

COMS30017

Computational Neuroscience

Neuronal computation and communication

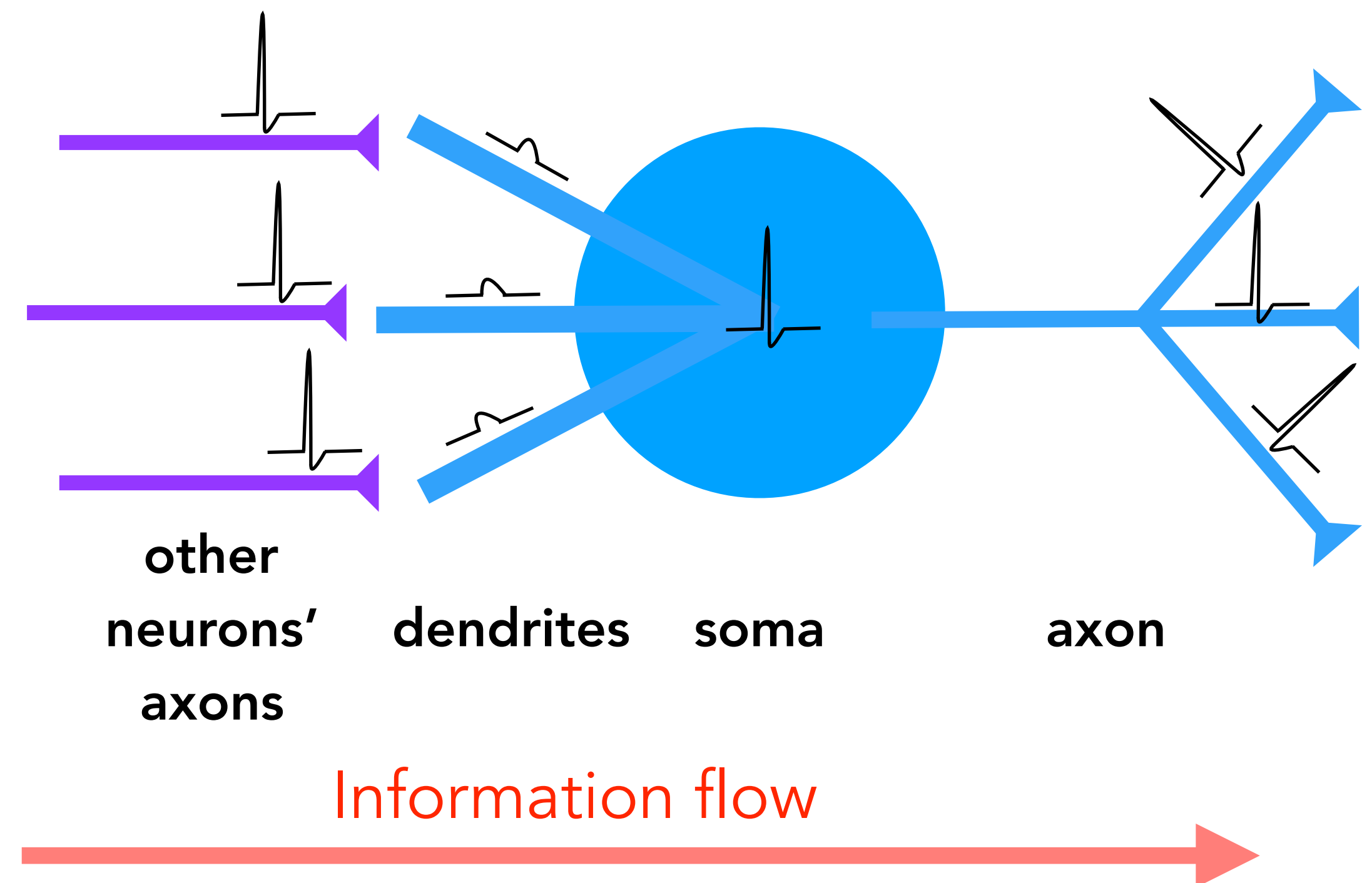


Intended learning outcomes

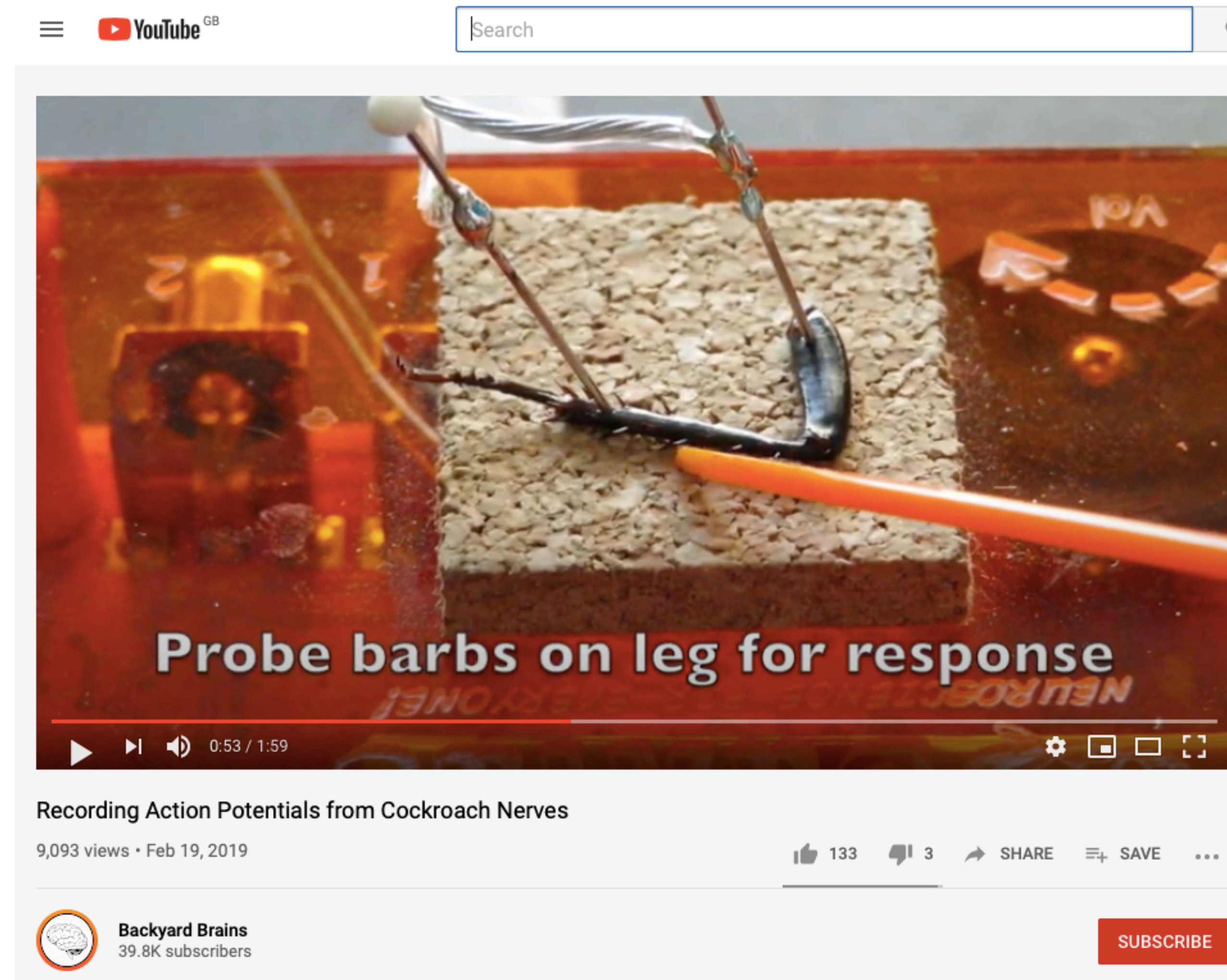
- Gain a basic understanding of the input-output function of a neuron.
- Understand the difference between a post-synaptic potential and an action potential.
- Distinguish between feedforward and recurrent neural networks.

Information flow in single neurons

- Input from other neurons arrives at the synapses.
- Each synapse triggers a small **post-synaptic potential** (PSP) in a dendrite, roughly 1mV in amplitude and 10ms duration.
- The somatic voltage **sums** all these PSPs (both excitatory and inhibitory).
- If the soma's voltage reaches a threshold (around 20 mV above rest), the neuron emits an **action potential** or "spike". The spike itself is around 100mV in amplitude and 1-2 ms in duration.
- Copies of this spike travel down the axon to target neurons.
- Each spike is stereotypical, information is encoded only in their timing and frequency.



Backyard brains video of cockroach nerve spikes



<https://youtu.be/zkE7wA1F6aU?t=53>

Sound on!

Where is the computation?

- Roughly speaking, the fundamental computation that neurons do is **weighted sum of their inputs, followed by a threshold**:

The diagram shows the equation $y = \Theta \left(\sum_i x_i w_i \right)$. Four purple arrows point from labels below to parts of the equation: 'output' points to y , 'threshold' points to Θ , 'inputs' points to x_i , and 'synaptic weights' points to w_i .

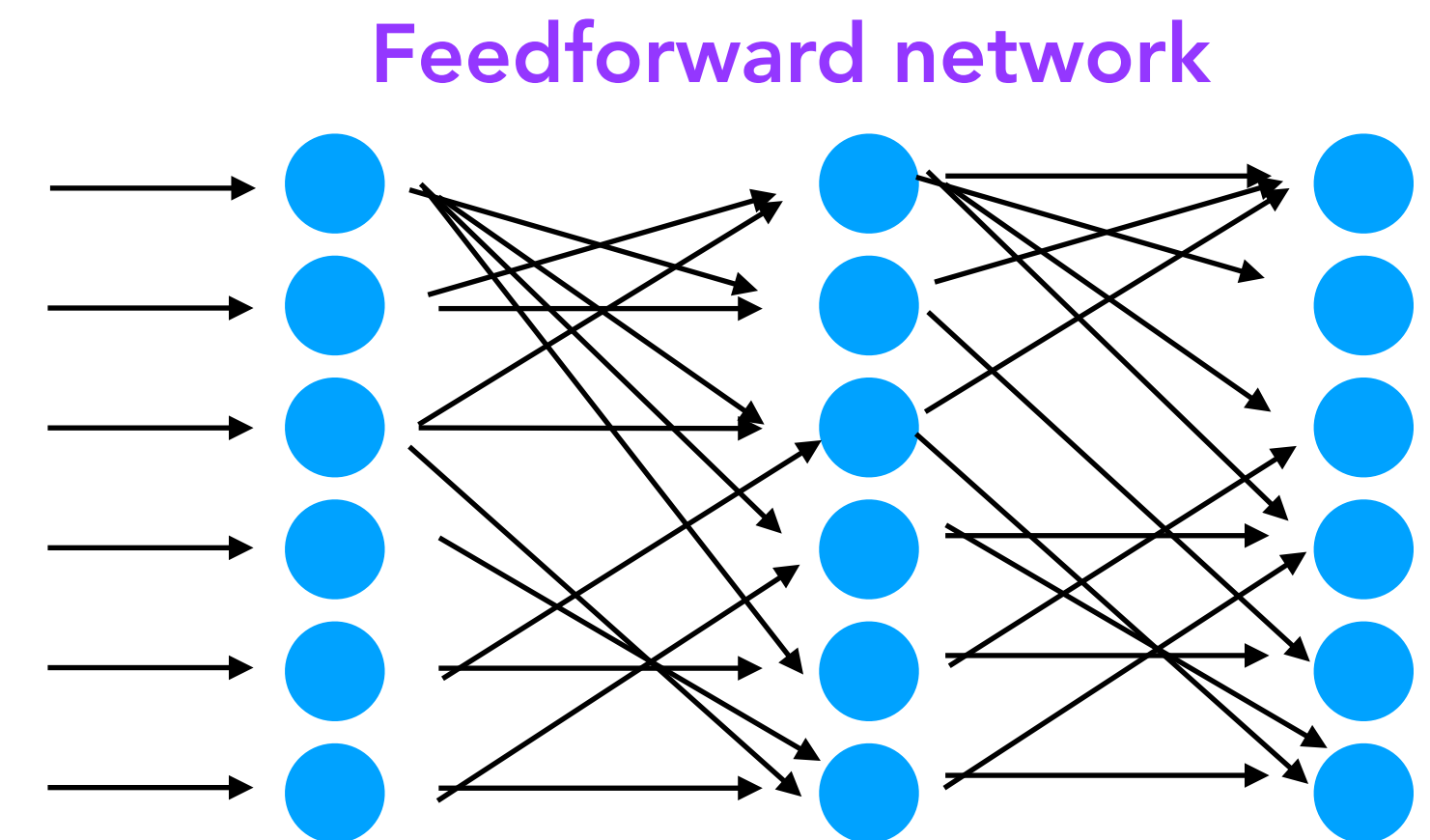
$$y = \Theta \left(\sum_i x_i w_i \right)$$

output threshold inputs synaptic weights

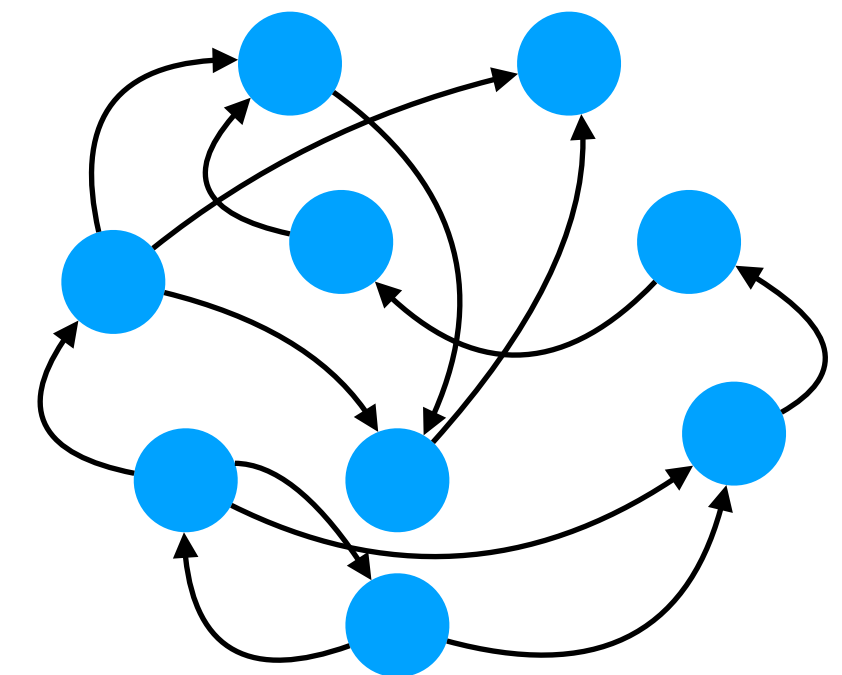
- However please remember that this model — although common — is a gross simplification of reality! The input-output function is also affected by:
 - other nonlinearities (at the synapses and dendrites)
 - dynamics (the recent past affects the current output)
 - noise (unavoidable randomness and stochasticity).

Networks of neurons

- The real computational power of the brain comes from hooking together lots of neurons.
- There are two common architectures for neural networks models:
 - **Feedforward** (no loops, neurons can be organised in sequential layers).
 - **Recurrent** (contains feedback loops).
- Feedforward networks are much easy to study and understand but are rarely accurate models for a brain circuit. Often used as a starting point for modelling.
- Recurrent networks are computationally more powerful, but harder to reason about and control. The real brain is very recurrent.



Recurrent network



Test yourself questions

- Which is bigger, the post-synaptic potential or the action potential?
- What is the key nonlinearity in the neuron's input-output function?

Summary

- Information flow within a single neuron is (mainly) **unidirectional**:
from synapse → dendrite → soma → axon.
- A single neuron take **input signals from many other neurons**, does a weighted sum, thresholds, and sends this **one output signal** to all its target neurons.
- Neural networks come in two basic flavours: feedforward and recurrent.