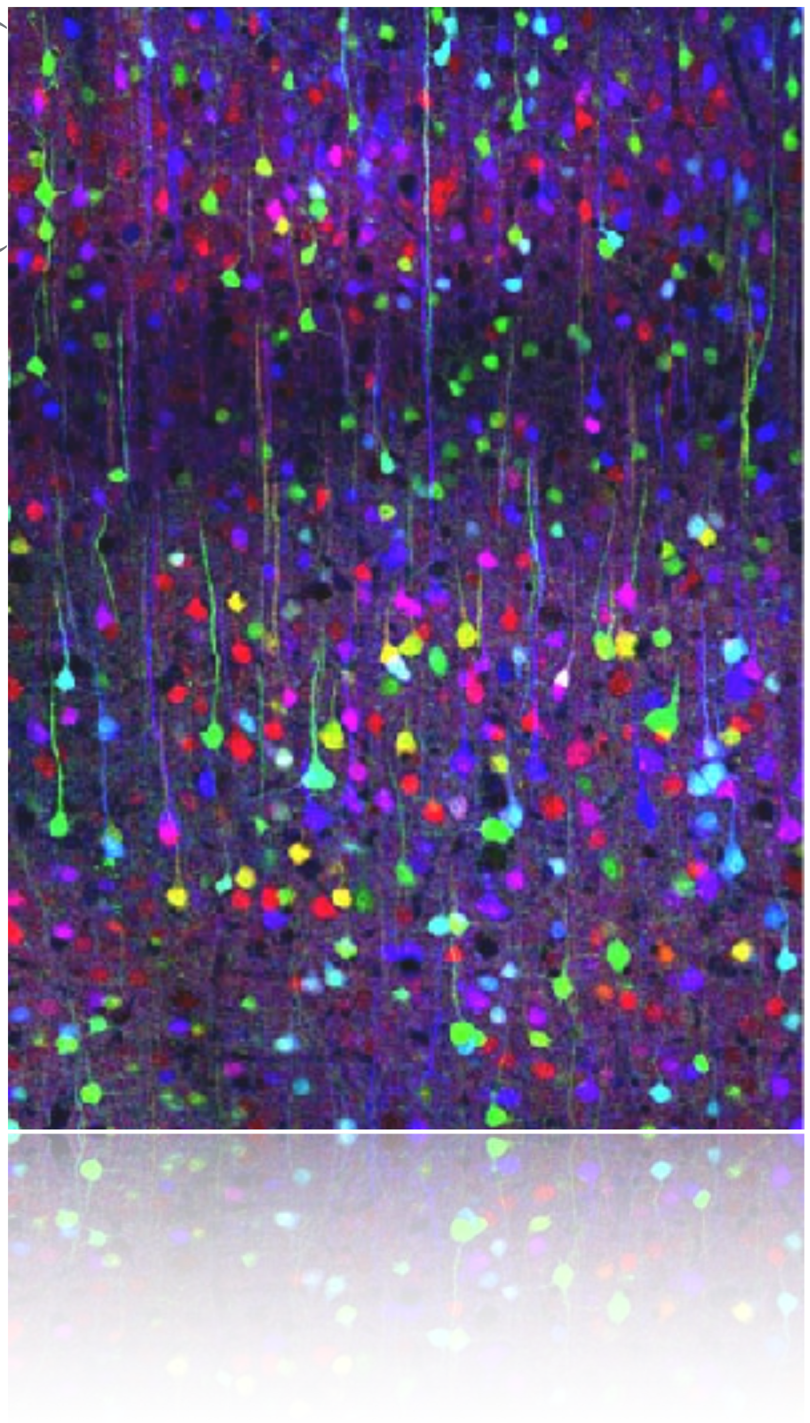
Information Processing & the **Brain 2019/2020**

University of BRISTOL

Brainbow (Litchman Lab)



IPB: Part 2

Lecture 11: Neural circuits and learning

Rui Ponte Costa

What’s going to happen?

- **Expectations**
  - Interactive lectures (class polls, group discussions, videos, simulations)
  - Research oriented (papers)
  - Neuroscience: a few theories and many unknowns
  - <u>Office hours</u>: Tues 12pm-2pm

- **Course work**
  - *Implement* and *discuss* a neuroscience learning algorithm
  - Labs: 12/11 + 03/12 (11am-2pm; **first hour** will be a lecture)
  - 20% of your mark

IPB: part 2
Neural circuits and learning

Temporal difference

Supervised learning

Balance

Pyramidal cells

Unsupervised learning

Synaptic plasticity

Backprop

Neural networks

Deep learning

Brain areas

Learning rules

Autoencoders

Reinforcement learning

States

LSTMs

Actions

Credit assignment

Neural circuits

Interneurons

Q-learning

RNNs

Optimization

Deep RL

Neuroscience

Meta-learning

IPB: part 2
Neural circuits and learning

- **L11[6]: Neural circuits and learning: introduction**
- L12[6]: Visual system: deep learning?
- L13[7]: Supervised learning & backprop
- L14[7]: Unsupervised learning
- L15[9]: Reinforcement learning
- L16[9]: Temporal processing & recurrent neural networks
- L17[10]: Recurrent neural networks
- L18[10]: Brain vs machine: meta-learning and inductive bias
- L19-20[11]: Neural data analysis (by Cian)
- L21-22[12]: Revision week

Lecture 11:

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?

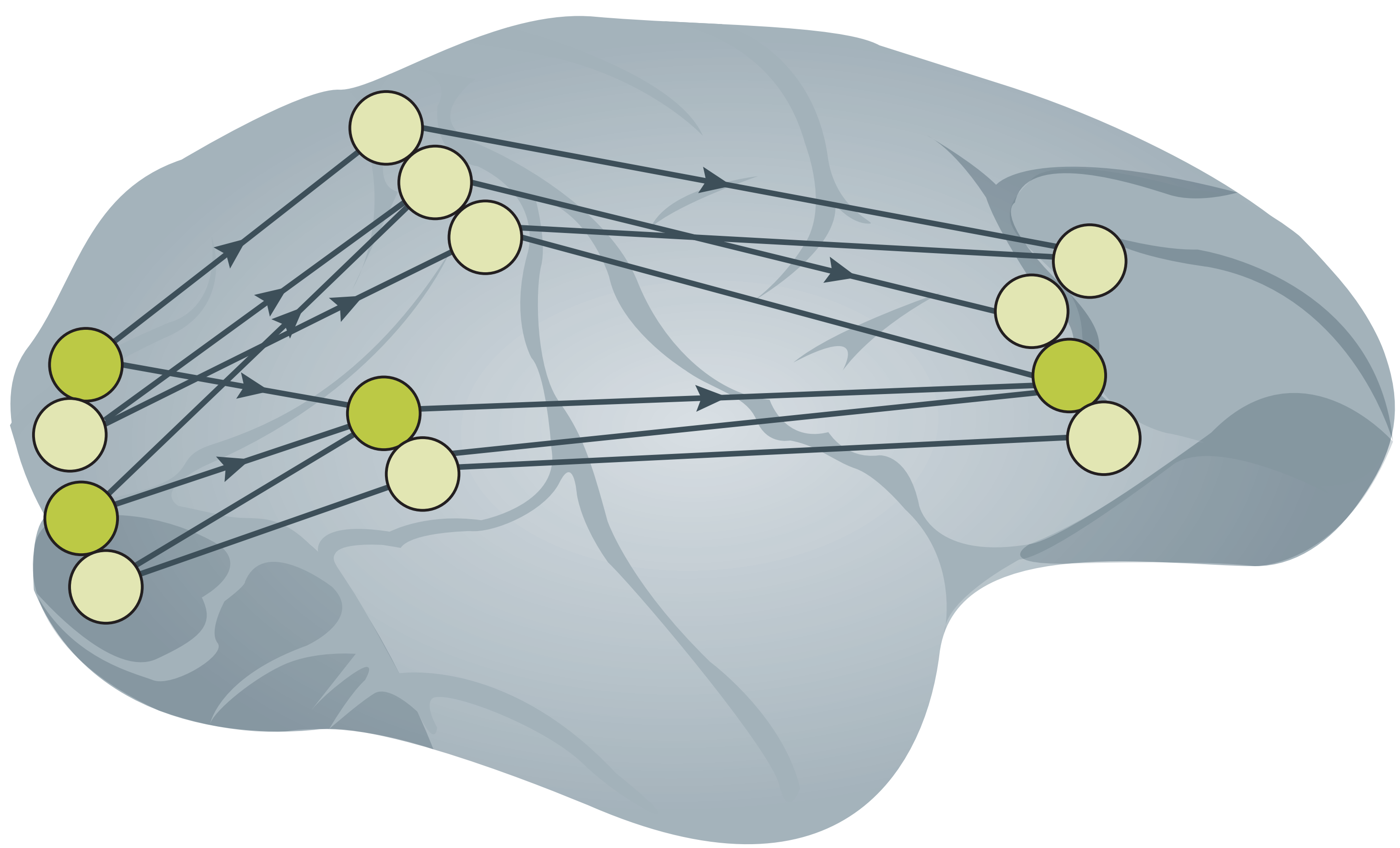
Visual input → Prepare movement → Hit (or not) the ball

How does the brain learn
to associate visual input with motor output?

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

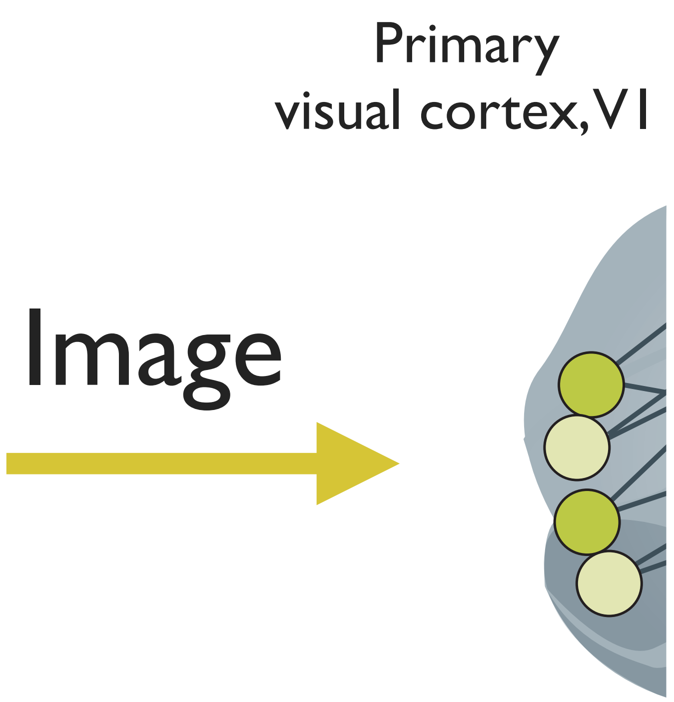
How to assign credit to ‘parameters’ in the brain?

(typically **synapses**)



Roelfsema et al. Nature Neuroscience Rev 2018

How to assign credit in the brain?



Roelfsema et al. Nature Neuroscience Rev 2018

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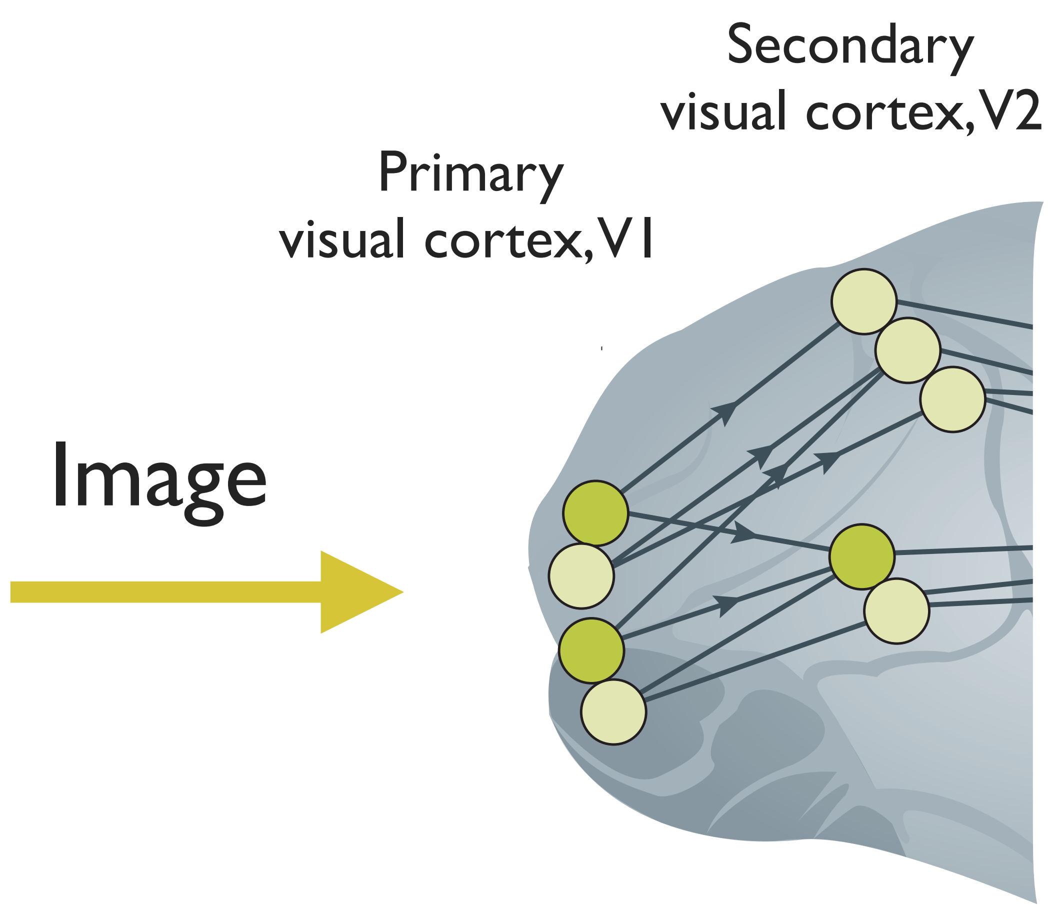

Roelfsema et al. Nature Neuroscience Rev 2018

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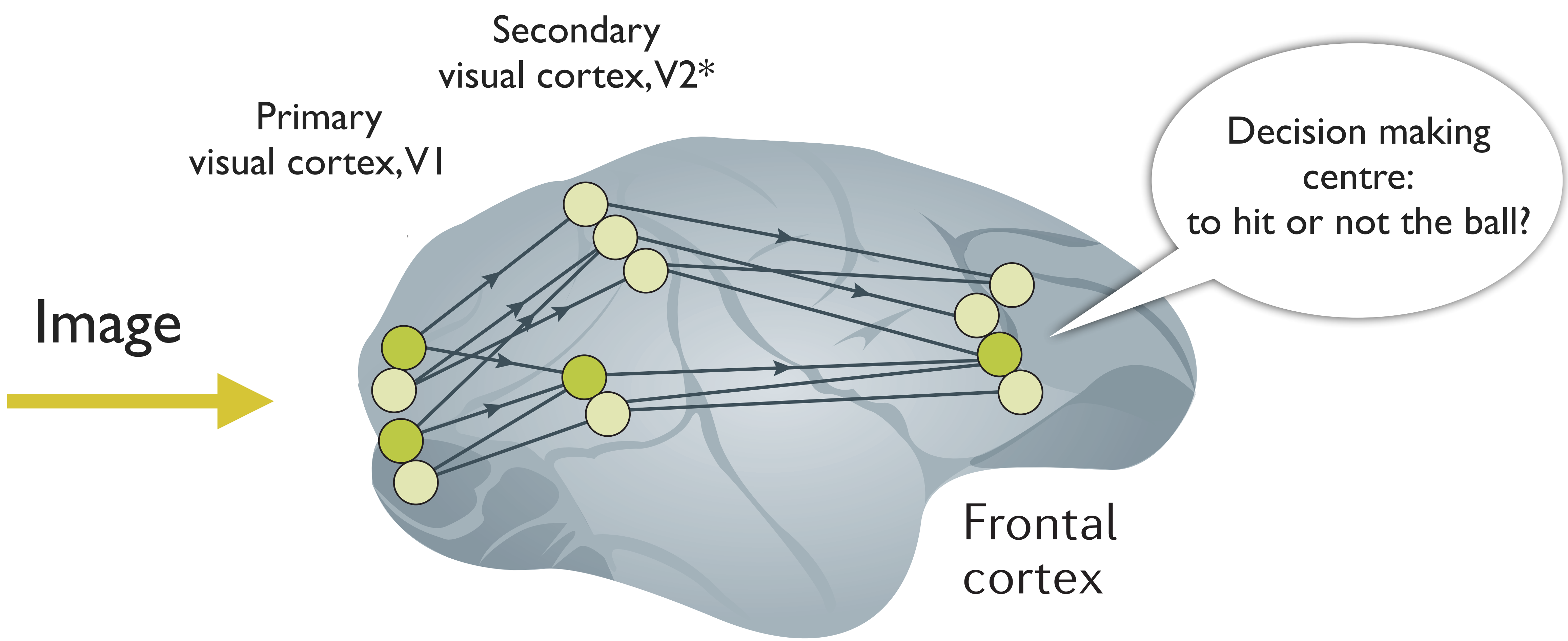
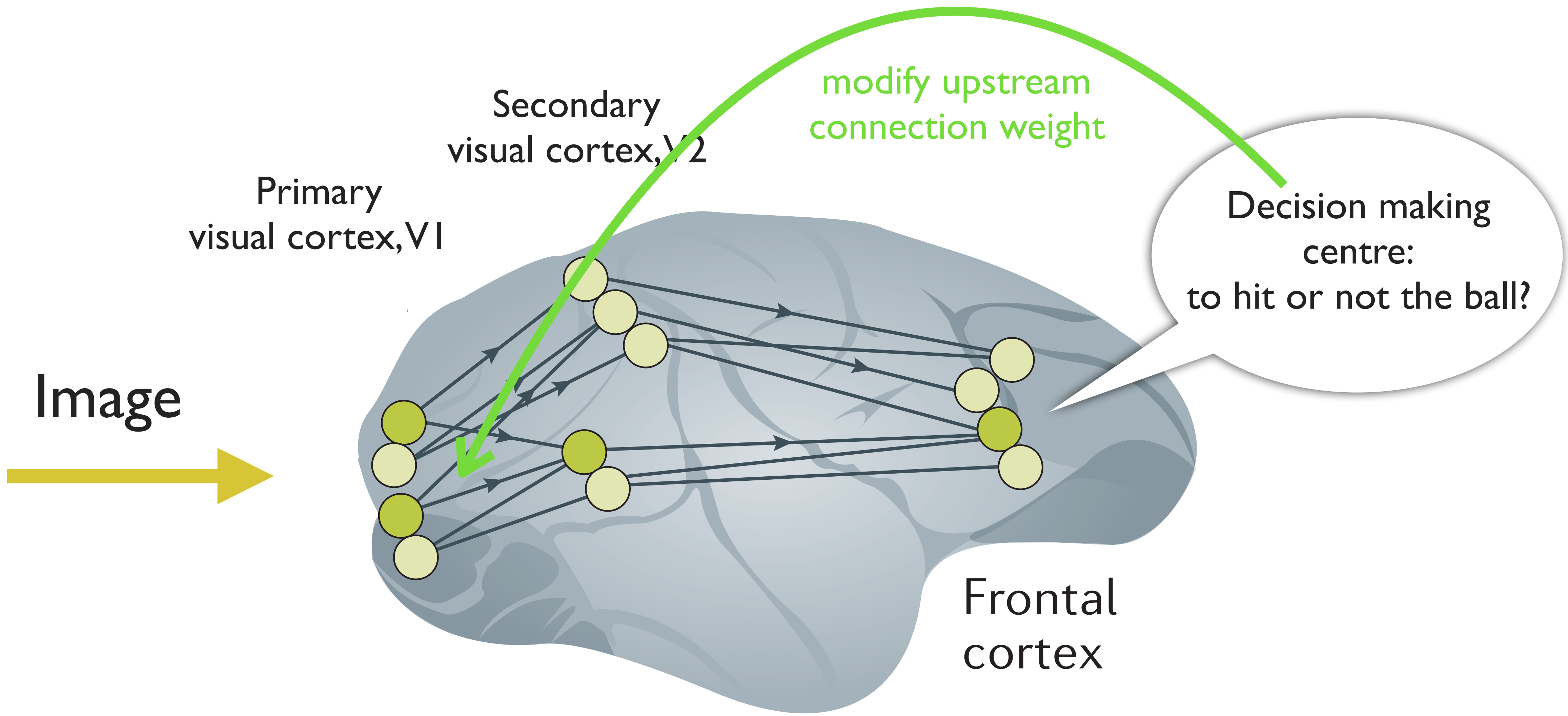


*: or associative cortices

Roelfsema et al. Nature Neuroscience Rev 2018

How to assign credit in the brain?



Credit assignment problem:
Which neural properties (e.g. connection weights) should be modified to improve a given behaviour?

Roelfsema et al. Nature Neuroscience Rev 2018

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

Supervised Learning

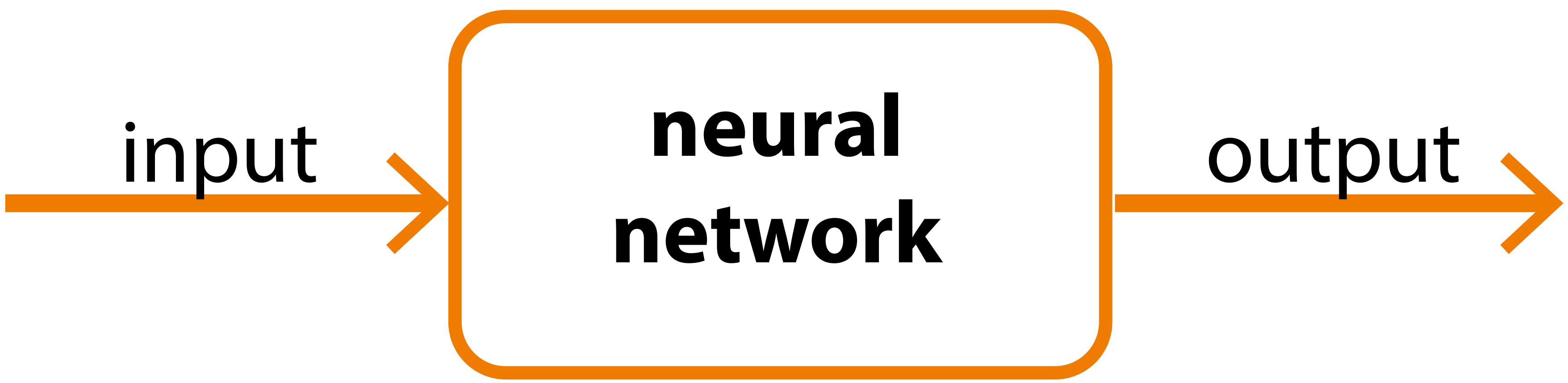
Unsupervised Learning

Reinforcement Learning

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

Unsupervised Learning:

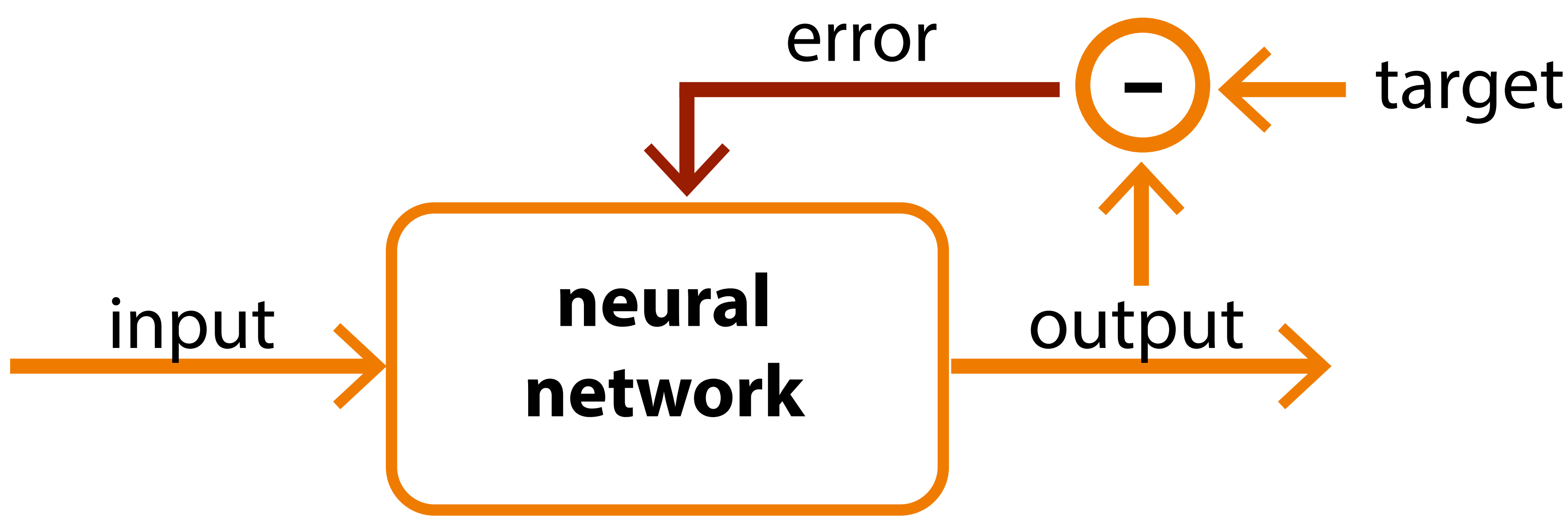
Extracts useful representations of input



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

Supervised Learning:

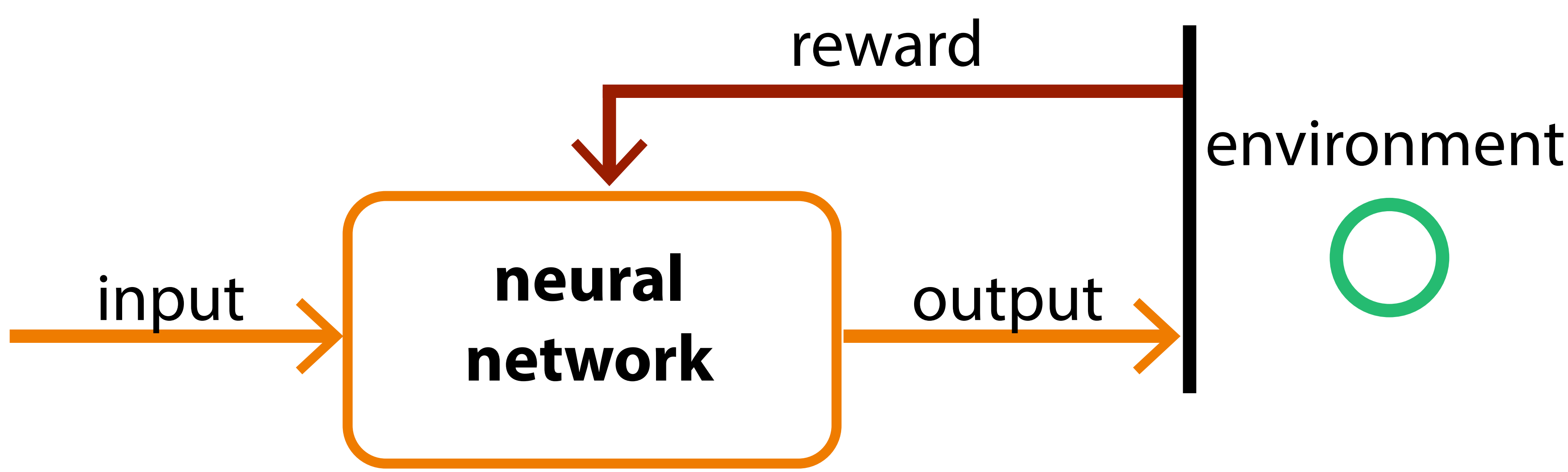
Relies on a teaching signal



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

Reinforcement Learning:

Learn to navigate/survive an environment



Poll and group discussion
groups of 2-3 (5 min)

What is the dominant form of learning in the brain? *2nd round*

Go to www.menti.com
Code: 94 90

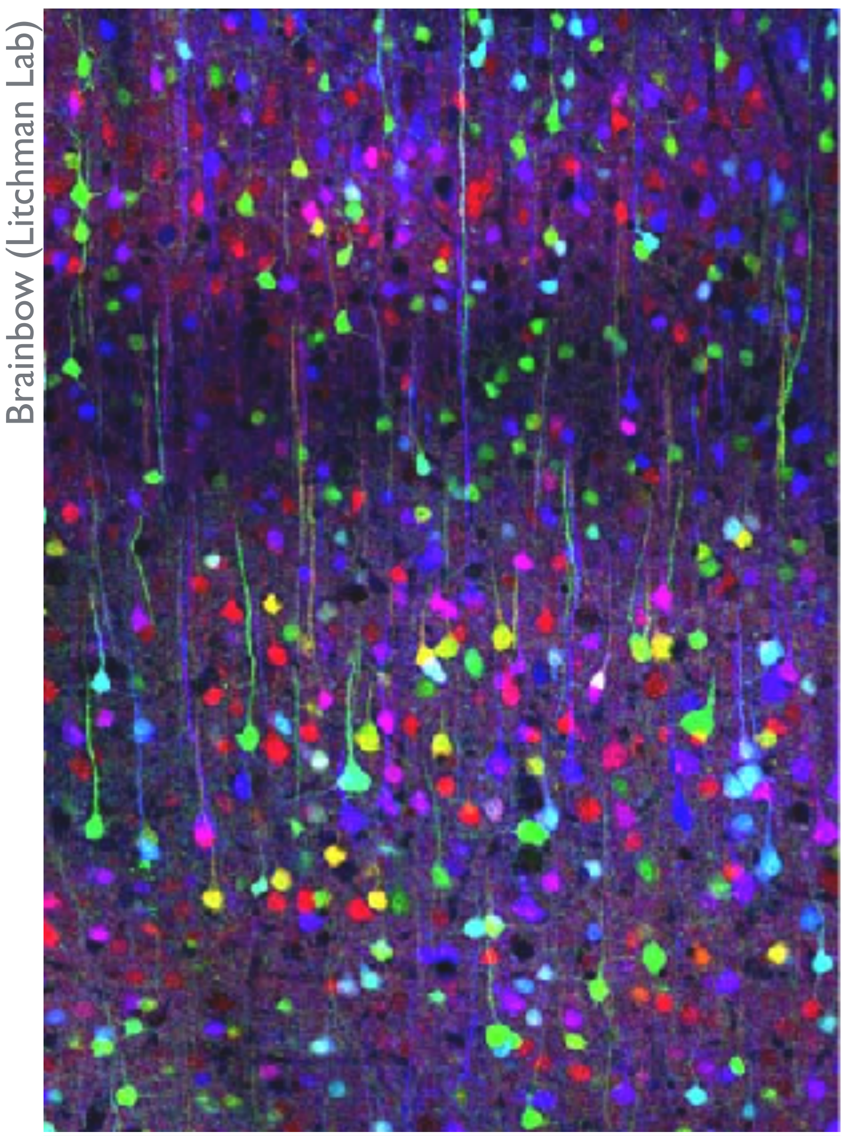
A feedforward neural network

The brain is like a tropical forest!

With many different neuron *types* and *architectures*..

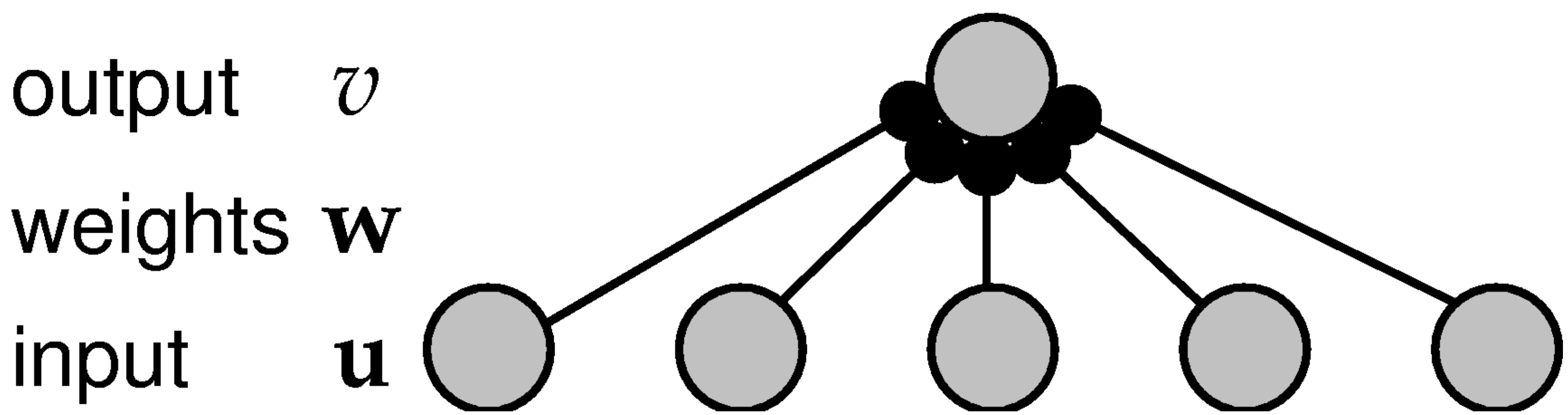
DeFelipe et al. Nat. Neurosci. Reviews 2013

Brainbow (Litchman Lab)



A feedforward neural network

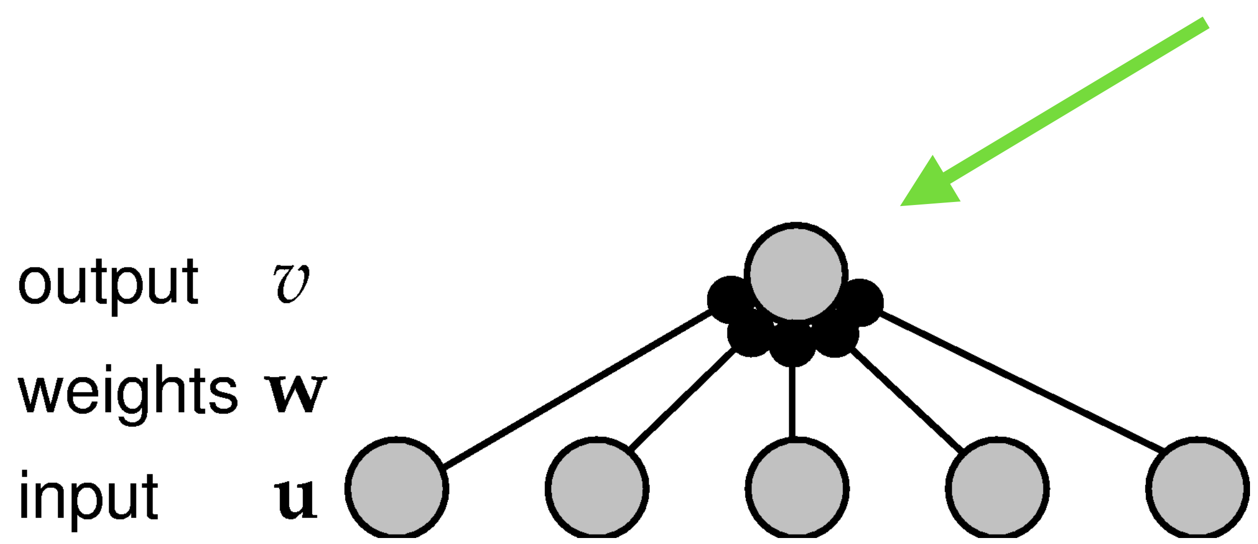
In theoretical neuroscience we need to abstract out some of this complexity to get at the principles of information processing in the brain!



Supervised learning

Goal: Classify input into different categories

Teaching signal, *y*

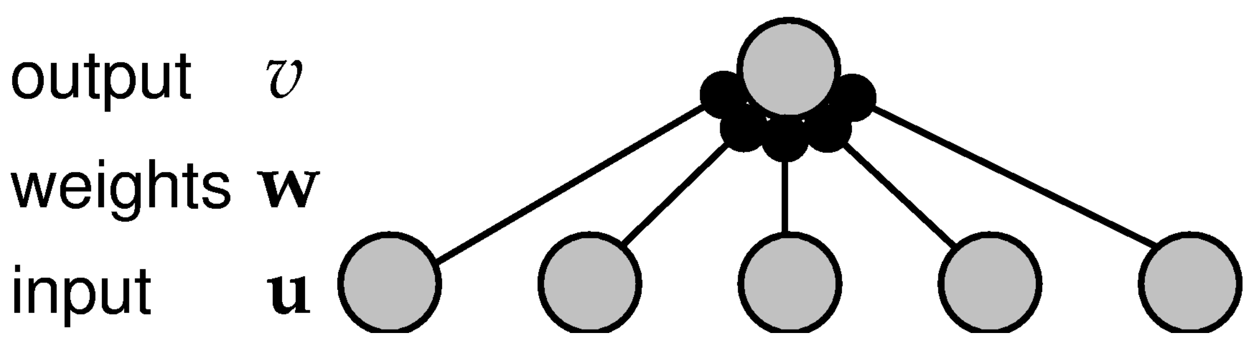


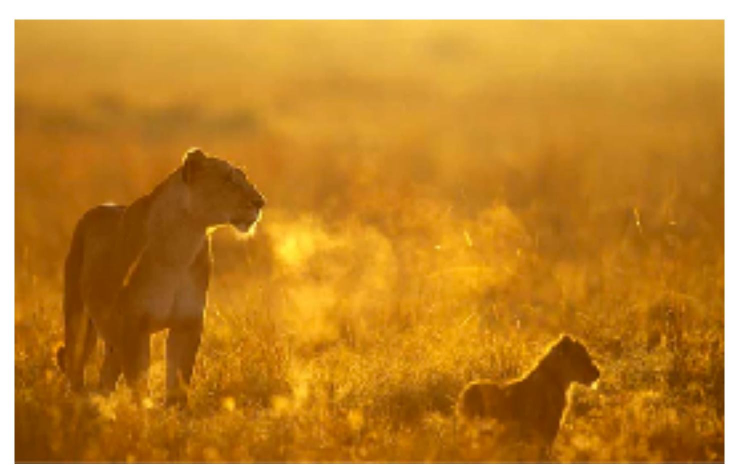
Supervised learning

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

where f is some (non)linear function

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



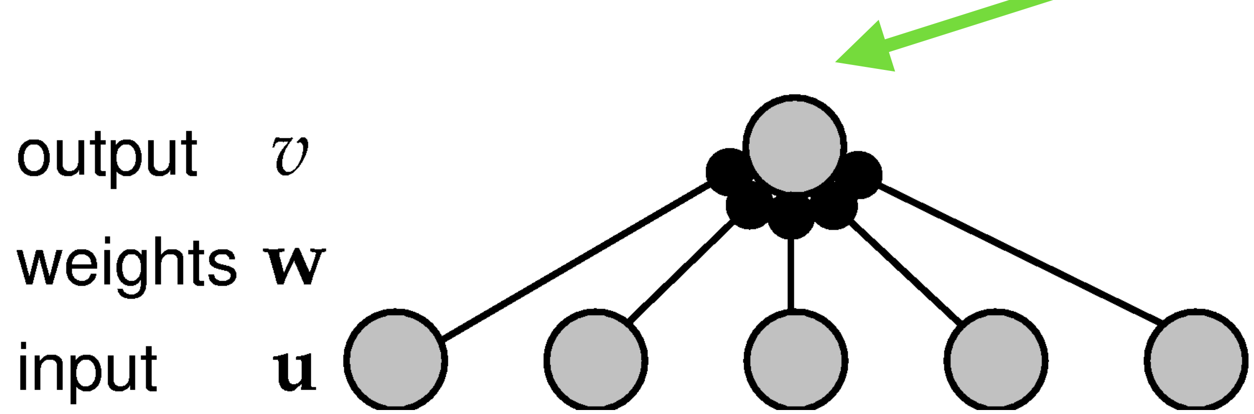


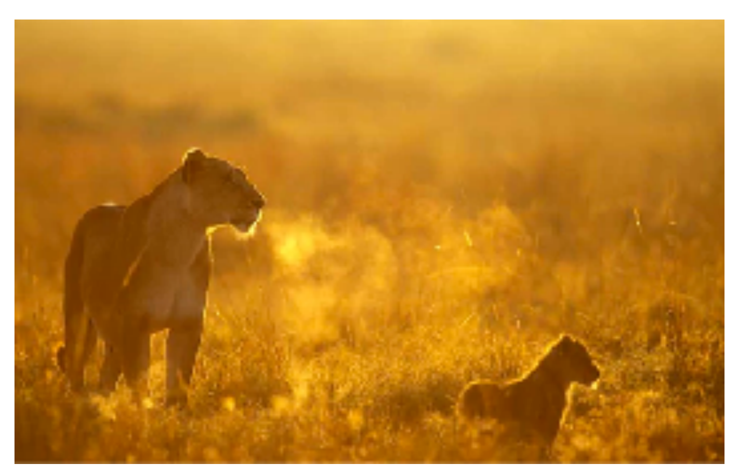
Supervised learning

Minimise cost

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

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





Supervised learning

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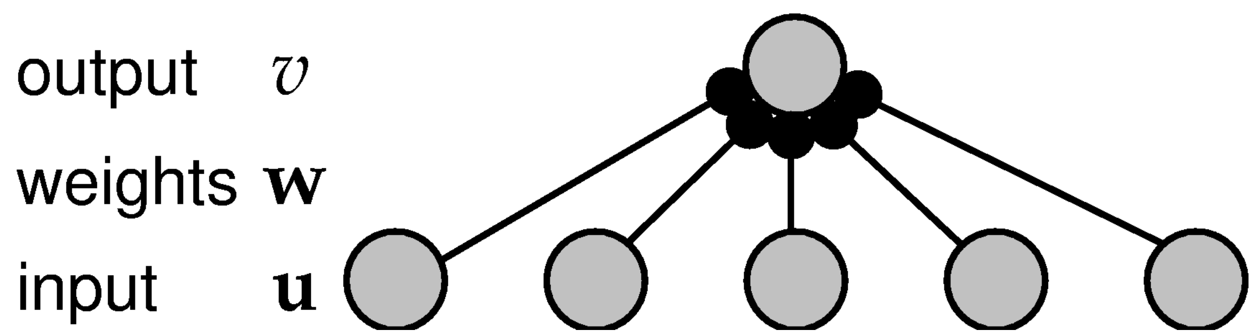
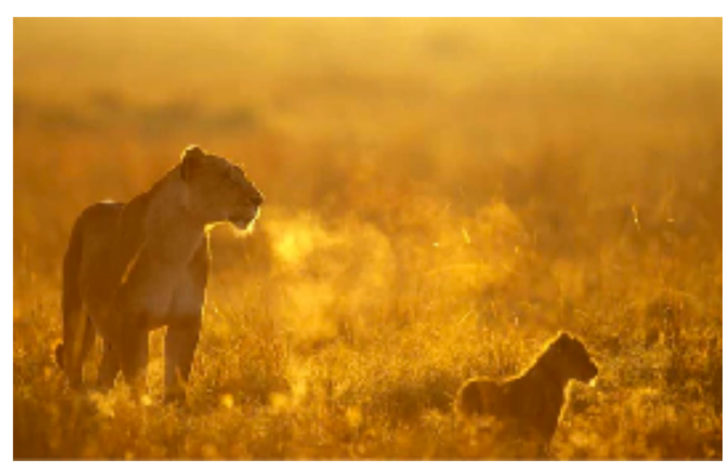
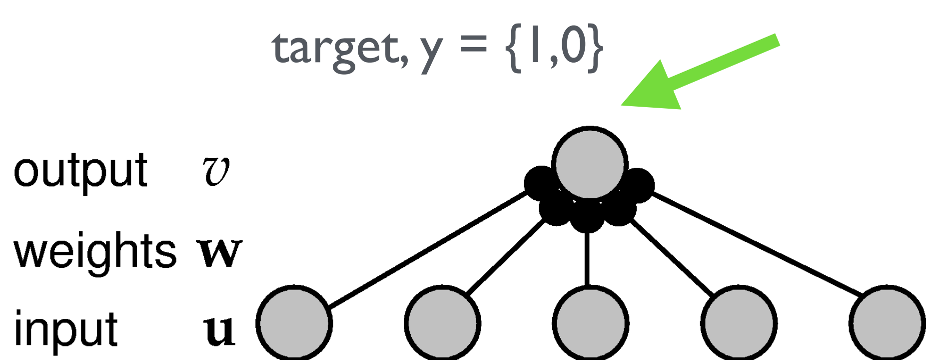




Supervised learning

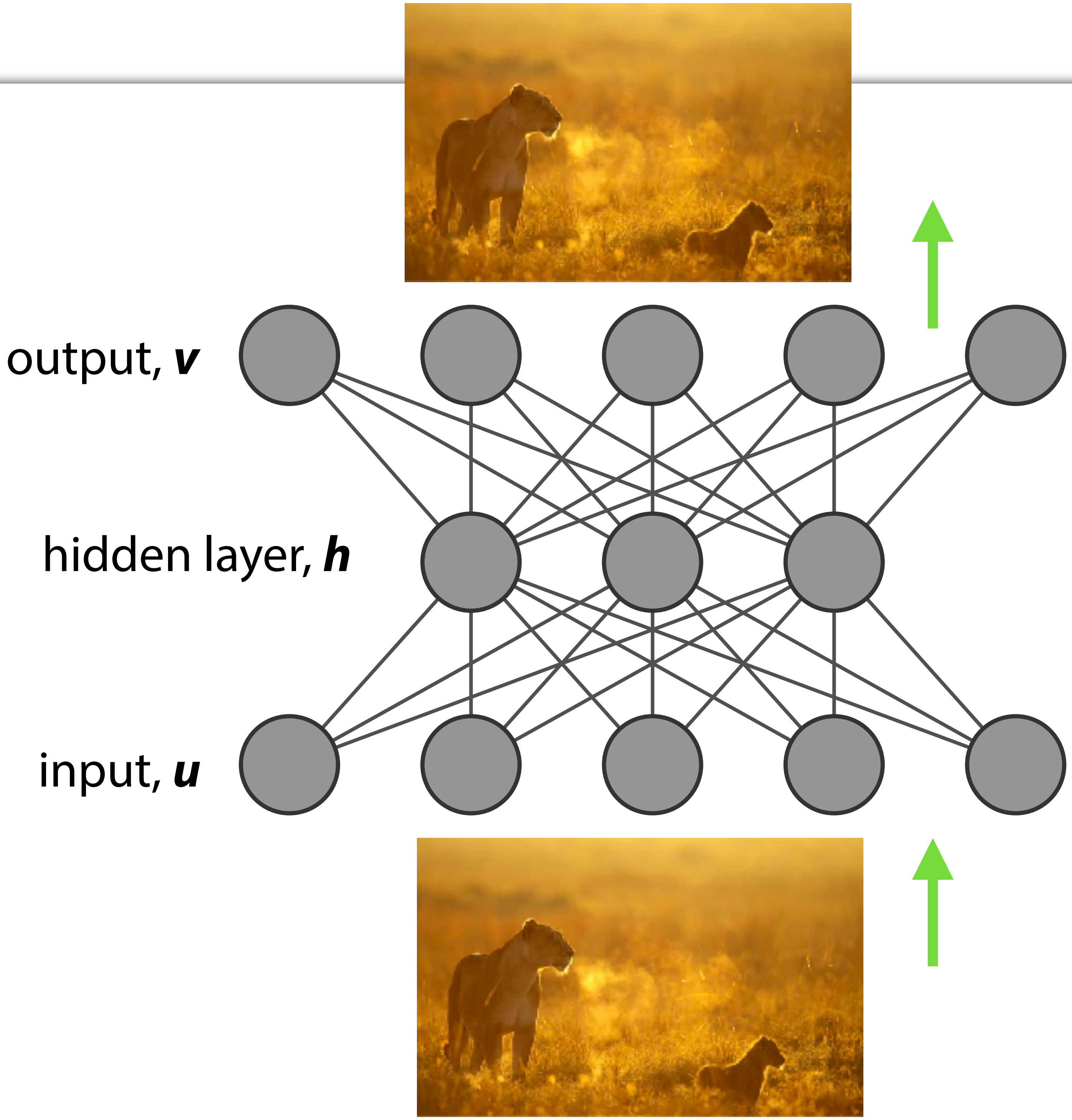


$$\text{cost} = (v - y)^2$$

- 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
  - Linear regression
- Animals experience some degree of supervised learning (e.g. with external teacher)

Unsupervised learning

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



Unsupervised learning

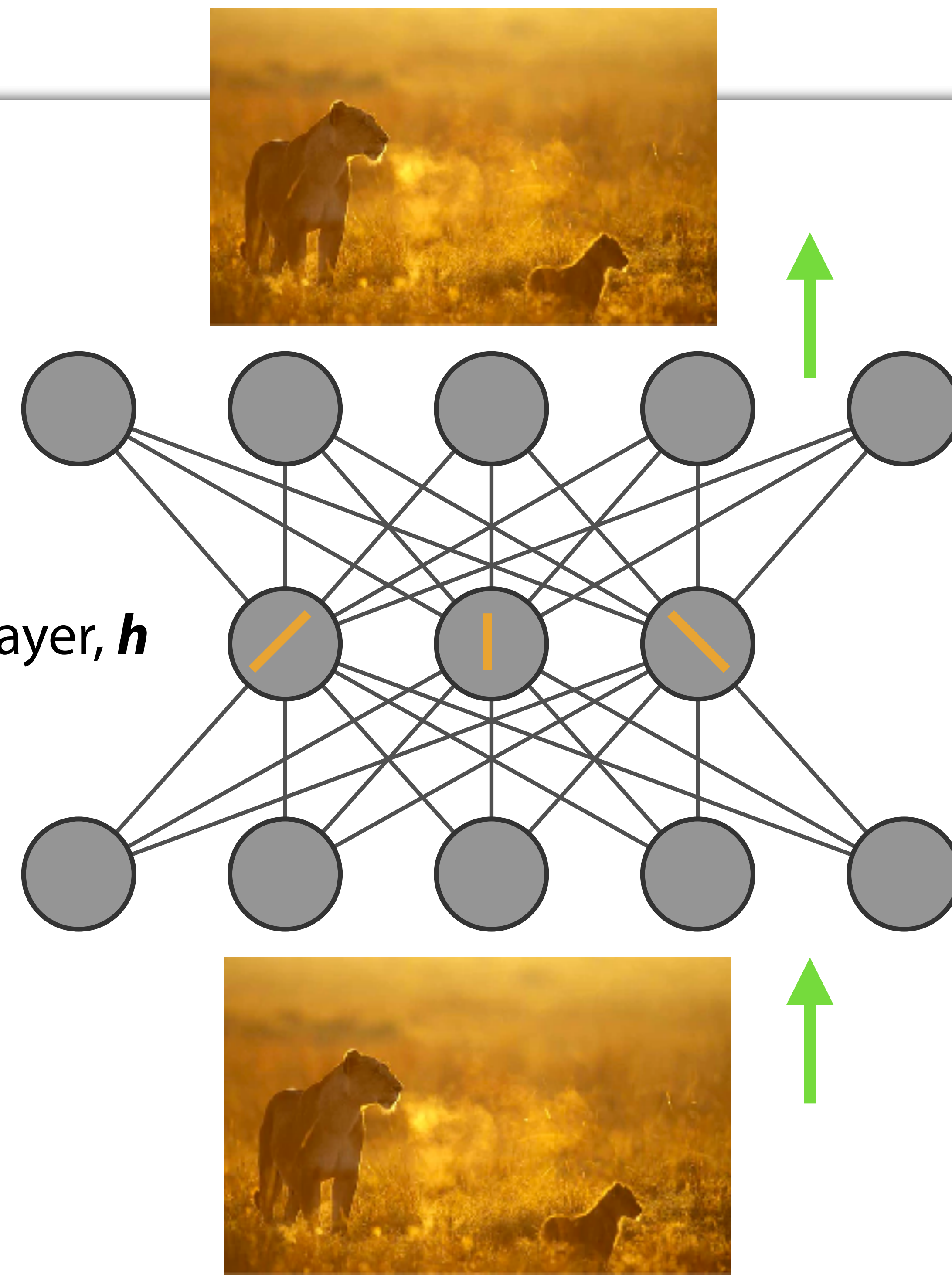
output, $v = f(wh)$

Learned representation
(e.g. edges)

output, $\boldsymbol{v}$

hidden layer, $\boldsymbol{h}$

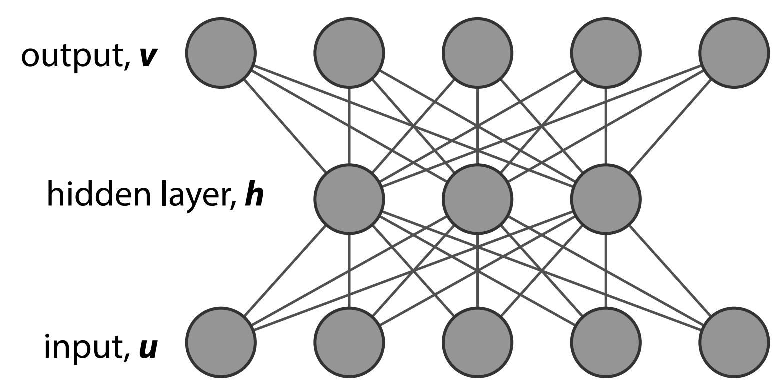
input, $\boldsymbol{u}$



Minimise cost

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

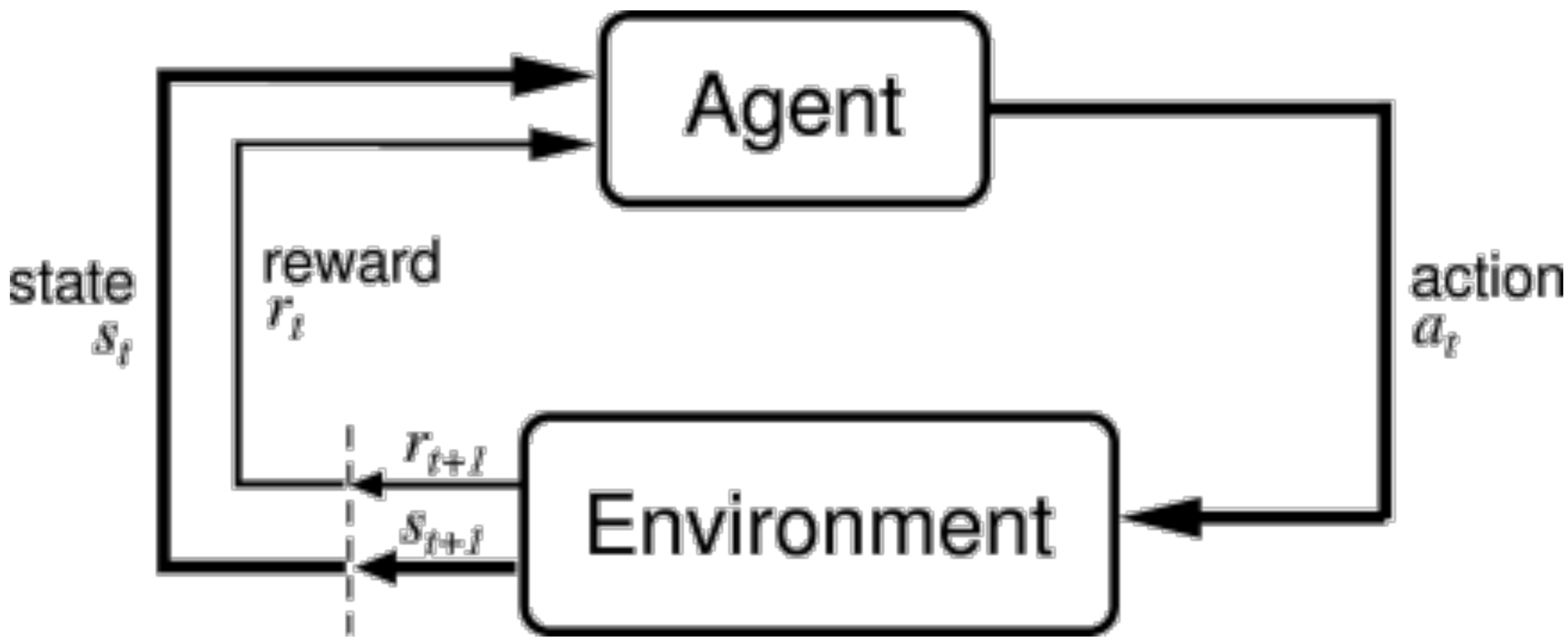
Unsupervised learning



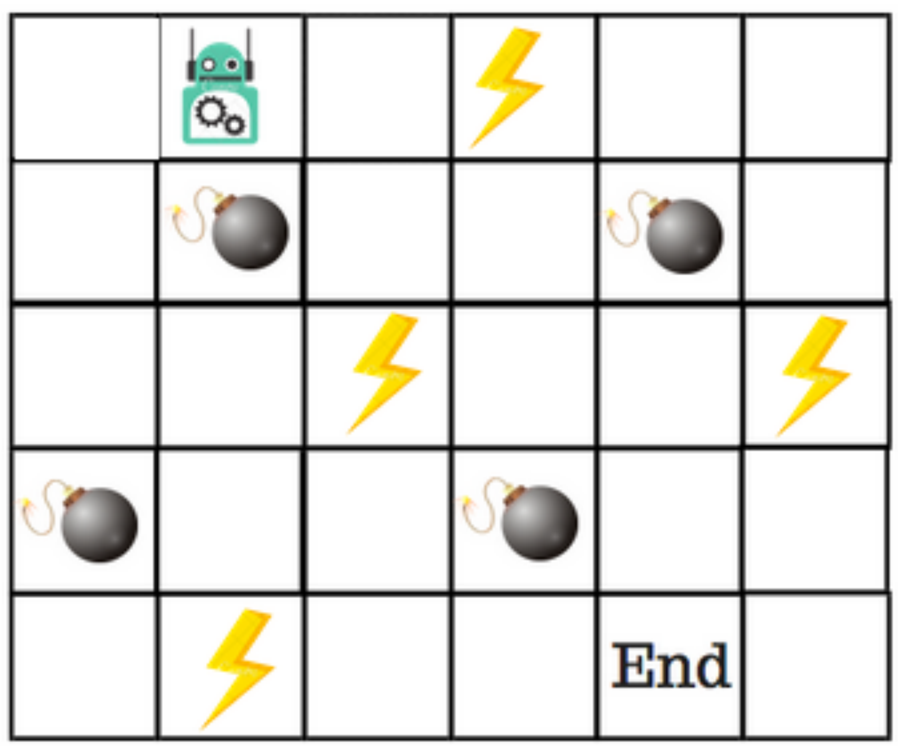
- The learning rules for **w** can be derived from the cost (or error) function for a particular network, e.g. sparse coding algorithm.
- Examples of unsupervised learning methods:
  - Sparse coding (akin to PCA)
  - Restricted Boltzmann Machines
  - Autoencoders
- Animals are bombarded with vast streams of sensory input with no supervisor

Reinforcement learning

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



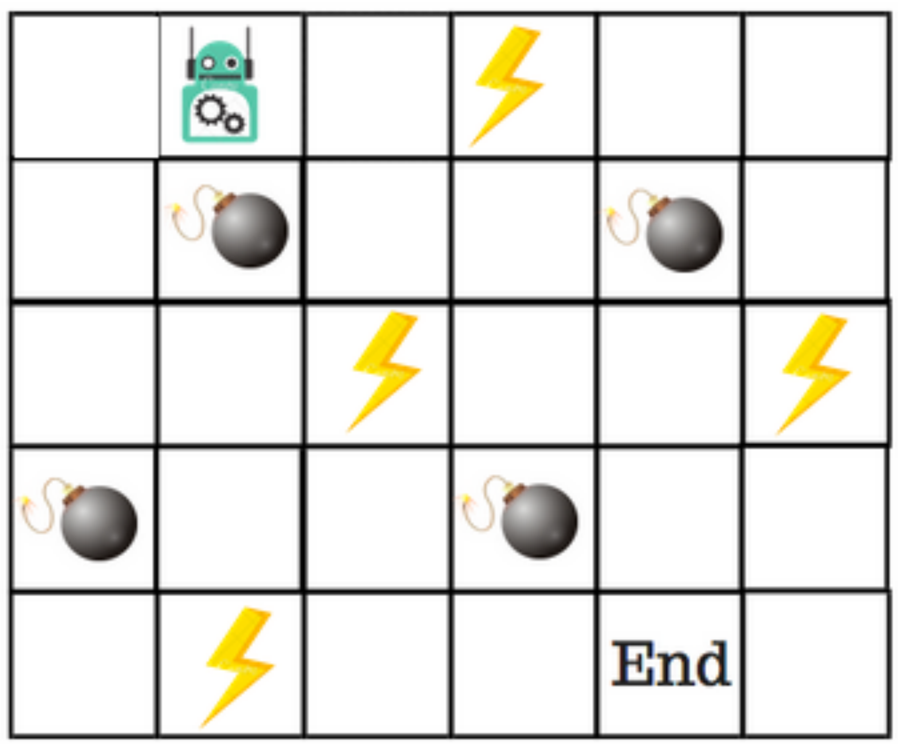
Reinforcement learning



Value table/policy

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

Reinforcement learning



Value table/policy

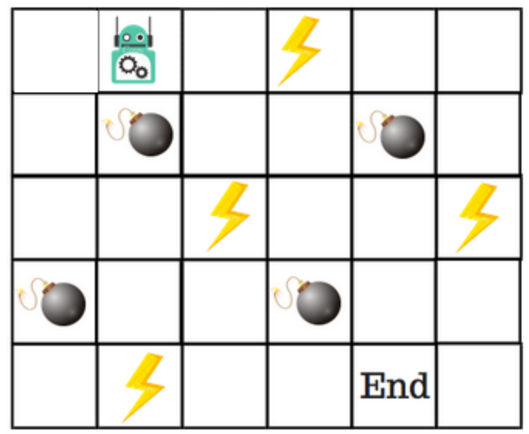
Actions :	↑	→	↓	←
Start	0	0	0	0
Nothing / Blank	0	0	0	0
Power	0	0	0	0
Mines	0	0	0	0
END	0	0	0	0

Update value table with temporal difference (TD) learning:

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

λ: discount factor

Reinforcement learning



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

- 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

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

Reinforcement Learning

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

Summary

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

Poll and group discussion

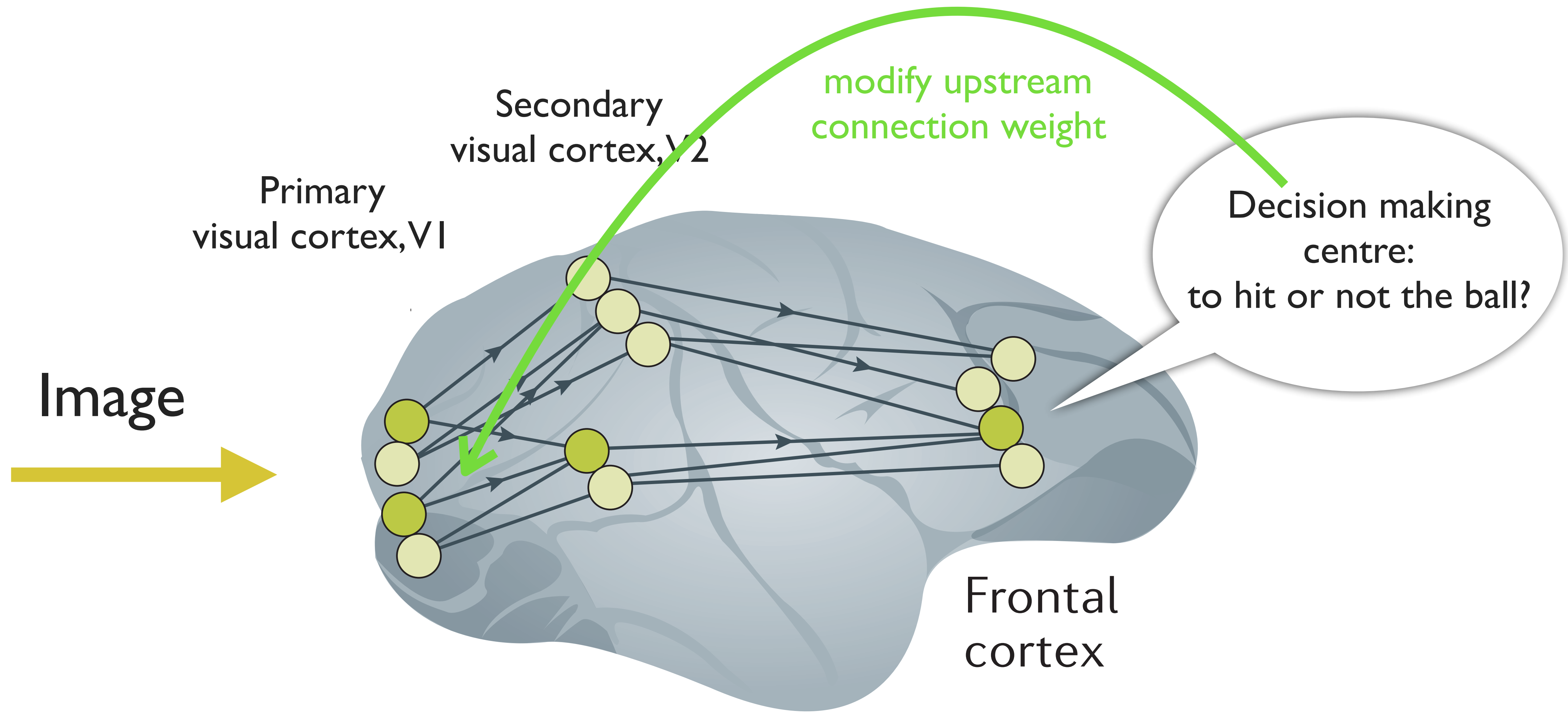
groups of 2-3 (5 min)

What is the dominant form of learning in the brain?

Go to www.menti.com

Code: 94 90

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!

Questions?

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)

Next lecture..

- L11[6]: Neural circuits and learning: introduction
- **L12[6]: Visual system: deep learning?**
- L13[7]: Supervised learning & backprop
- L14[7]: Unsupervised learning
- L15[9]: Reinforcement learning
- L16[9]: Temporal processing & recurrent neural networks
- L17[10]: Recurrent neural networks
- L18[10]: Brain vs machine: meta-learning and inductive bias
- L19-20[11]: Neural data analysis (by Cian)
- L21-22[12]: Revision week

Course work

On Blackboard and
https://github.com/comsm0034/2019_20

- Implement a classical learning 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: 6th of December 2019 (noon)
  - Teaching assistants: Anne-Lene Sax (anne-lene.sax@bristol.ac.uk)
    Milton Llera Montero (m.lleramontero@bristol.ac.uk)