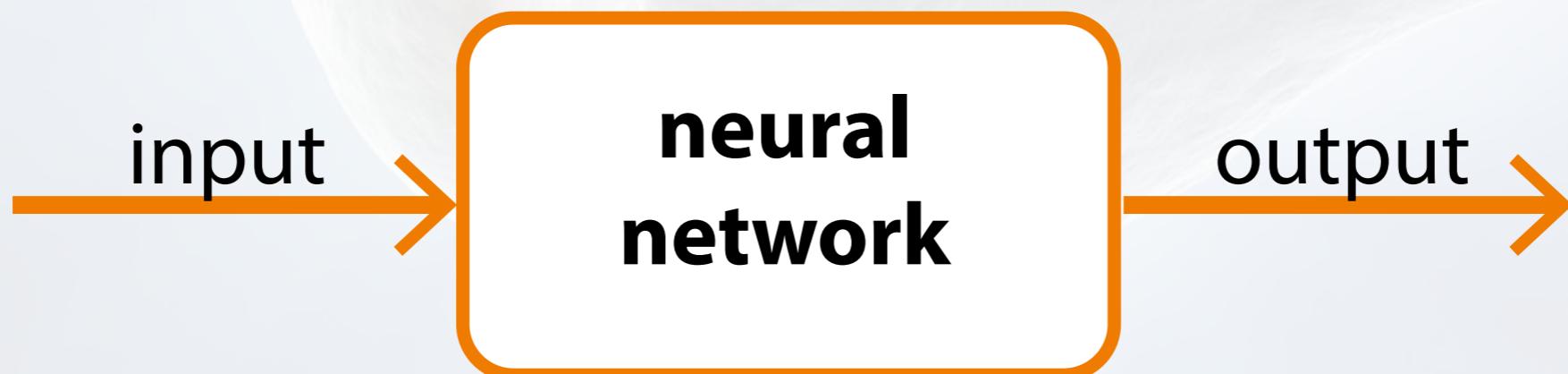


- The learning rules for  $w$  can be derived from the cost (or error) function for a particular network, e.g. sparse coding algorithm.
- Examples of unsupervised learning methods:
  - Sparse coding (akin to PCA)
  - Restricted Boltzmann Machines
  - Autoencoders
- Animals are bombarded with vast streams of sensory input

## **Group discussion**

groups of 2-3 (5 min)

- Why would it be useful for the brain to form representations?



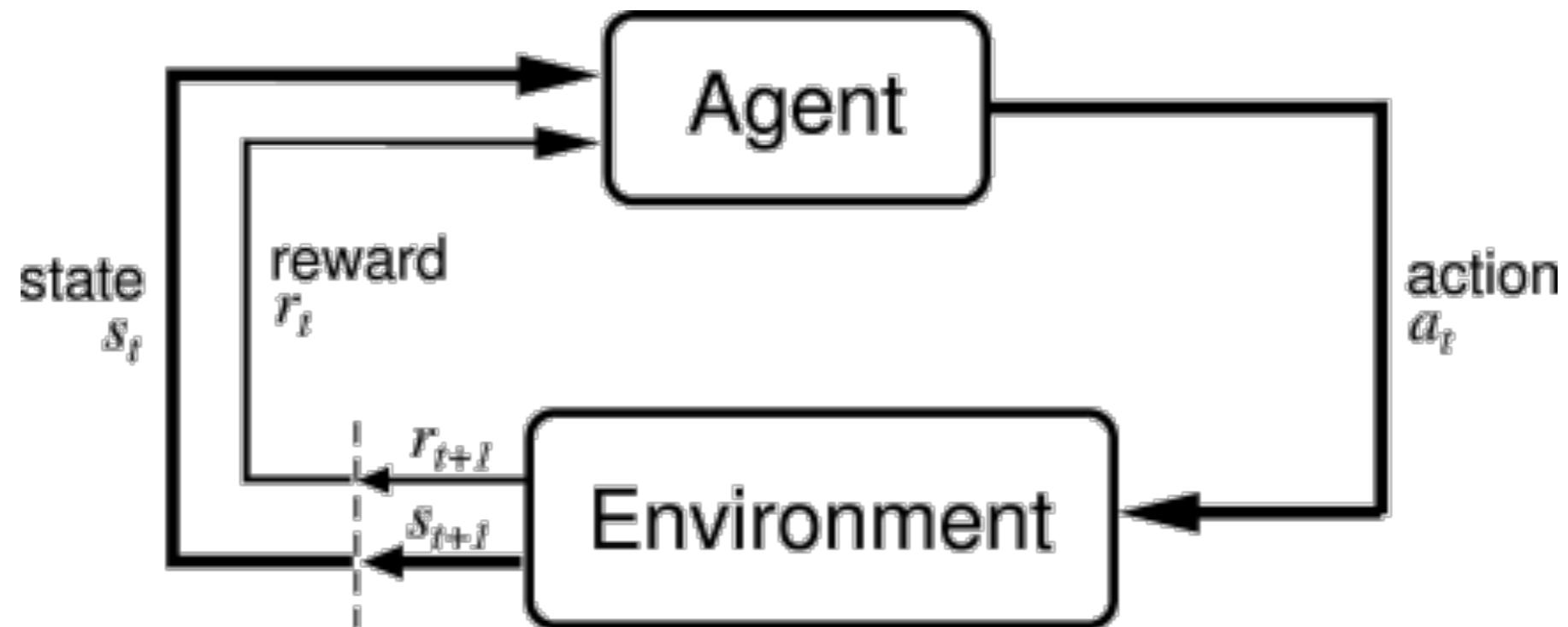
## **Group discussion**

groups of 2-3 (5 min)

- **Why would it be useful for the brain to form representations?**
- Hint: Learn important statistics of the environment

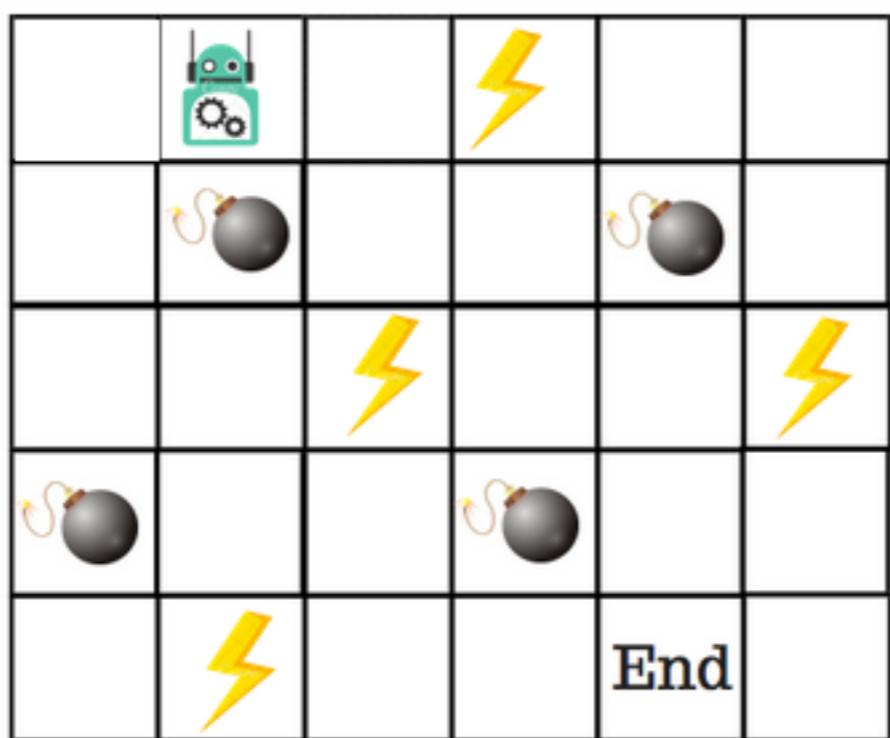
# Reinforcement learning

**Goal:** Find best policy (which actions to take) to maximise reward



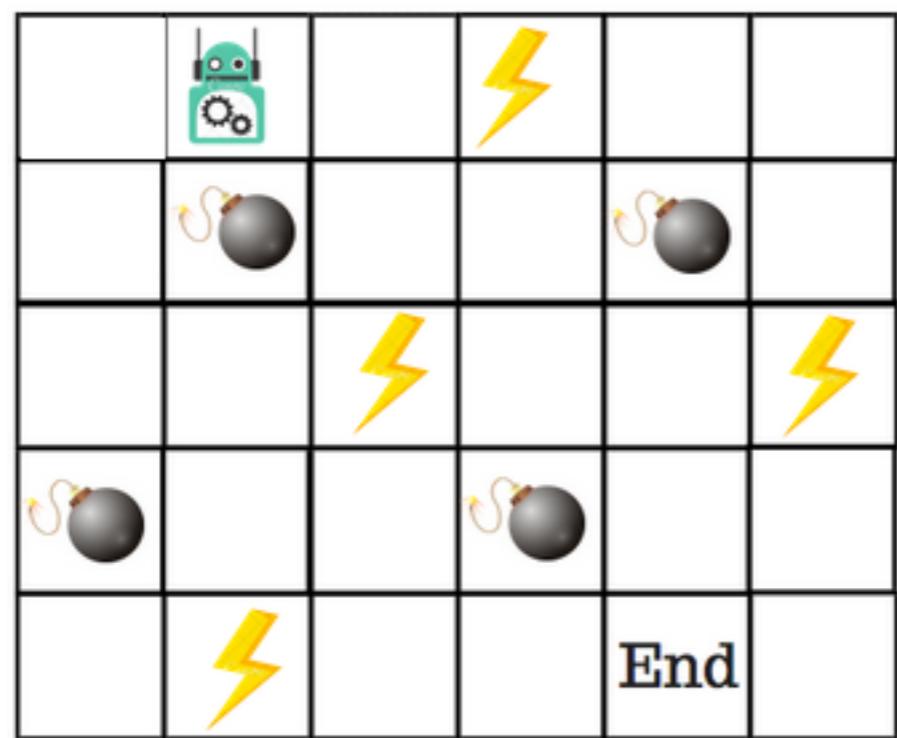
# Reinforcement learning

## Value table/policy



		Actions :			
		↑	→	↓	←
Nothing / Blank	Start	0	0	0	0
	Power	0	0	0	0
Mines	0	0	0	0	0
END	0	0	0	0	0

# Reinforcement learning



**Value table/policy**

Actions :  $\uparrow$   $\rightarrow$   $\downarrow$   $\leftarrow$

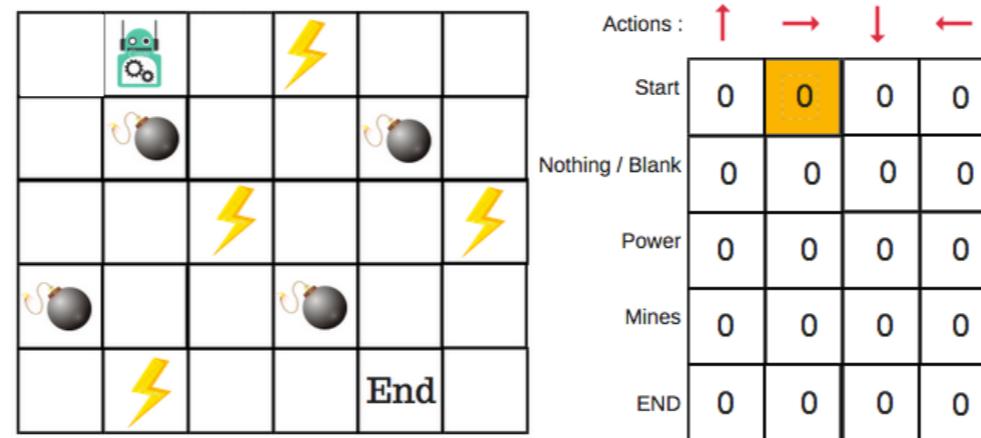
	Start	$\uparrow$	$\rightarrow$	$\downarrow$	$\leftarrow$
Nothing / Blank	0	0	0	0	0
Power	0	0	0	0	0
Mines	0	0	0	0	0
END	0	0	0	0	0

Update value table with temporal difference (TD) learning:

$$\underbrace{V(S_t)}_{\text{value}} = V(S_t) + \left( \underbrace{R_{t+1}}_{\text{reward}} + \lambda \underbrace{V(S_{t+1})}_{\text{future value}} \right) - V_t$$

$\lambda$ : discount factor

# Reinforcement learning



- The *TD learning equation* enables the agent to gradually learn to predict *future reward* ( $R$ ), based on *value estimates* ( $V_{t+1}$ ).
- Examples of reinforcement learning methods:
  - Temporal difference (TD) learning
  - Q-learning
  - Deep Q-learning
- Because of the role of rewards RL is a common framework in neuroscience

# Different objective/cost functions of learning

## Supervised Learning

$$\text{cost} = (v - y)^2$$

## Unsupervised Learning

$$\text{cost} = (v - f(wu))^2$$

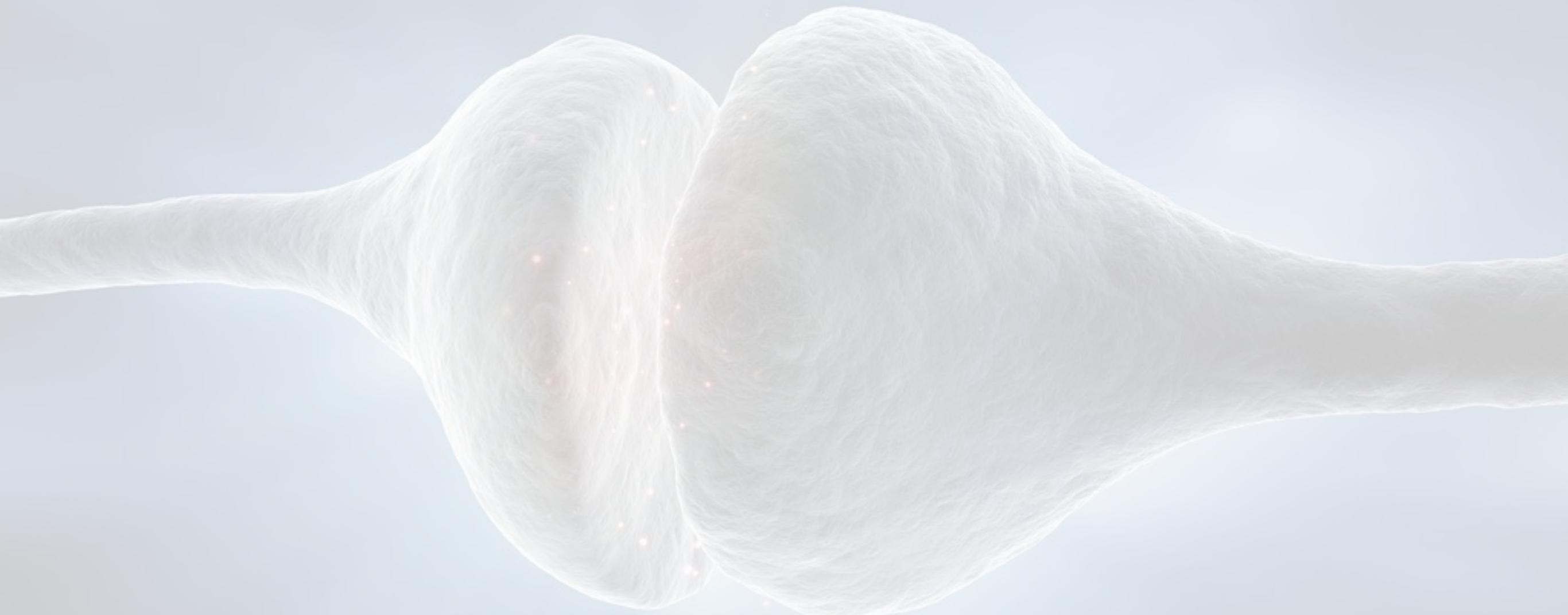
## Reinforcement Learning

$$\underbrace{V(S_t)}_{\text{value}} = V(S_t) + \left( \underbrace{R_{t+1}}_{\text{reward}} + \lambda \underbrace{\overbrace{V(S_{t+1})}^{\text{future value}}}_{\text{learned value}} - V_t \right)$$

# Summary

- Different forms of learning (or credit assignment) in the brain
- Supervised, unsupervised and reinforcement learning

# Questions?

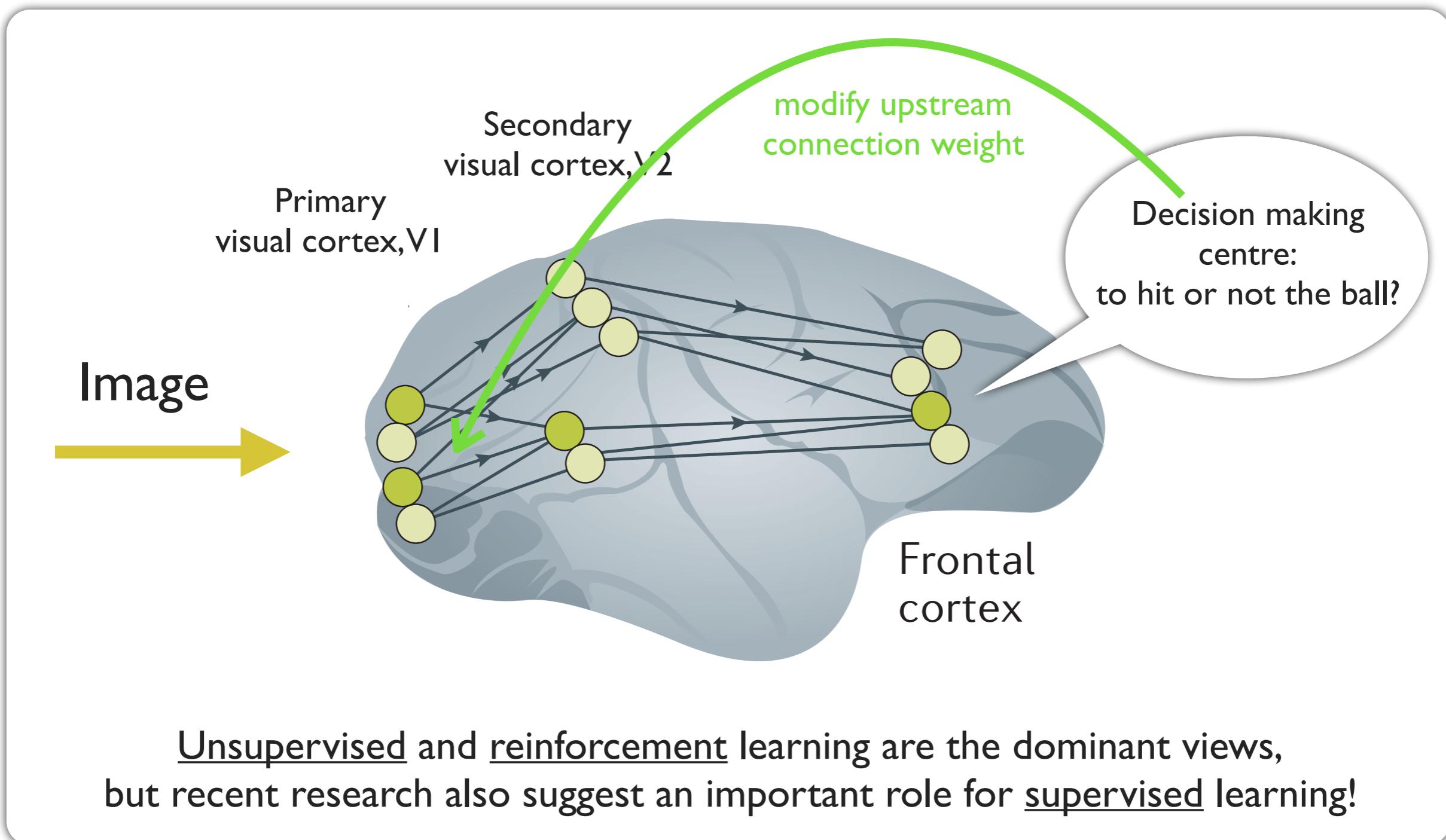


## **Group discussion**

groups of 2-3 (5 min)

- Which form of learning is more biologically plausible and why?

# How to assign credit in the brain?



Unsupervised and reinforcement learning are the dominant views,  
but recent research also suggest an important role for supervised learning!

# Upcoming lectures

- **Neural circuits: sensory cortices**
  - Visual cortex
  - Convolutional neural networks
  - Supervised learning: The backpropagation algorithm
  - Unsupervised: Sparse coding and Boltzmann Machines
- Temporal credit assignment
  - Recurrent neural networks
  - Gated recurrent neural networks: LSTMs, GRUs and subLSTMs
- Reinforcement learning in the brain
  - Temporal difference learning
  - Q-learning
  - Deep RL

# References

## **Text books:**

General theoretical neuroscience: Dayan and Abbott, Principles of Neuroscience (Chapter III)

Deep Learning by Courville, Goodfellow and Bengio

Reinforcement Learning: Sutton & Barto, Reinforcement Learning: An Introduction (see online the newer 2018 edition)

Others: Mackay book on Information Theory, Inference and Learning; Rumelhart and McClelland, Parallel Distributed Processing books

## **Relevant papers:**

- Roelfsema and Holtmaat, Nature Neuroscience Reviews 2018 (recent review on the credit assignment problem)
- Olshausen and Field, Nature 1996 (seminal paper on sparse coding)
- Schultz et al. Science 1997 (seminal paper on neural substrates of reinforcement learning)

# Course work

[https://github.com/comsm0021/2018\\_19](https://github.com/comsm0021/2018_19)

- Implement a classical algorithm:
  - Backpropagation algorithm (supervised)
  - Sparse coding (unsupervised)
  - Temporal difference learning (reinforcement)
- **Explain** the behaviour of the algorithm and **contrast** the algorithm you have chosen with the other two in terms of biological plausibility and performance. Note: Please support your statements with relevant citations.
- Deadline: 7th of December 2018
- Teaching assistants: Anne-Lene Sax (anne-lene.sax@bristol.ac.uk)  
Milton Llera Montero (m.lleramontero@bristol.ac.uk)