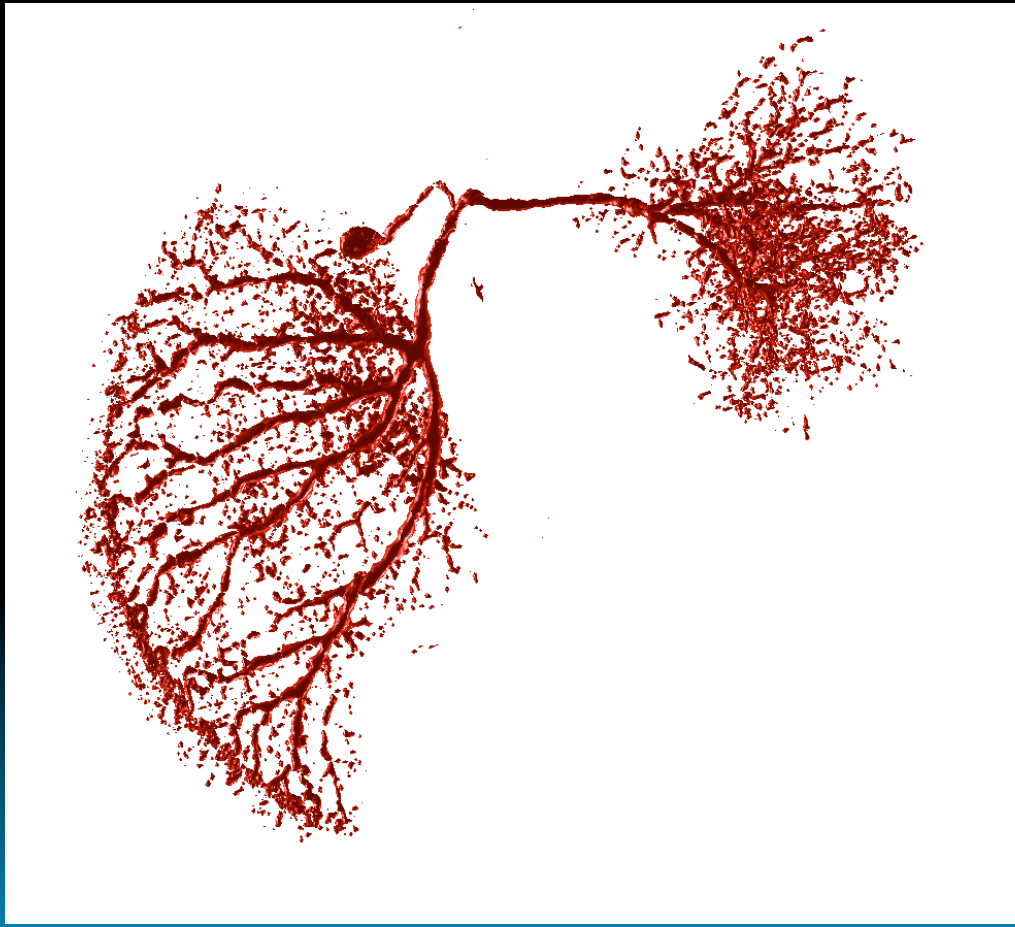
WHAT ARE NEURONS?



Angelique Paulk

Objectives

- How do neurons work?
- How does a network of neurons work to produce behaviors?
- What is a synapse?
- How do neurons communicate?

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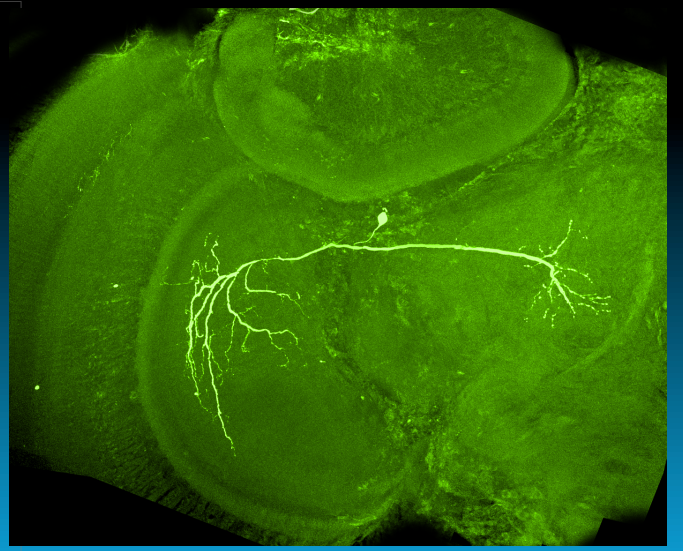
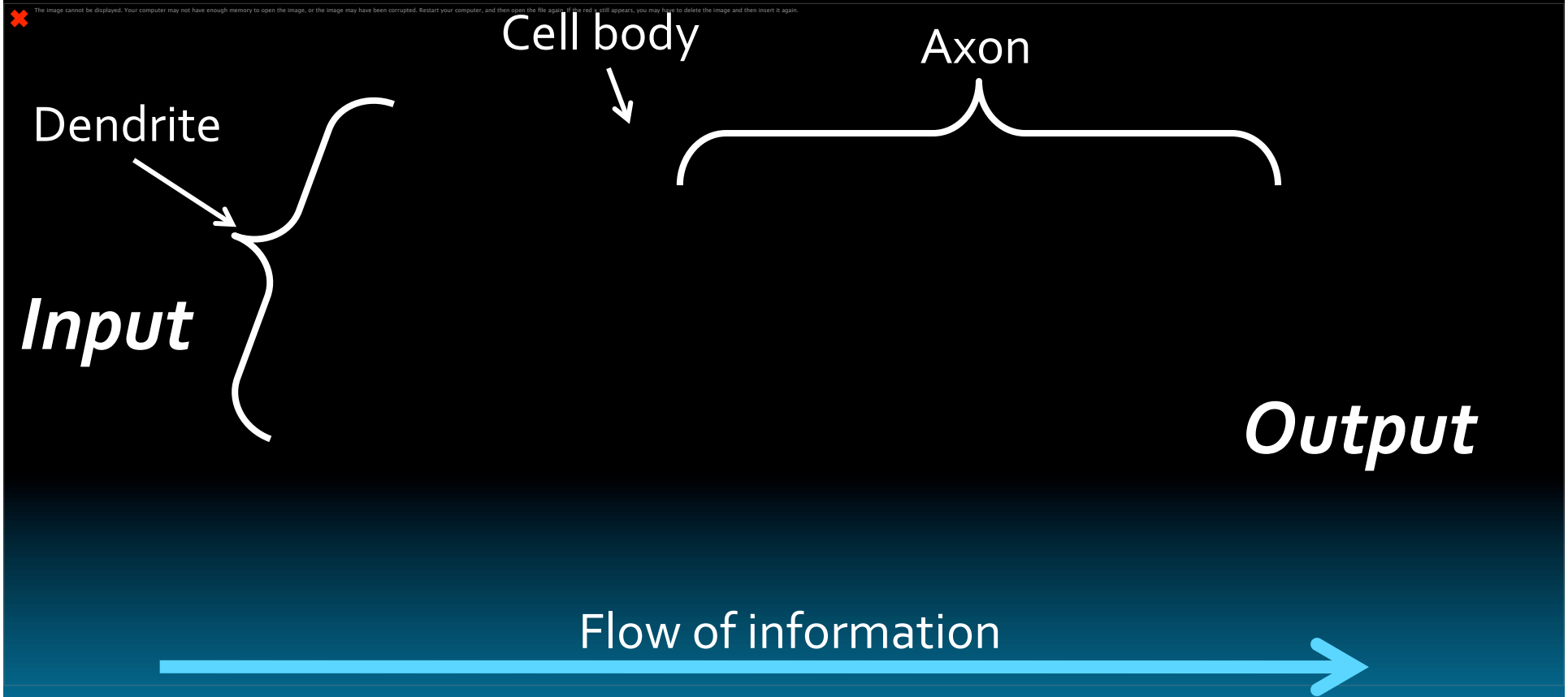


The basic structure of many insect neurons

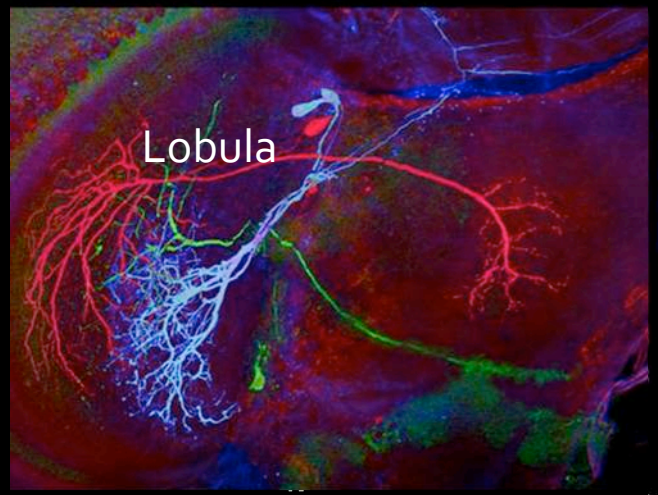


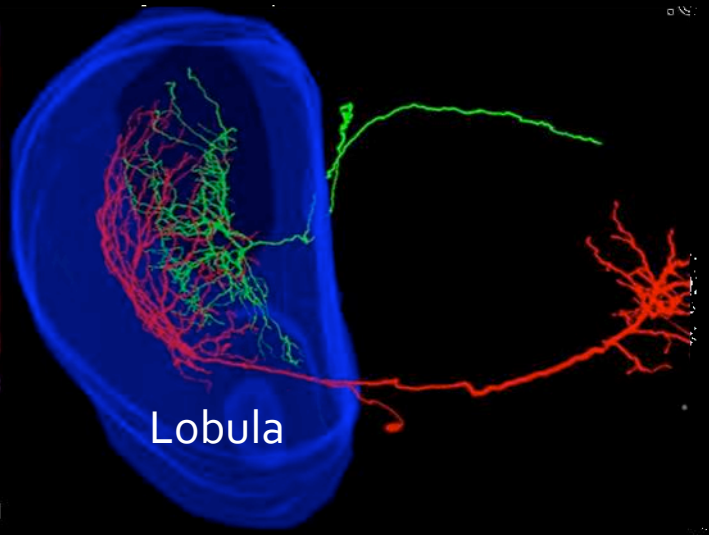
Insect neurons generally have an input and an output region, with the cell bodies located to the side of the rest of the neuron.
This is called a unipolar cell type.

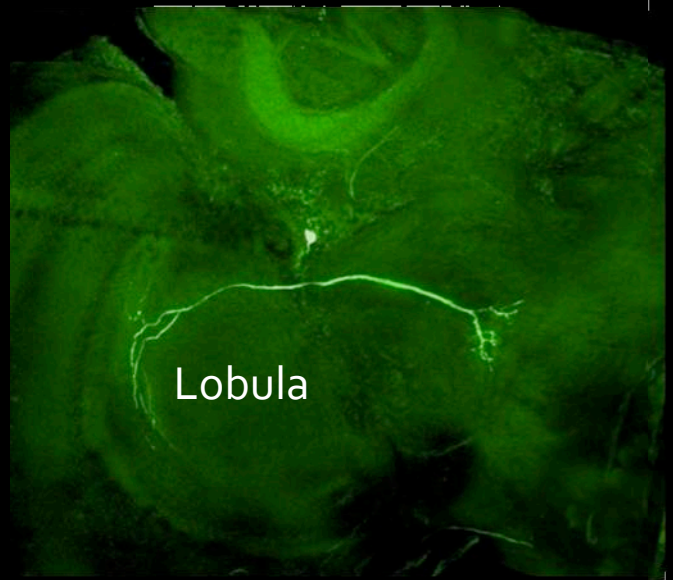
Neurons come in many shapes and sizes

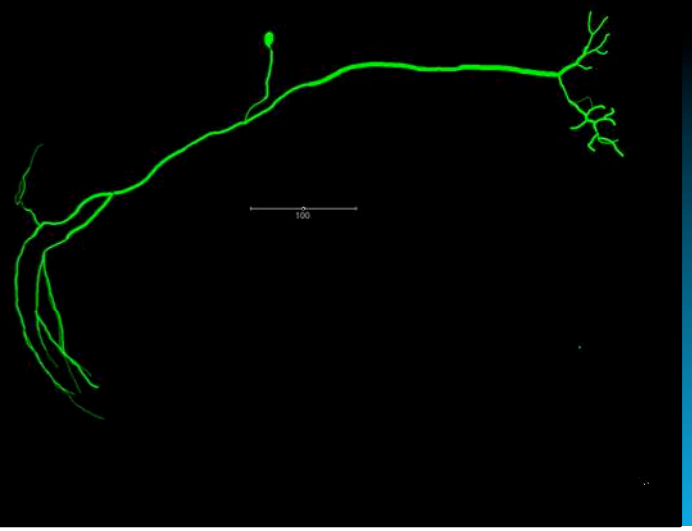
Original cells, frontal view

Three dimensional reconstructions

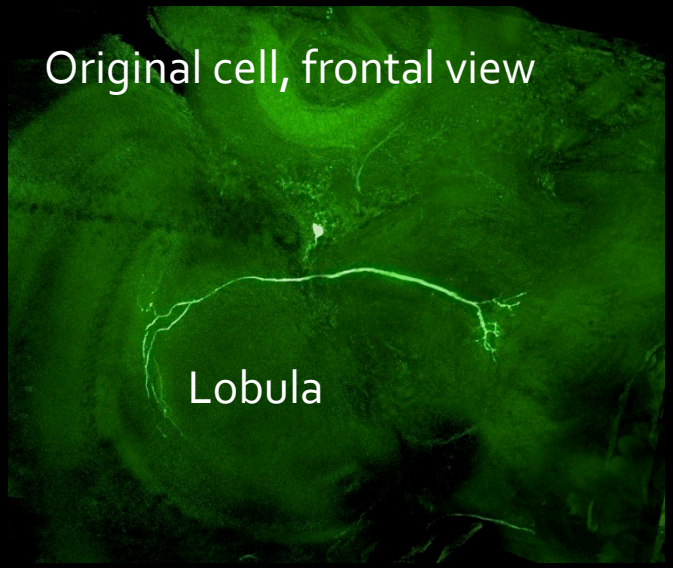


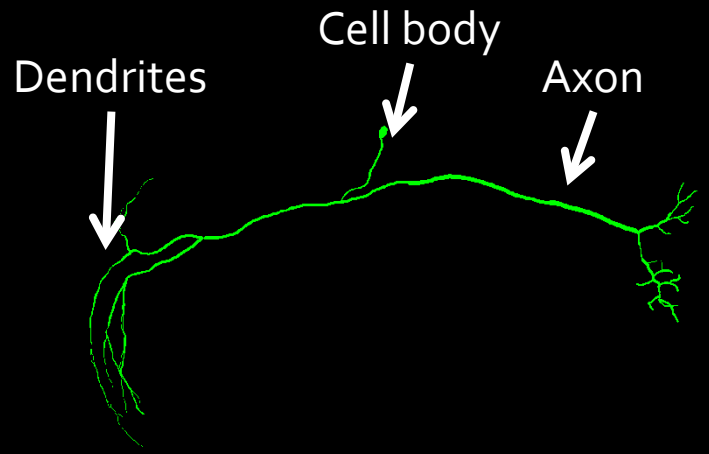




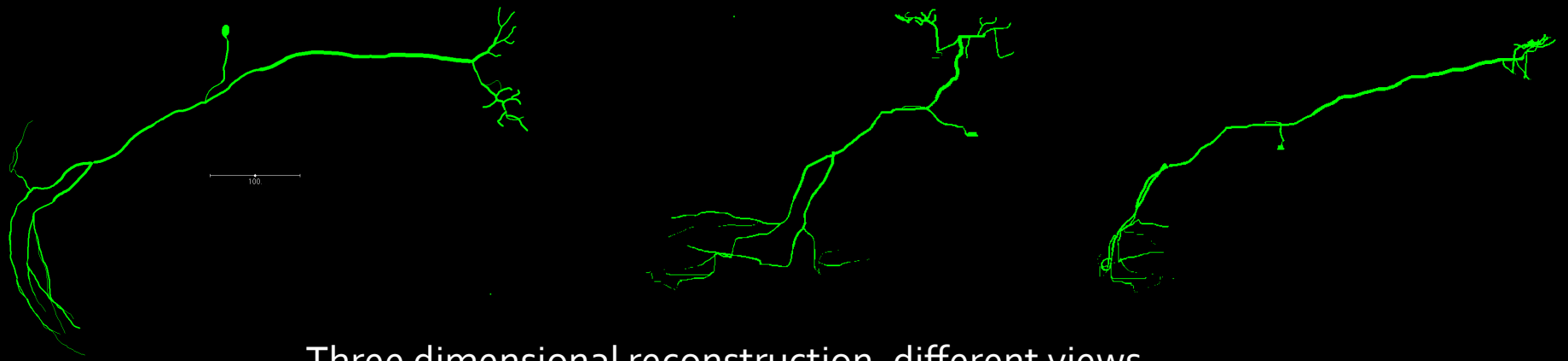


Neurons generally have complex shapes, which likely have a role in their function



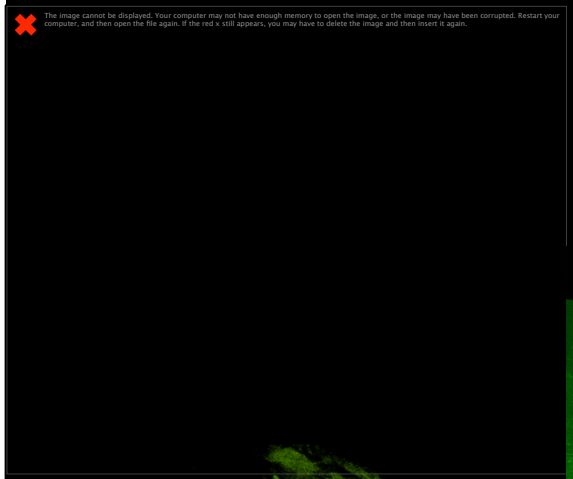


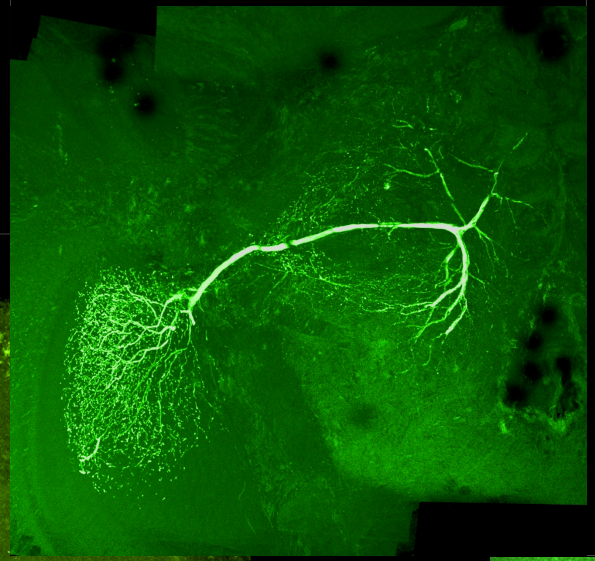
Three dimensional reconstruction

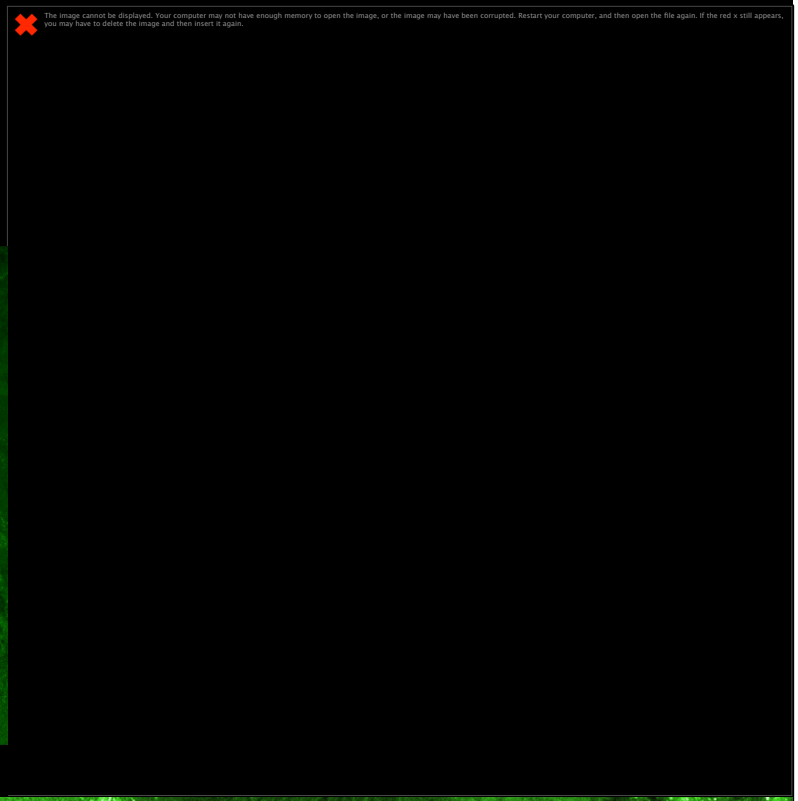


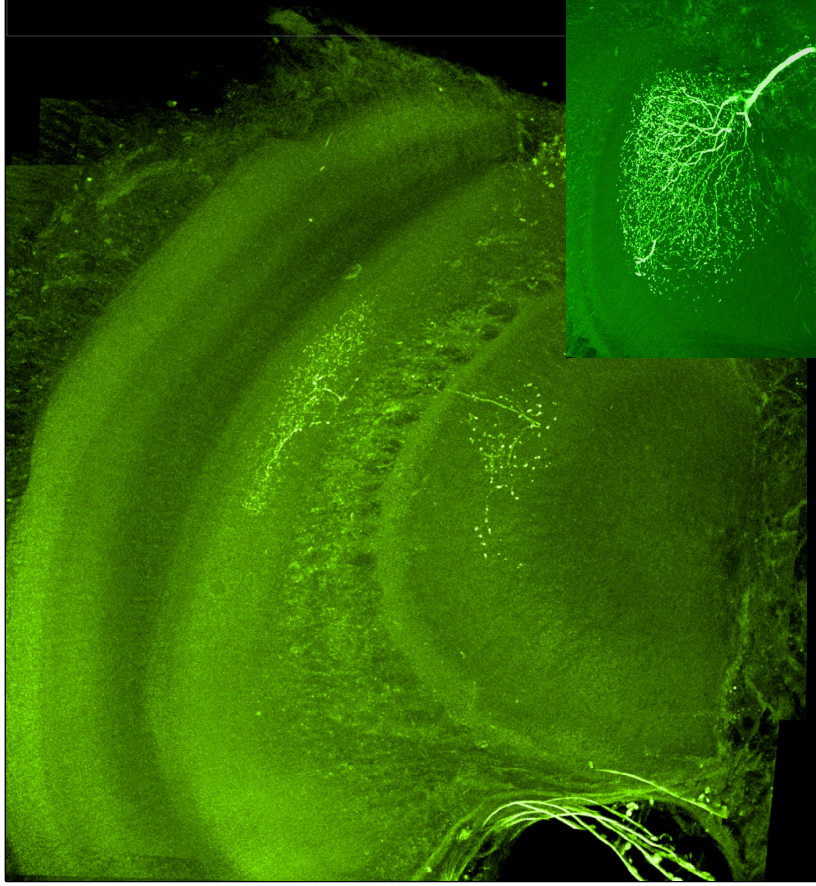
Three dimensional reconstruction, different views

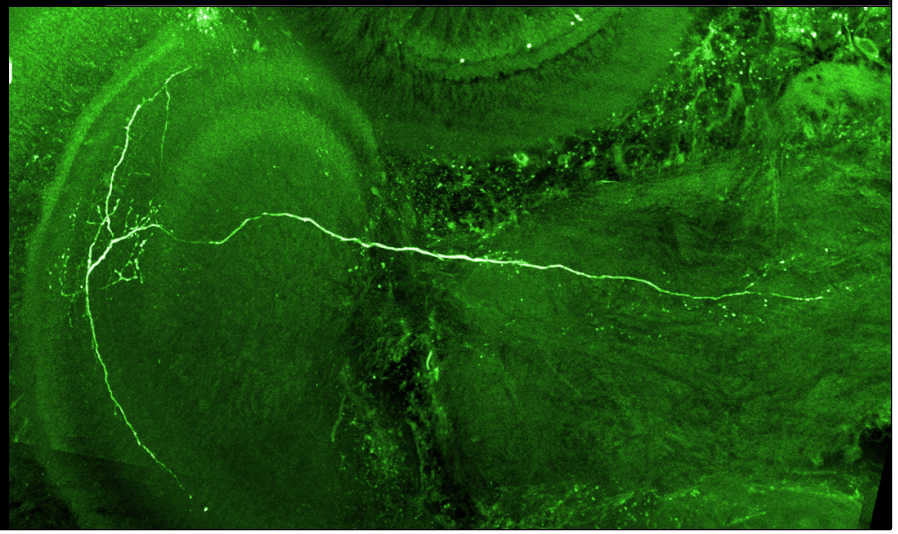
Neurons come in many different forms





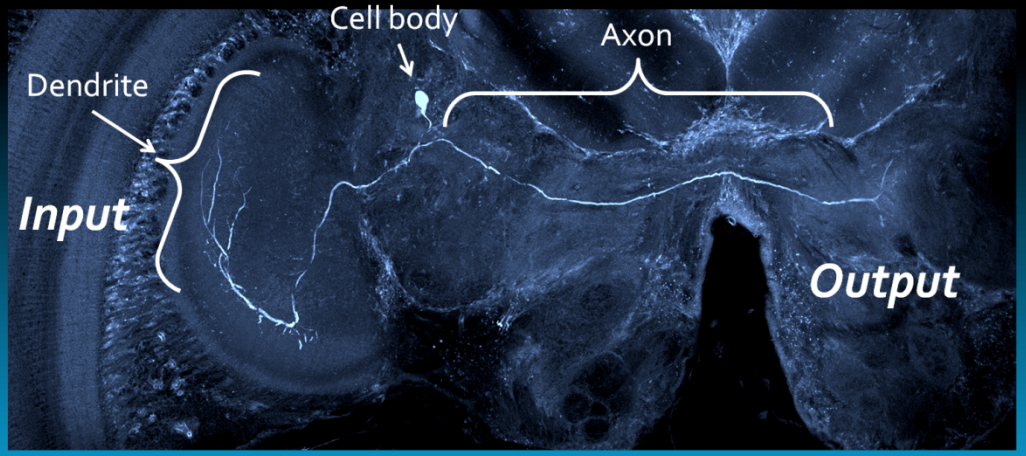






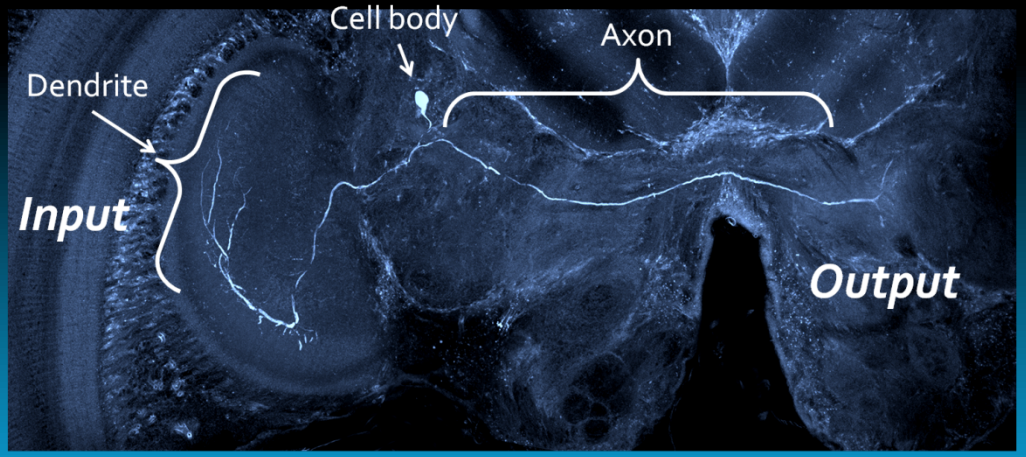
Flow of information: what does that mean?

- The neuron can conduct electrical signals from the input to the output sites
- This is essential for the encoding of information and the production of an output signal
- How is this done?
- The information is conducted from the dendrite (the input area) through to the axon and output via synapses (the connections between cells)



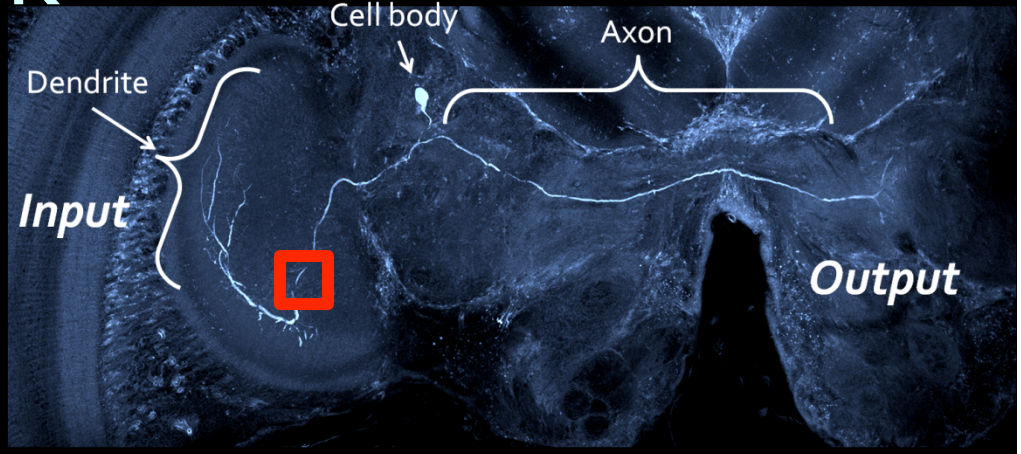
Neurons use electrical and chemical to communicate

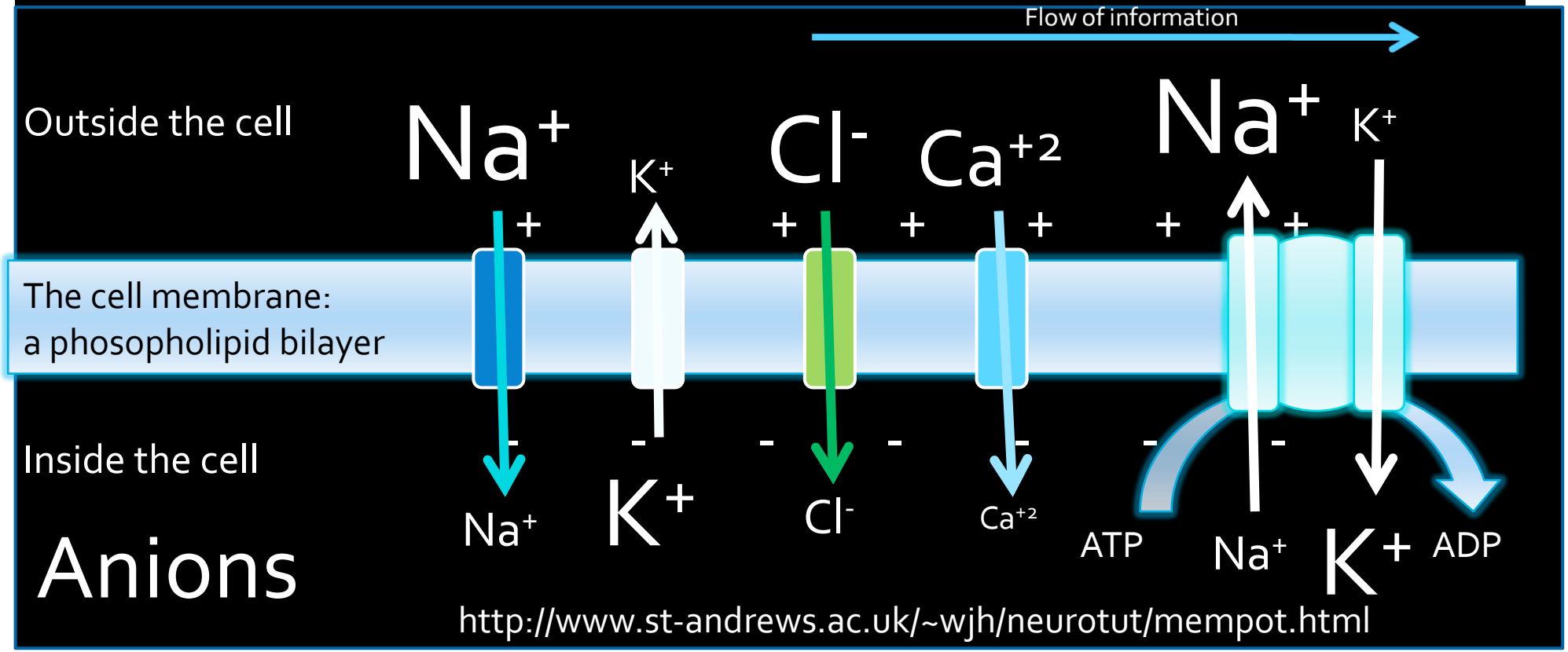
- Neurons, like all neurons, have a balance of ions across the membrane.
- By creating different ion concentrations across the membrane using ion pumps, neurons can create an electrochemical gradient.
- This gradient means that some ions have a tendency to move across the membrane when channels in the membrane are opened



How neurons work

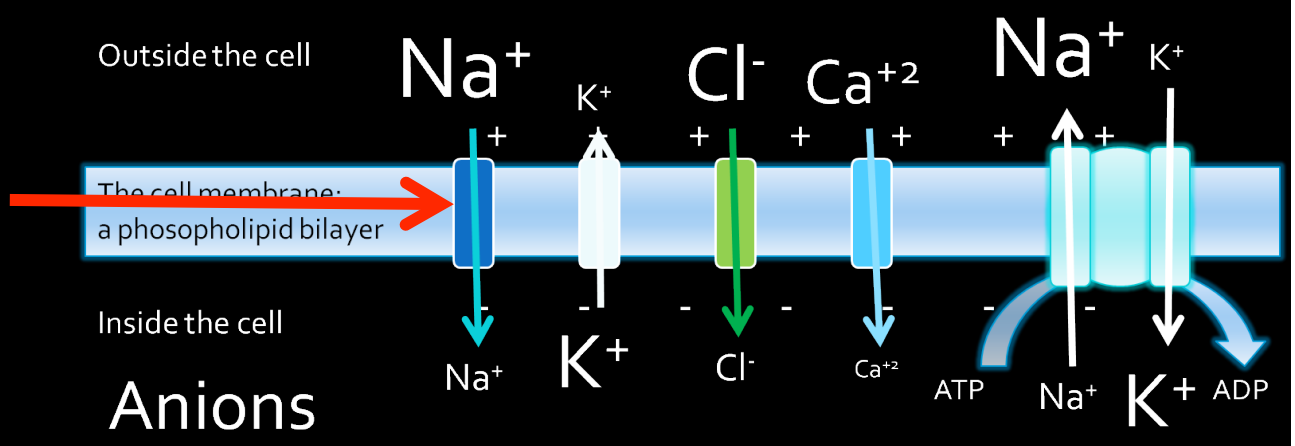
Sodium (Na), potassium (K), cloride (Cl), and calcium (Ca) operate as key players in creating this gradient and in traveling across the membrane





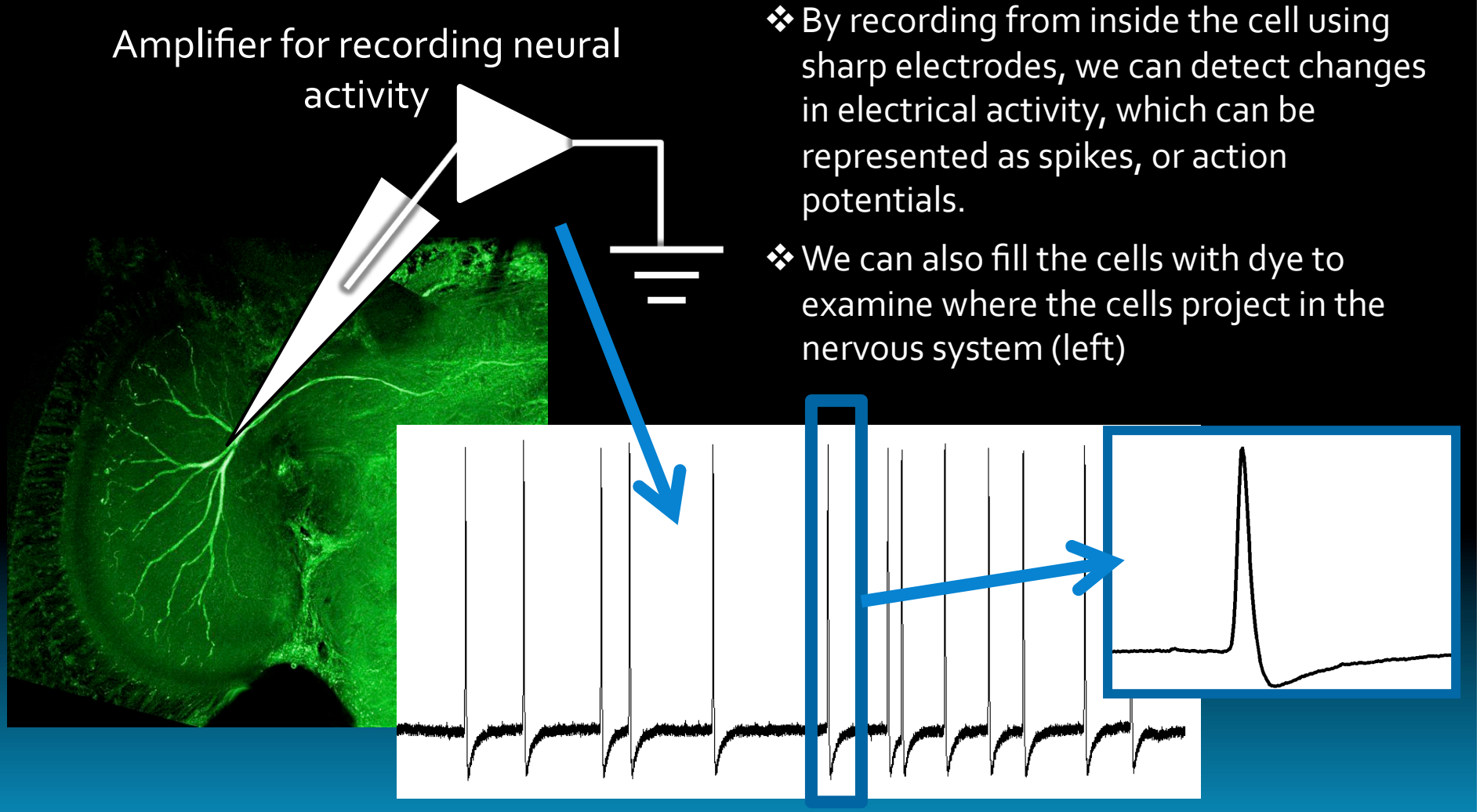
How neurons work

When , for example, the neuron is excited, it can trigger voltage gated channels , which are ion channels which open or close based on changes in voltage



- The opening of specific ion channels can allow those ions to cross the membrane, such as when sodium channels open, sodium rushes into the cell
- The purpose of creating this gradient and controlling the concentration of ions across the cell membrane is to allow electrical activity to be spread through changes in charged ion concentrations, which is important for communication throughout the cell.
- This can happen through passive spread of ionic changes or through active spread, which involves a mechanisms called action potentials, or spikes

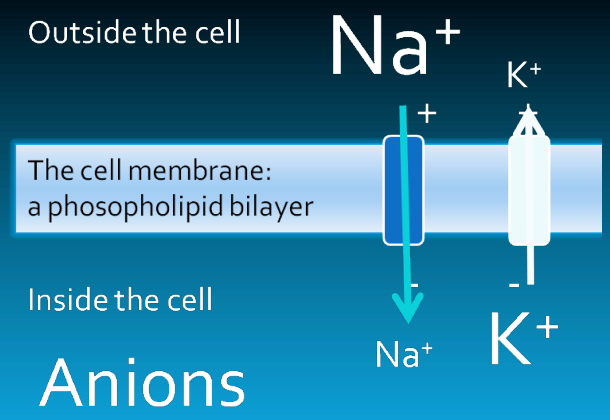
Electrical activity in neurons

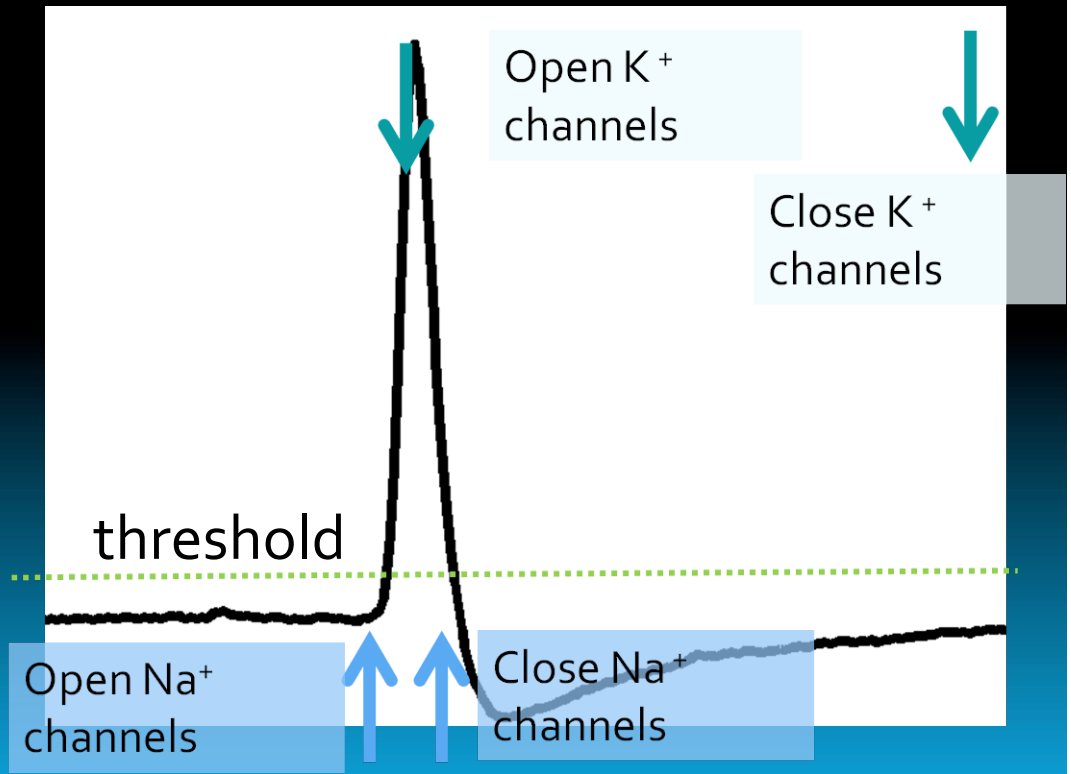


- By recording from inside the cell using sharp electrodes, we can detect changes in electrical activity, which can be represented as spikes, or action potentials.
- We can also fill the cells with dye to examine where the cells project in the nervous system (left)

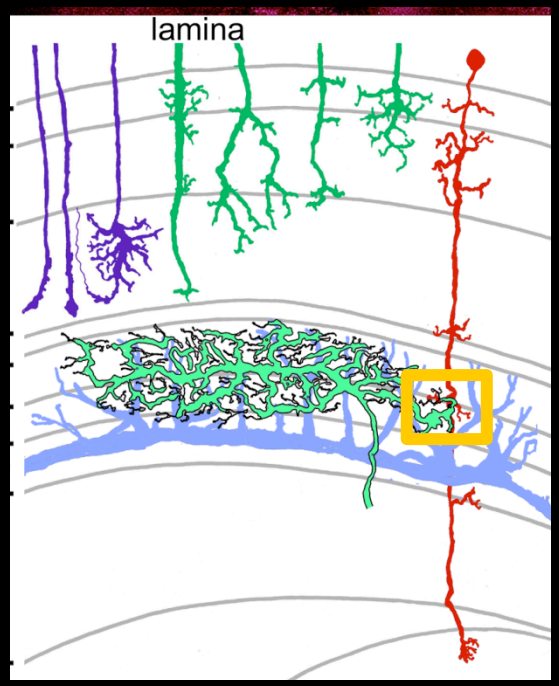
The action potential

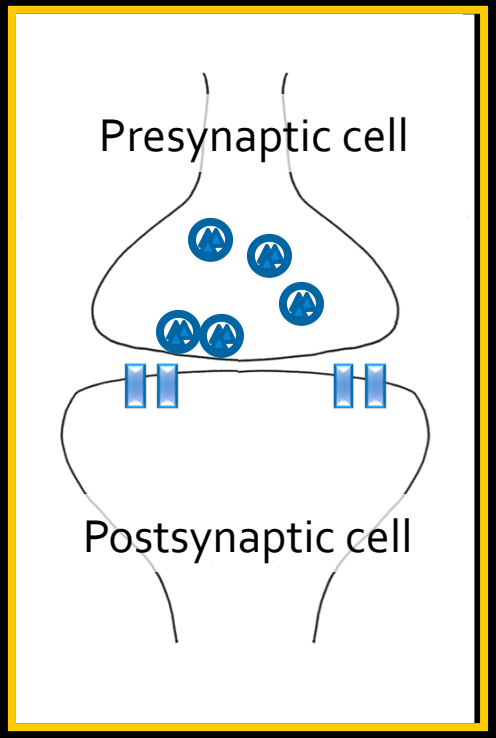
- When the cell is excited, the membrane potential moves toward threshold, where an explosive opening of sodium ion channels allow sodium to rush in the cell (due to the concentration gradient and the negative charge inside the cell)
- The inside of the cell becomes very positive, which is called depolarization and is measured as the membrane potential
- The sodium channels, after some time, close, and potassium channels open, causing potassium to exit the cell and make the membrane potential negative, which is called hyperpolarization.





The synapse: the connections between cells



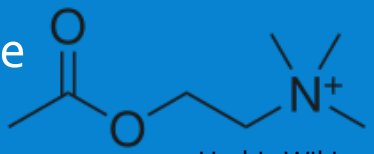


- While cells can send electrical signals to communicate between areas within the cell, the site of communication between cells is called the *synapse*
- The synapse can be electrical, where gap junctions form open channels for transport of ions directly between cells.
- The synapse is more often chemical, where chemical cues are sent from one cell to the next

Neuromodulators and neurotransmitters

Neurotransmitters:

acetylcholine



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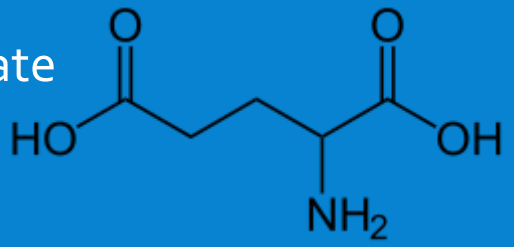
glutamate



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GABA

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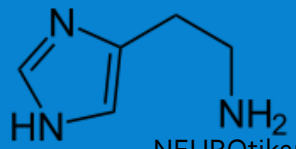
histamine



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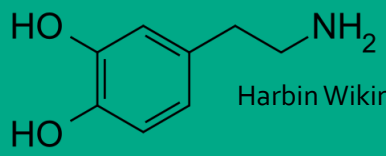
Neuromodulators:

dopamine



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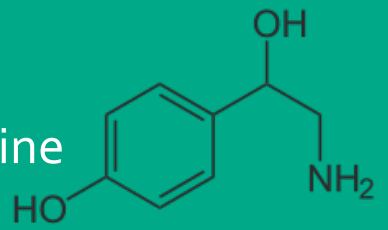
octopamine



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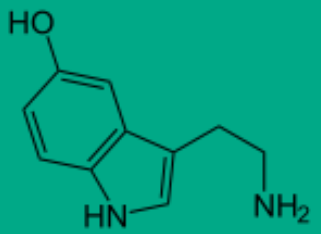
serotonin



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Neuropeptides:
Diverse structures

http://en.wikipedia.org/wiki/Neuromodulators

Neurotransmitter functions

- Neurotransmitters are generally released at the synaptic cleft, where they travel from the presynaptic site to bind to receptors at the postsynaptic site to trigger a response in the postsynaptic cell.
- Neurotransmitters generally have a fast effect on the postsynaptic cell
- Neurotransmitters can be ***excitatory*** (increasing the chance that the cell will spike) or ***inhibitory*** (thereby decreasing the chance that the cell will spike)

Neurotransmitters	Location	Role(s)
acetylcholine	Most of the central nervous system (CNS)	Excitatory
glutamate	At the junction between the motor neurons and the muscle (the neuromuscular junction, NMJ)	Excitatory
GABA	Broadly in the CNS	Inhibitory
histamine	In the CNS, released mostly by the photoreceptors of the eye and ocelli (as well as some local interneurons in the antennal lobe)	Inhibitory

Neuromodulator functions

- Neuromodulators can be released at the synapse, around the synapse, or even
- Neuromodulators generally have a slow effect on the postsynaptic cell and induce long-term changes in the cell through second messenger systems and changes in protein expression patterns of the cell
- Neuromodulators can cause the target cells to increase or decrease general activity, change synaptic strength, or change the entire dynamics of the network

Neuromodulators	Location	Role(s)
dopamine	In the CNS	Change synaptic strength, change activity of the cells, associated with aversive learning in flies
serotonin	In the CNS	Change synaptic strength, change activity of the cells, associated with neural activity correlated with circadian rhythm
octopamine	In the CNS	Change synaptic strength, change activity of the cells, associated with reward learning and memory in flies and bees
Neuropeptides	In the CNS	Various roles, depending on the neuropeptide

http://en.wikipedia.org/wiki/Neuromodulators

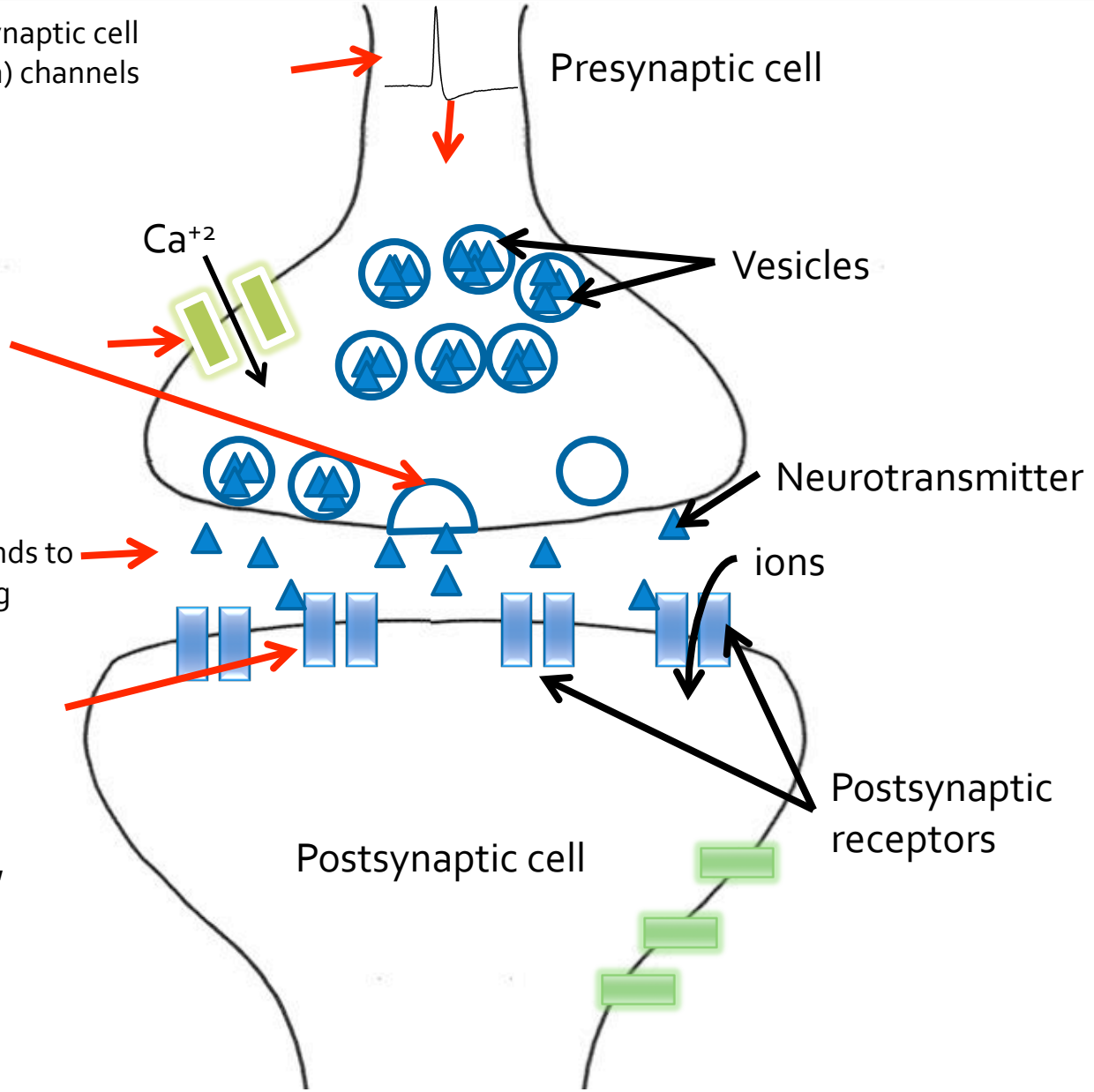
The synapse: the connections between cells

1. Spikes coming down the presynaptic cell opens voltage-gated calcium (Ca) channels

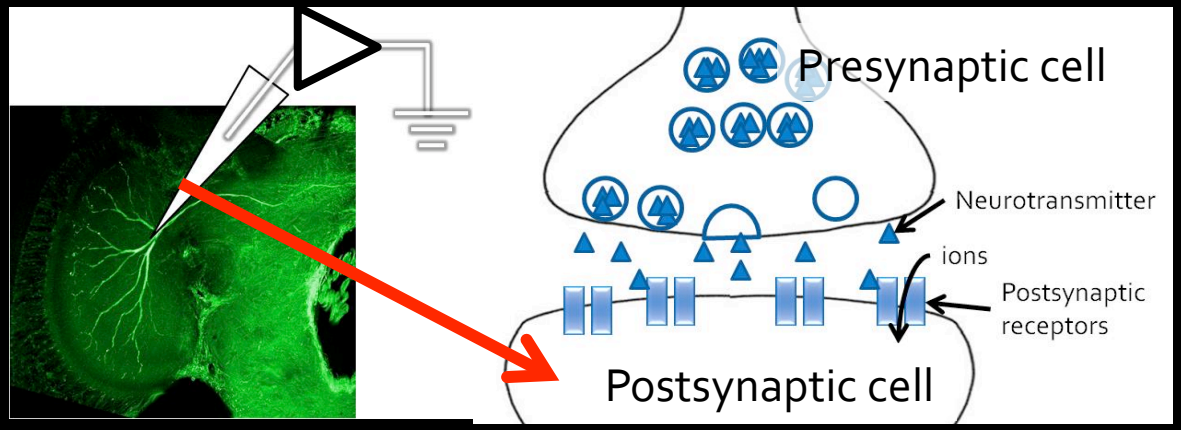
2. Calcium entry triggers vesicle fusion of the membrane and release of neurotransmitter

3. The neurotransmitter travels across the synaptic cleft and binds to postsynaptic receptors, opening channels in the membrane

4. The channels opening can allow positive or negative ions to move across the membrane, which can cause excitatory or inhibitory responses in the postsynaptic cell

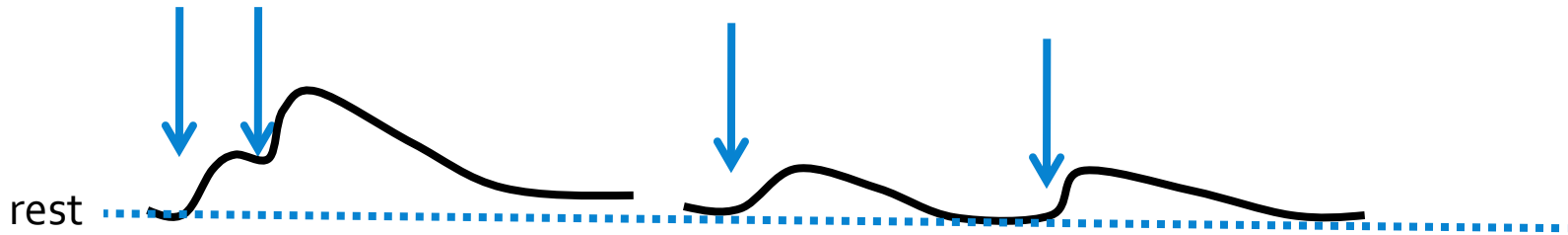


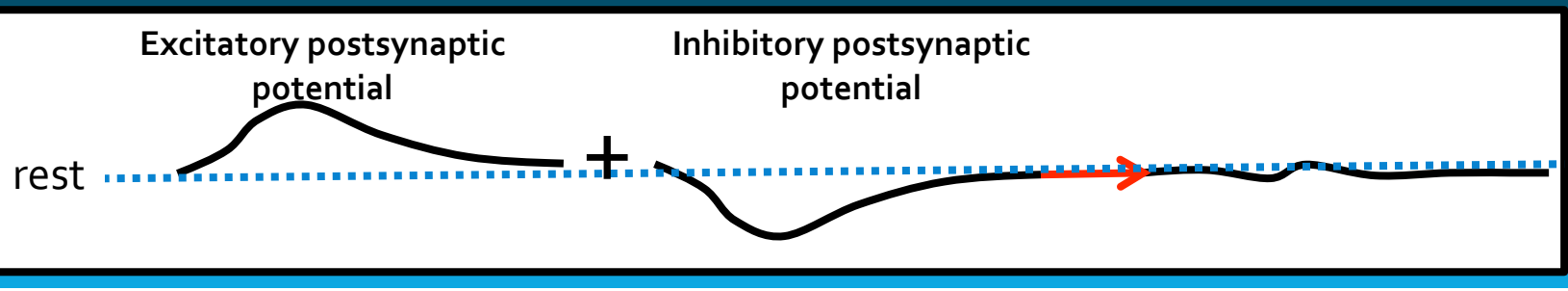
Timing and placement of synaptic input makes a difference



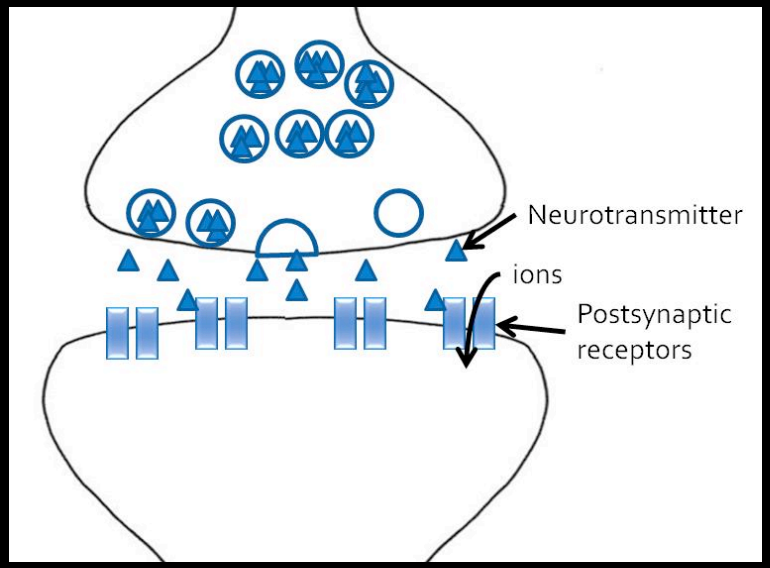
Synaptic release: spatial and temporal summation

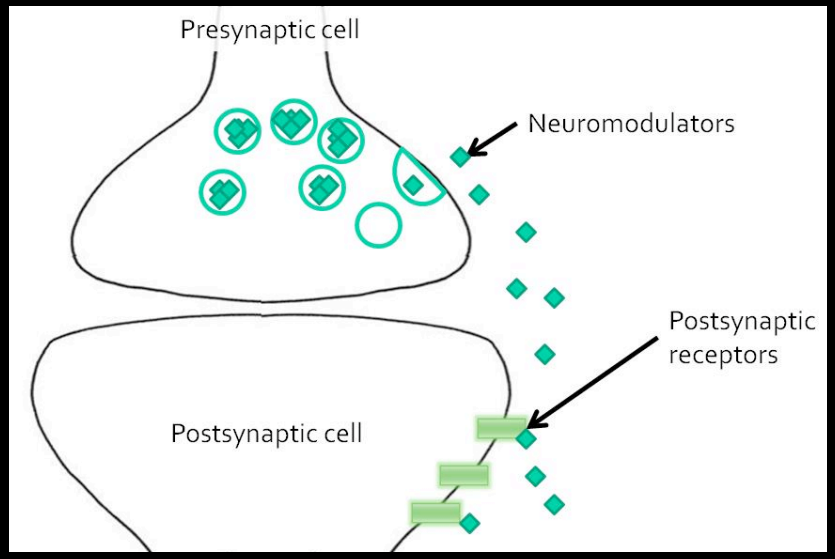
Synaptic release: When the potentials are too spread apart, there is no summation

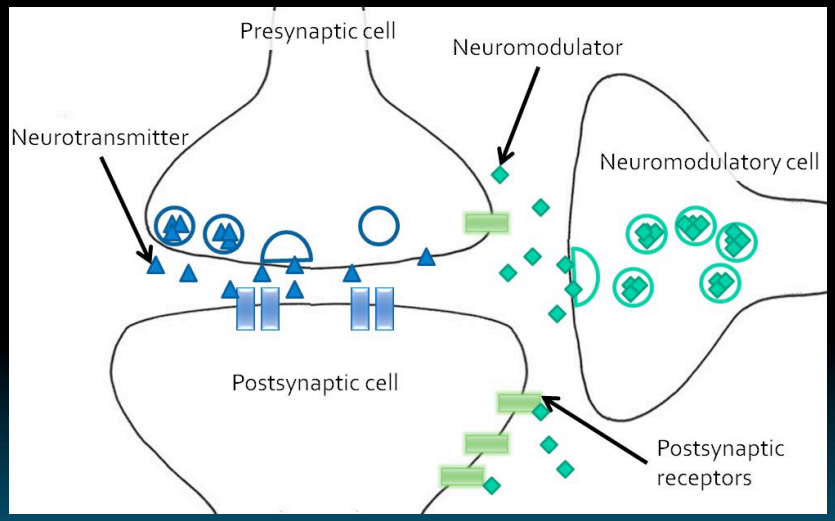




The synapse

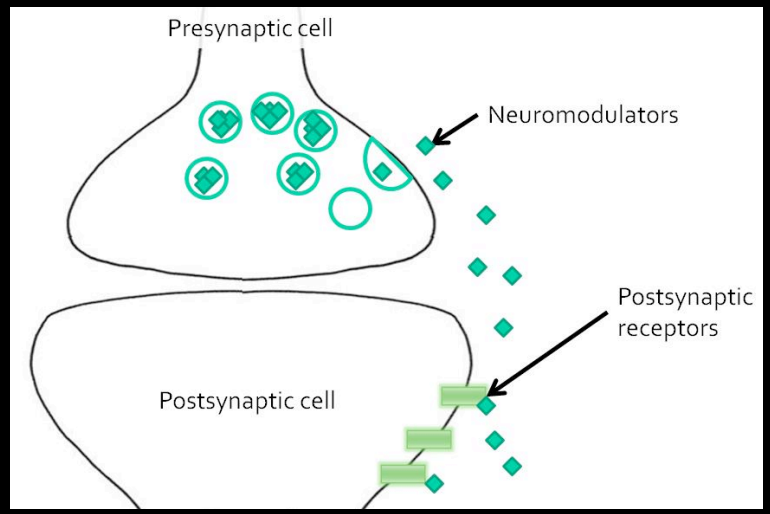


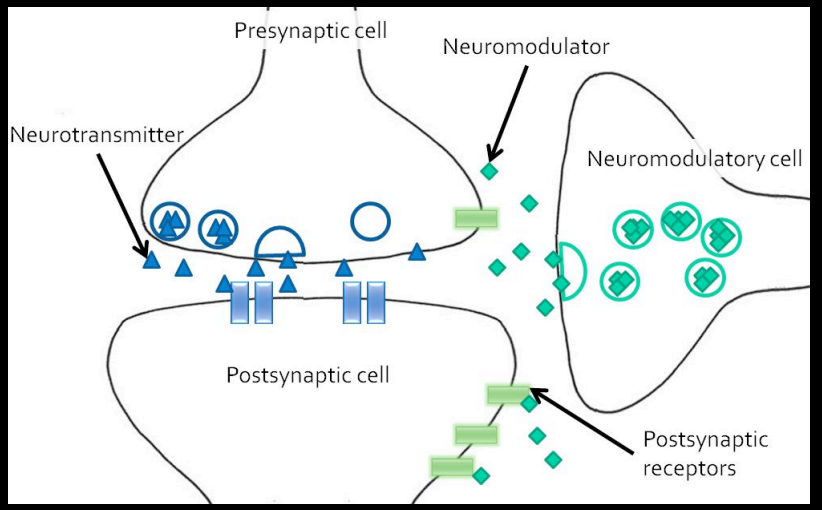




- Synaptic release can come in different forms
- Paracrine release occurs when the cell releases neurotransmitters outside of the synaptic cleft
- POIPOIP release is the direct release of neurotransmitters within the synapse
- The vesicle content can be neurotransmitters, neuromodulators, or neurohormones

Neuromodulators



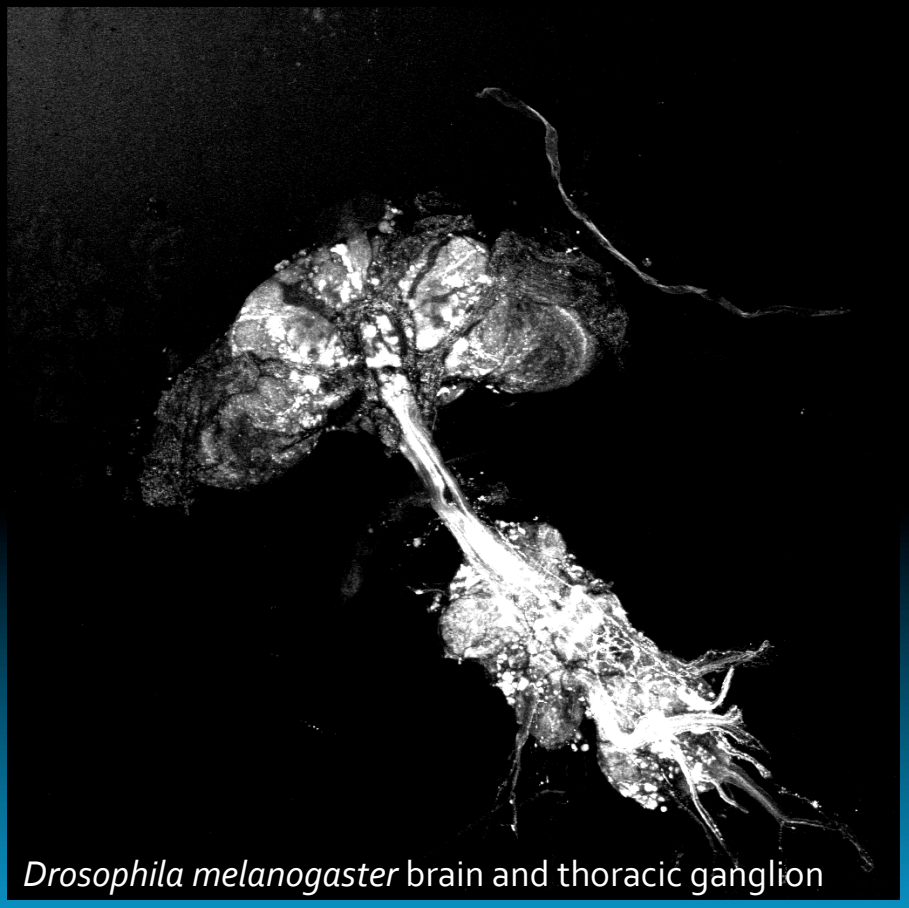


- Binding to receptors can trigger second messenger pathways, which can lead to learning and memory
  Changing the responsiveness to the different neuromodulators, you can also trigger different behaviours
- For example, by blocking octopamine receptors in the cockroach brain using their venom, wasps can paralyze cockroaches and 'drive' them using their antennae:

How to make a zombie cockroach, *Nature News* (2007)
Gal, Ram; Rosenberg, Lior Ann; Libersat, Frederic (2005). "Parasitoid wasp uses a venom cocktail injected into the brain to manipulate the behavior and metabolism of its cockroach prey". *Archives of Insect Biochemistry and Physiology* **60** (4): 198–208. doi:10.1002/arch.20092.
http://www3.interscience.wiley.com/journal/112152224/abstract.

Neurons operate in a massive network

Neurons are interconnected in a massive network, allowing insects to live, perform numerous behaviours, and operate on many different levels.
The ways these networks of neurons operate and connect to one another allows insects to interact with the world around them.



Drosophila melanogaster brain and thoracic ganglion

Neobellieria bullata brain, serotonin staining