Neurons: The basic unit of information Processing

- ✓ **The Neuron**
- ✓ **The Neural representation of information**

Recent Brain-Excitements

1. **Connectomics – Complete 3D road-map for the brain**

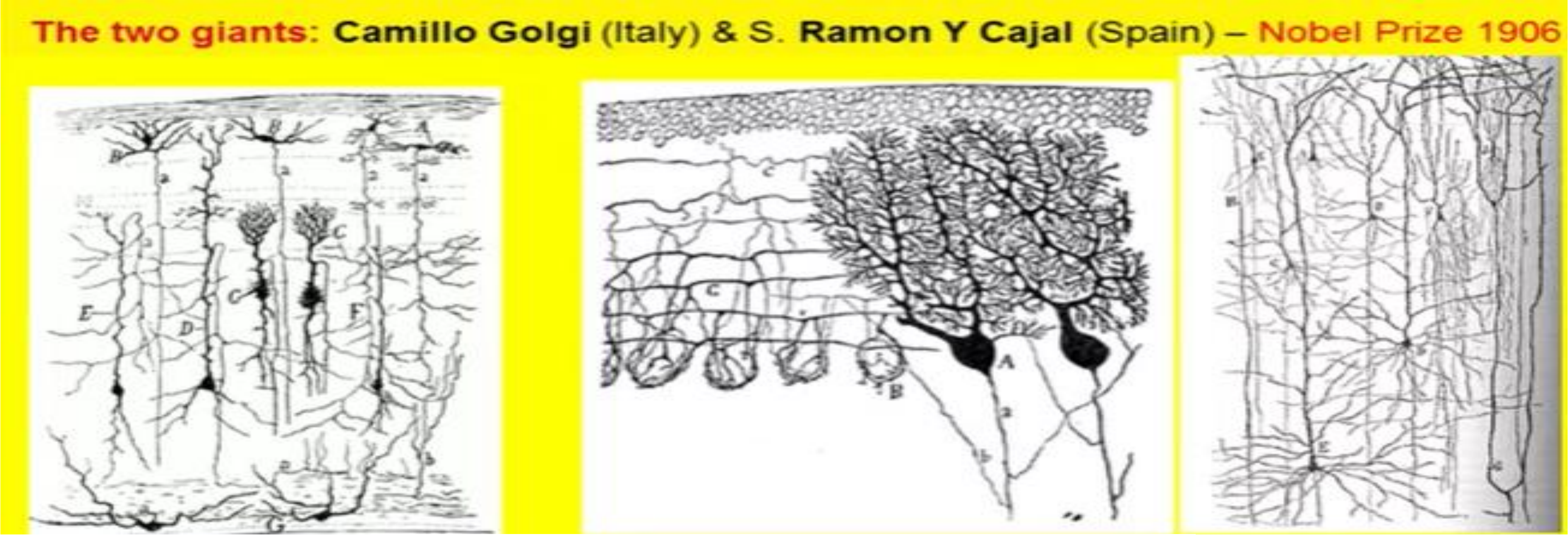
2. Brainbow – Colorful, genetically-designed, brains

3. Brain-machine/computer interface (BMI)

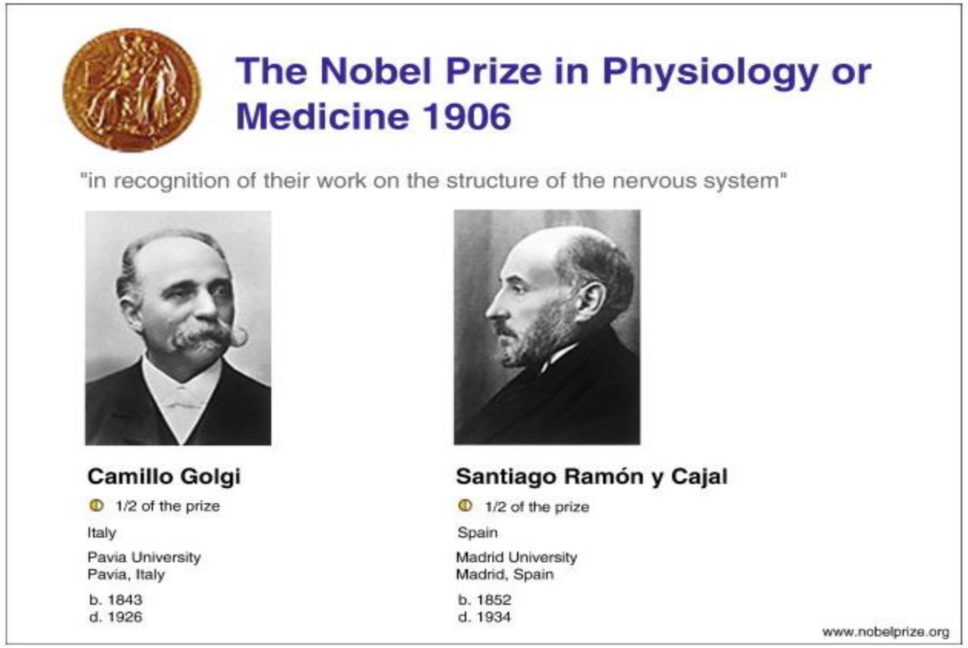
4. Optogenetics – Light-activated brain circuits

5. Computer simulation of the brain - "Blue Brain Project"

Beginning of modern neuroscience – Understanding cellular anatomy



Golgi – Using Golgi staining method
Very small percentage of cells stained
Connections (synapses) not seen



Cajal - The Neuron Doctrine
Our brain is built of individual cells (neurons)

Information Processing: The Communicative Neurons

- A **neuron** is a cell that receives and transmits signals through electrochemical activity

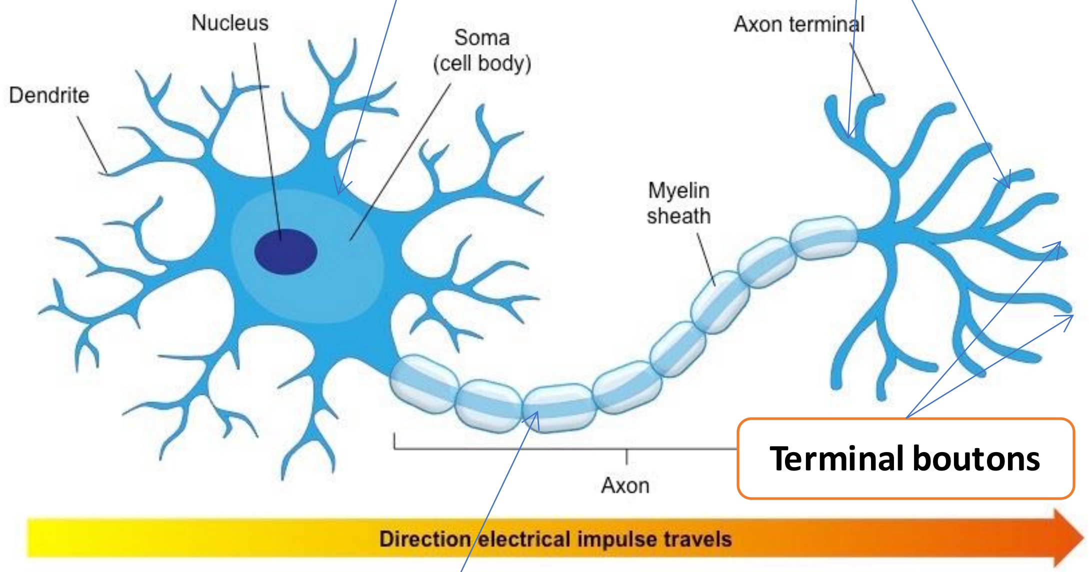
- The human brain contains approximately **100 billion neurons** each may have roughly the processing capability of a small computer

- Neurons are active simultaneously
- Information processing occurs through interactions with one another

Synapse: near contact between axon and dendrite

Soma is 5 to 100 micrometers (µm) in diameter

Arborizations

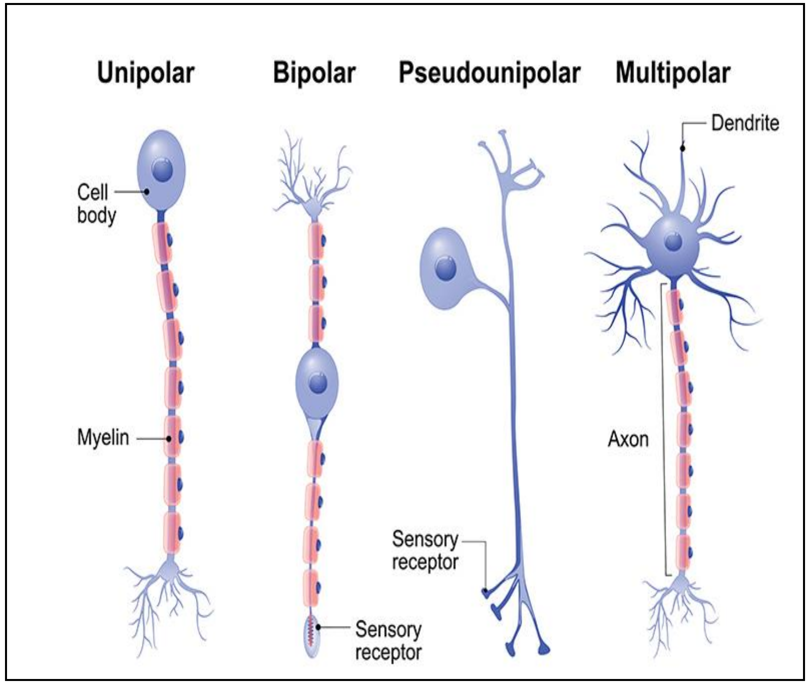


Terminal boutons

Fixed path by which neurons communicate with one another

Gap b/w terminal bouton and dendrite is in the range of 10 to 50 nanometers (nm) (A human hair is 75000 nm wide)

Types of Neurons



Sensory neurons are **activated by sensory stimulation in the form of light, sound, touch**, etc Most sensory neurons are pseudo-unipolar, which means they only have one axon which is split into two branches

Bipolar neurons -The dendritic branching is typically limited, and the axons of such neurons are usually short in length. BN are often sensory neurons **associated with receptor organs of the visual and auditory systems**. **Imp for resolution of vision and sound**

Multipolar neurons - Interneurons are the ones in between - they **connect spinal motor and sensory neurons**. As well as **transferring signals between sensory and motor neurons**, interneurons can also communicate with each other, forming circuits of various complexity. They are multipolar, just like motor neurons

Motor neurons - These neurons transmit impulses from the spinal cord to skeletal and smooth muscles (such as those in your stomach), and so directly control all our muscle movements

2 types of motor neurons: those that travel **from spinal cord to muscle are called *lower* motor neurons**, whereas those that travel **between the brain and spinal cord are called *upper* motor neurons**
Motor neurons have the most common type of 'body plan' for a nerve cell - they are multipolar, each with one axon and several dendrites

Can Neurons multiply?

Belief for more than a century – Unlike other body cells, new neurons not produced after birth

Current research: stem cells – New, undifferentiated progenitor cells for neurons – are born in some parts of the adult brain

MENU

nature
International journal of science

Letter | Published: 07 March 2018

Human hippocampal neurogenesis drops sharply in children to undetectable levels in adults

Shawn F. Sorrells, Mercedes F. Paredes, Arantxa Cebrian-Silla, Kadellyn Sandoval, Dashi Qi, Kevin W. Kelley, David James, Simone Mayer, Julia Chang, Kurtis I. Auguste, Edward F. Chang, Antonio J. Gutierrez, Arnold R. Kriegstein, Gary W. Mathern, Michael C. Oldham, Eric J. Huang, Jose Manuel Garcia-Verdugo, Zhengang Yang & Arturo Alvarez-Buylla

Nature **555**, 377–381 (15 March 2018) | Download Citation

MENU

nature medicine

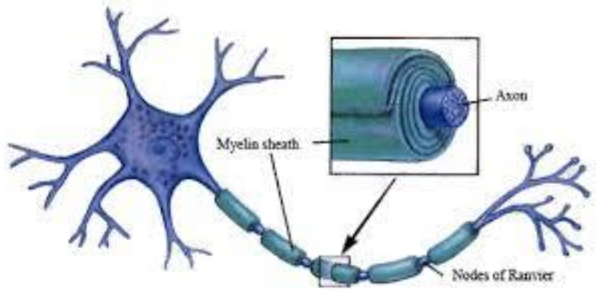
Letter | Published: 25 March 2019

Adult hippocampal neurogenesis is abundant in neurologically healthy subjects and drops sharply in patients with Alzheimer's disease

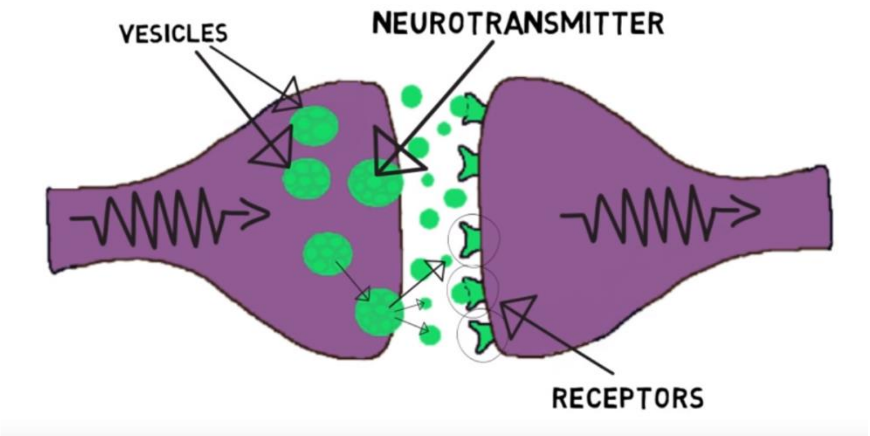
Elena P. Moreno-Jiménez, Miguel Flor-García, Julia Terreros-Roncal, Alberto Rábano, Fabio Cafini, Noemí Pallas-Bazarra, Jesús Ávila & María Llorens-Martín

Nature Medicine **25**, 554–560 (2019) | Download Citation

Synapses are known to grow throughout the adult lifetime, and small dendritic spines can grow in minutes to support new synapses

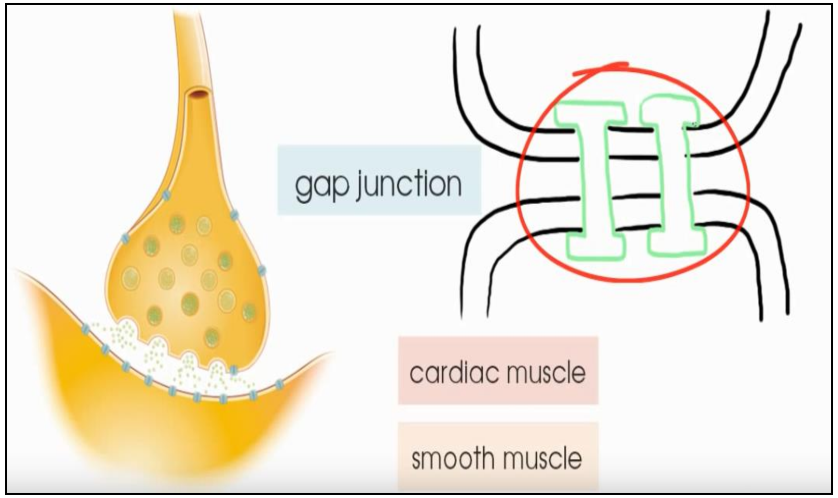


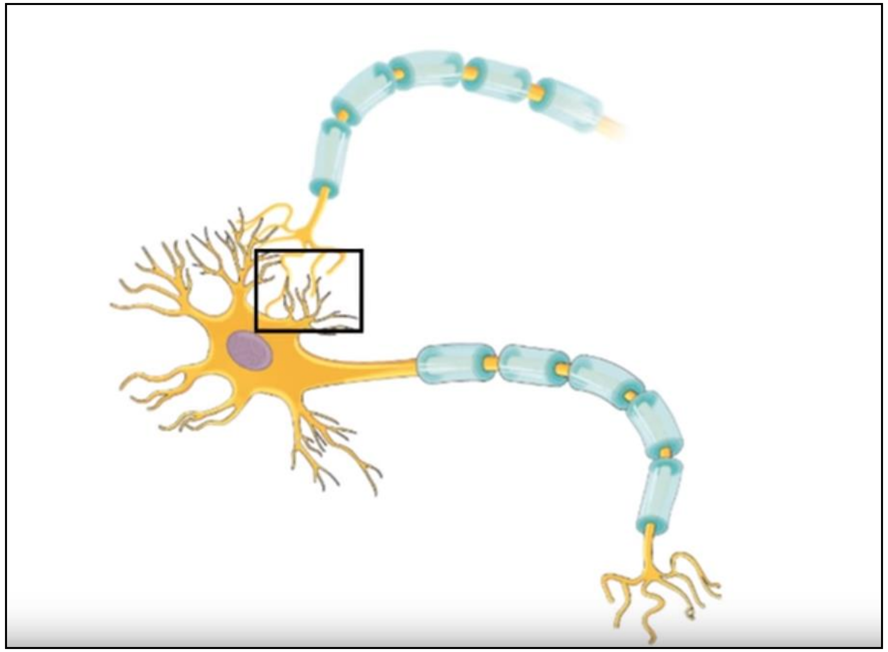
Synaptic transmission



Chemical synapse

Electrical synapse

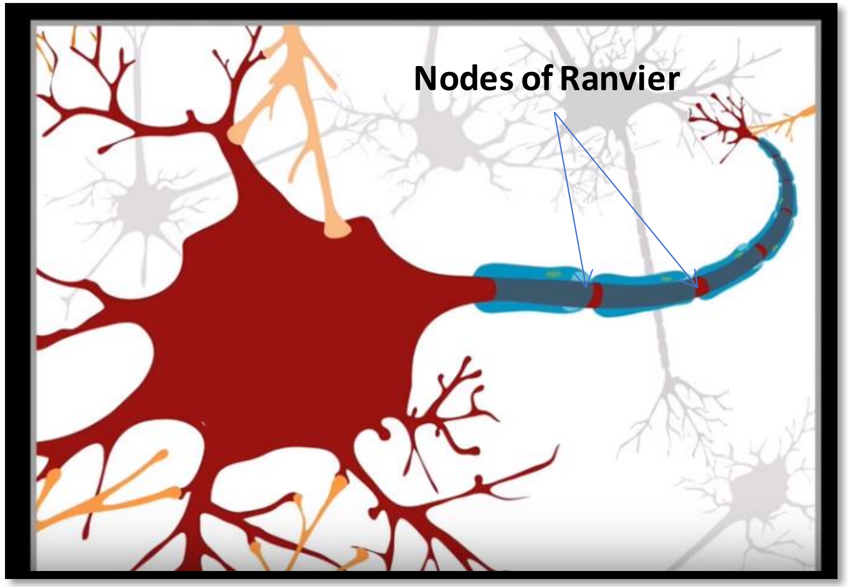




Two connecting neurons

- Depending on the nature of the neurotransmitter, the potential difference can decrease or increase
- Synapses that decrease the potential difference are called excitatory, and those that increase the difference are called inhibitory

The Action Potential



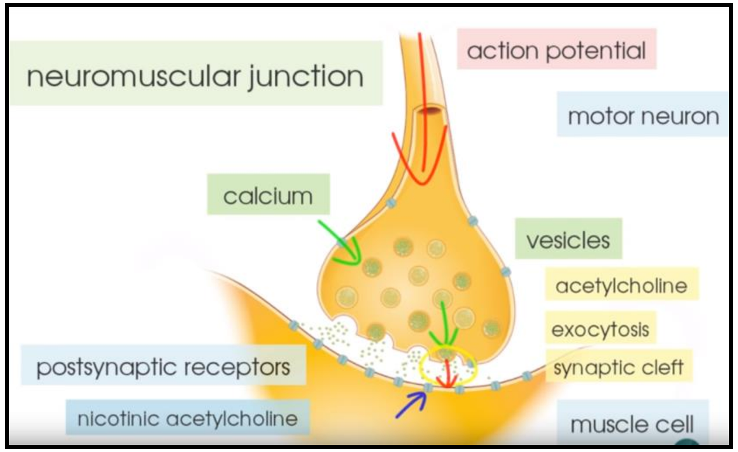
Information is communicated through electrical signals - The fluid inside and outside the cell contains electrically-charged molecules called ions

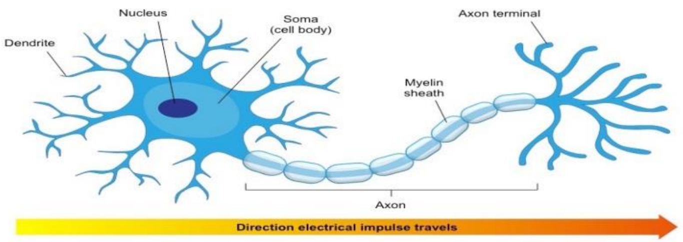
Neuron at rest → the difference in charge between the extracellular fluid and intracellular fluid is about **-70mV,** → known as the ***resting potential***

When stimulation from a neighbouring neuron exceeds a particular threshold then the membrane potential reverses, creating an exchange of ions. This is known as an **Action Potential**

The action potential <u>is always of the same size</u>; that is, it does not depend on the strength of stimulation
All that matters is that stimulation is sufficient to trigger the action potential

Synaptic Transmission





Action Potential generated from the axon of the neuron, moves to terminal bouton

Influx of Ca+ from the extra cellular space due to change in voltage across the membrane – opening up of Ca+ channels

With the opening of the voltage gated channels the vesicles move towards the presynaptic membrane

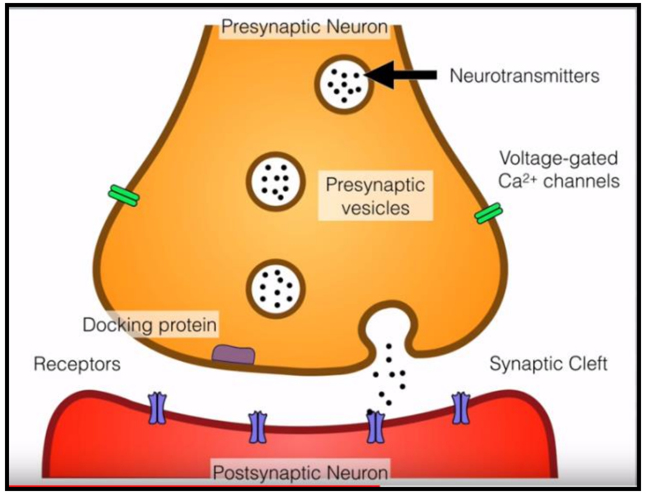
Through exocytosis the vesicles fuse to synaptic membrane and release neurotransmitters

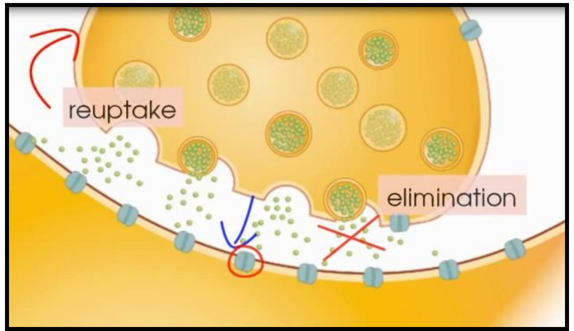
Neurotransmitters bind to the receptors in the post synaptic membrane of the other neuron

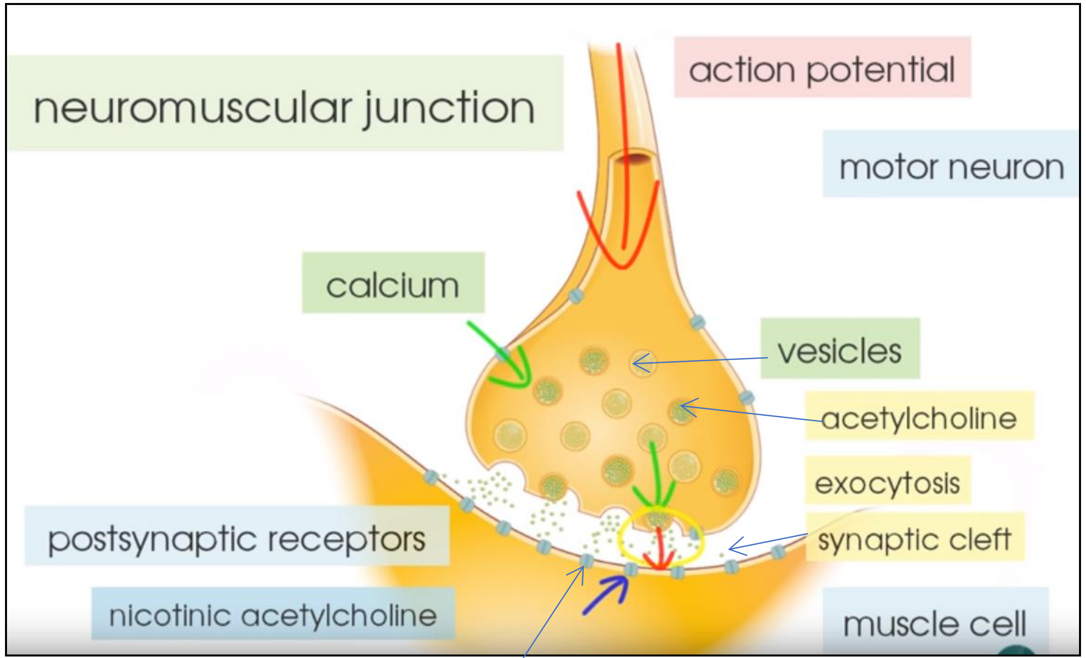
The ion channels open up and allow ions to enter the post synaptic neuron

Change in ion concentration leads to the generation of another action potential across the neuron

Elimination of neurotransmitter release and re-uptake to presynaptic terminal





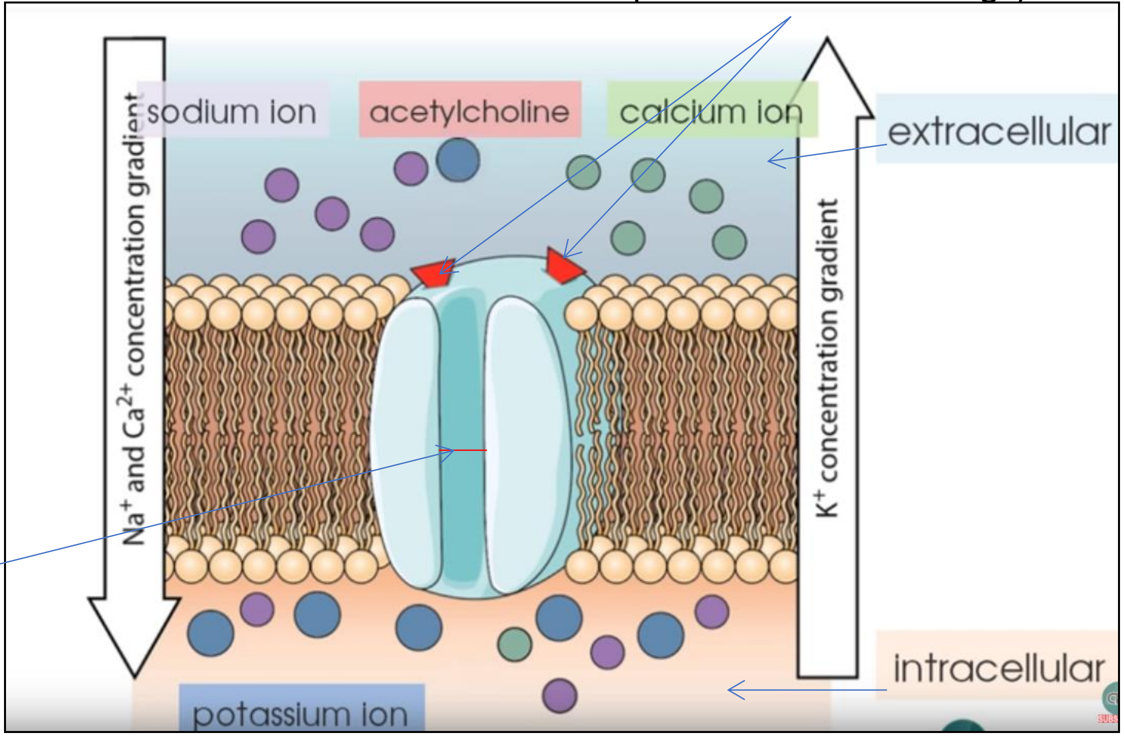


An eg:

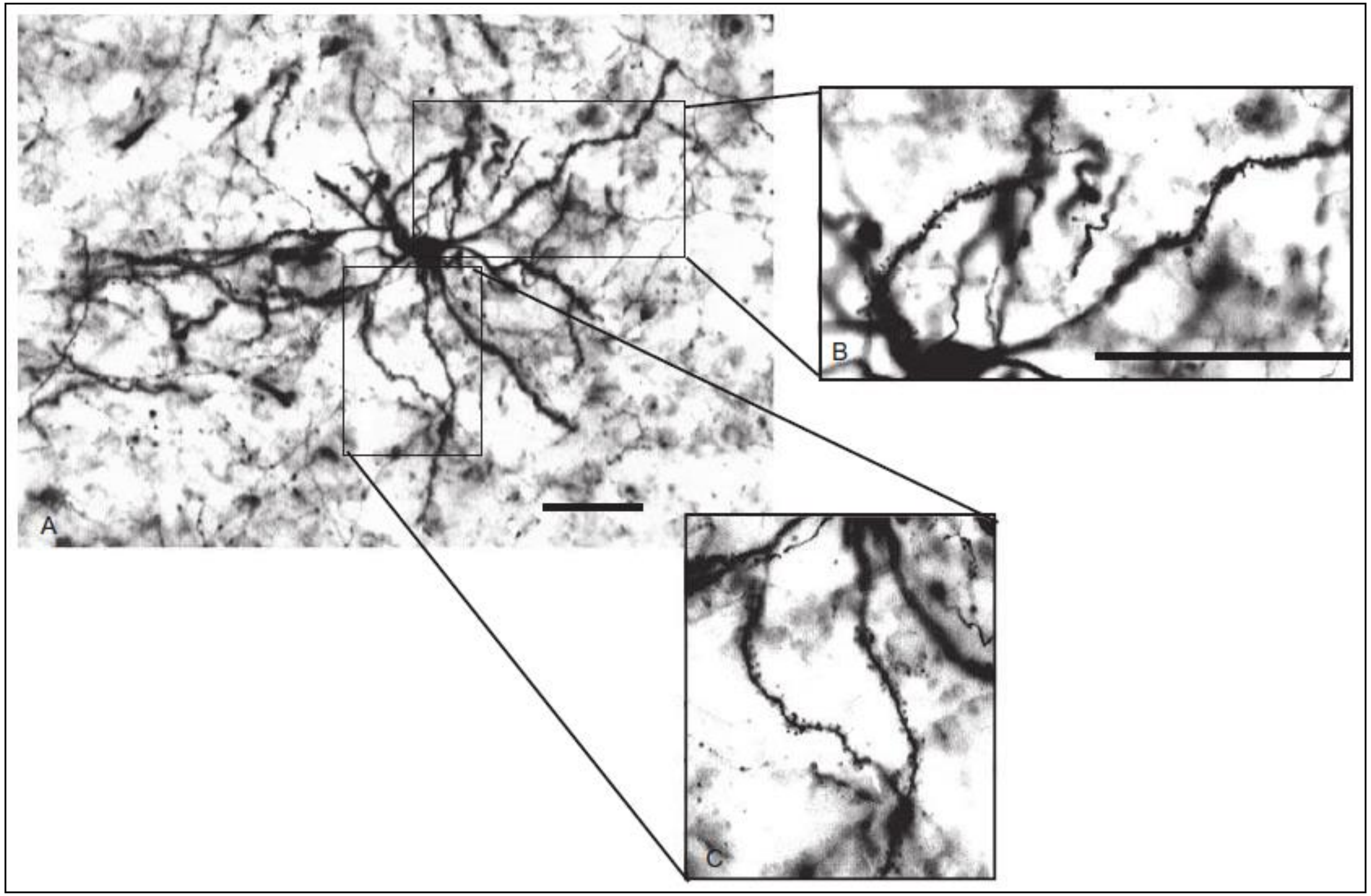
A single unit transfer of information

Neurotransmitter (brings in change in membrane potential and cell voltage)

A look at the Post synaptic receptor



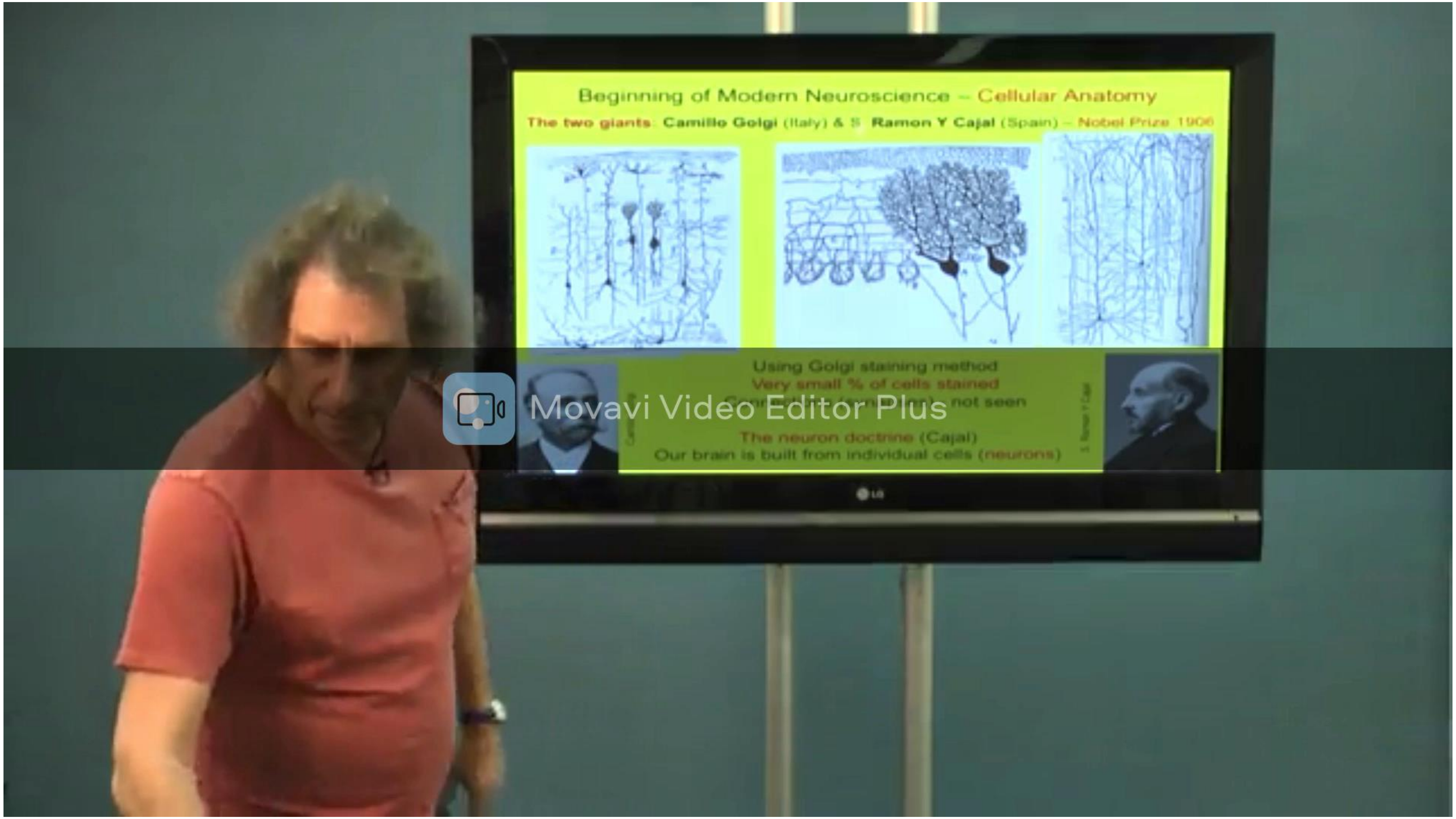
Channel opens to allow passing of higher conc. ions into intracellular fluid (Na+, Ca+), K+ – out of cell



An actual photomicrograph of a single neuron in the basal ganglia. Notice the dendritic spines – tiny protrusions on the dendrites, often containing end buttons for synapses. The horizontal bars mark 50 micrometers

Source: Paxinos, 2004

The connectome – mapping the structural connectivity of the nervous system

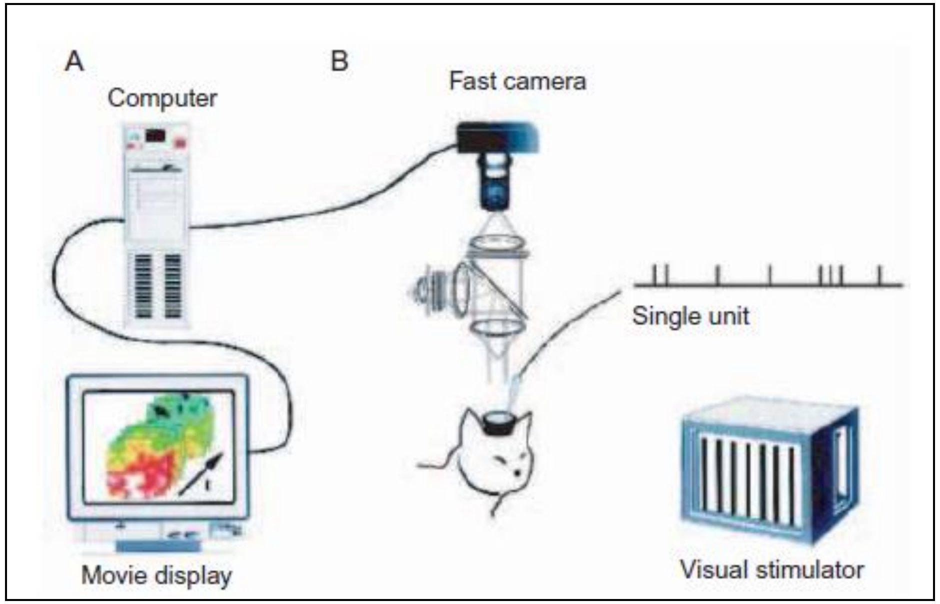


Neurons – additional slides

Neurons and Information Processing

- Biological evidence about the operation of neurons was obtained by David Hubel and Torsten Wiesel → neurons in the visual system of cats were specialized for particular tasks

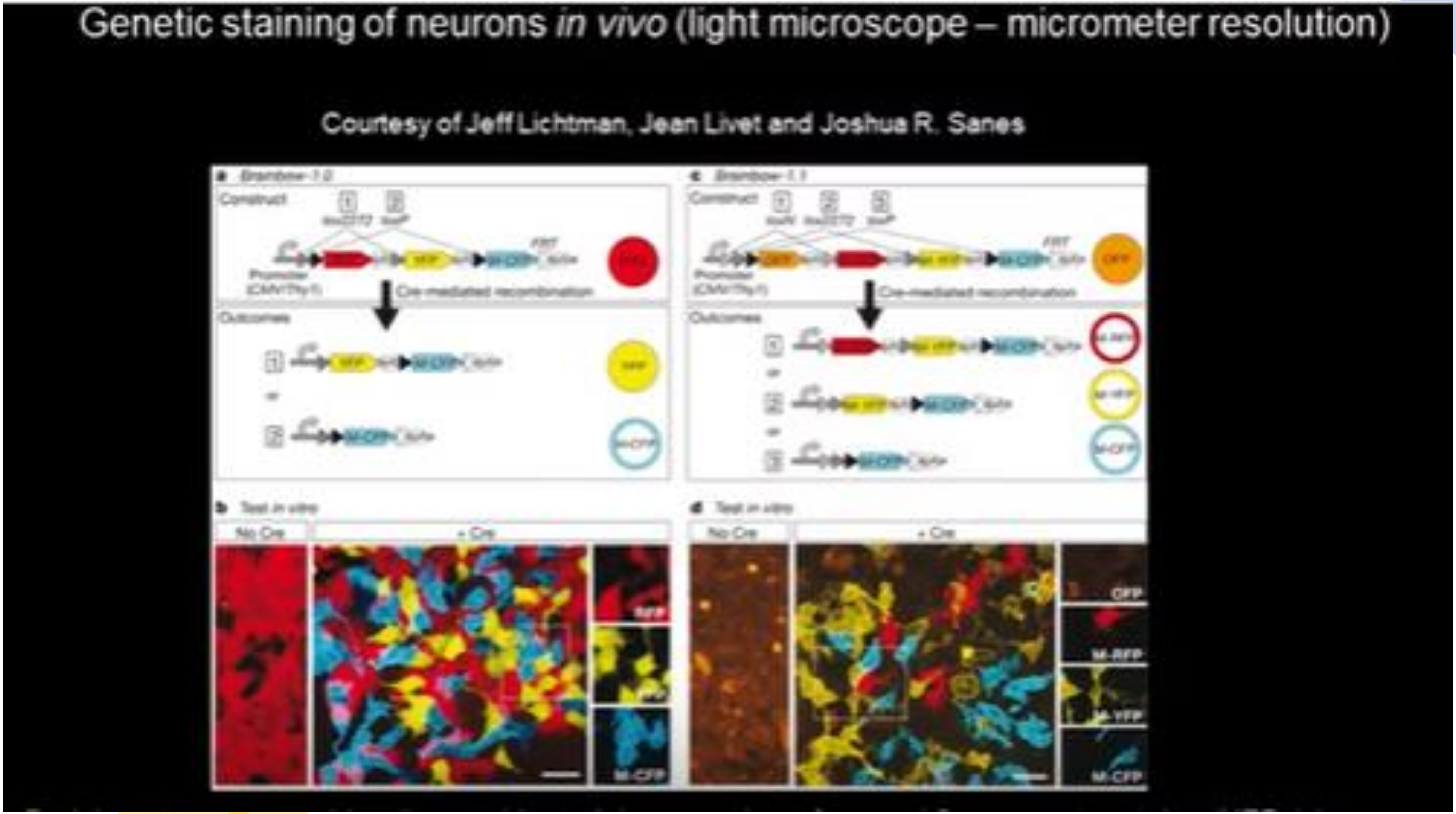
- By inserting microelectrodes into cats' brains they were able to identify different types of cells
- Simple cells only fired when presented with bars of light of a particular orientation; some cells would only fire if shown a horizontal bar, other cells would only fire if shown a vertical bar, and so on. Complex cells would only fire if shown a bar of light of a particular orientation moving in a particular direction
- This work won Hubel and Wiesel a Nobel prize (shared with Roger Sperry)



The needle electrode causes no pain, since the brain itself has no pain receptors. It is implanted using a scalp attachment that allows the cat to move comfortably.
The electrode picks up ‘ spikes ’ from a single neuron, which are amplified and shown on the upper right. Trials over time are shown on the colored screen.

Source **: Tsodyks *et al.* , 1999**

Brainbow Technology



Brainbow transgenes drive the combinatorial expression of several fluorescent proteins in neurons, resulting in the colour tagging of individual cells

The Brainbow technique

Some prospects for the Brainbow

1. The structural basis for learning in the brain
2. Tagging and genetic-characterization of the different cell-types (the building blocks) in a given system (e.g., retina)
3. Tracing short-and-long range connections in brain circuits

Neural computation

What is an Artificial Neuron?

How do computations actually arise through the action of nerve cells?

In 1943 **Warren McCulloch** and **Walter Pitts** proposed an artificial neuron they called the **Threshold Logic Unit (TLU),** also called the **McCulloch-Pitts neuron**

McCulloch-Pitts neurons took binary inputs and produced binary outputs, enabling them to compute logical functions such as AND and OR.

Later, in 1957, **Frank Rosenblatt** developed the **Perceptron**, a neural network that took *matrix eigenvalues* and produced binary output

ANNs are artificial

but provide a greater understanding of the ways neural computation might work

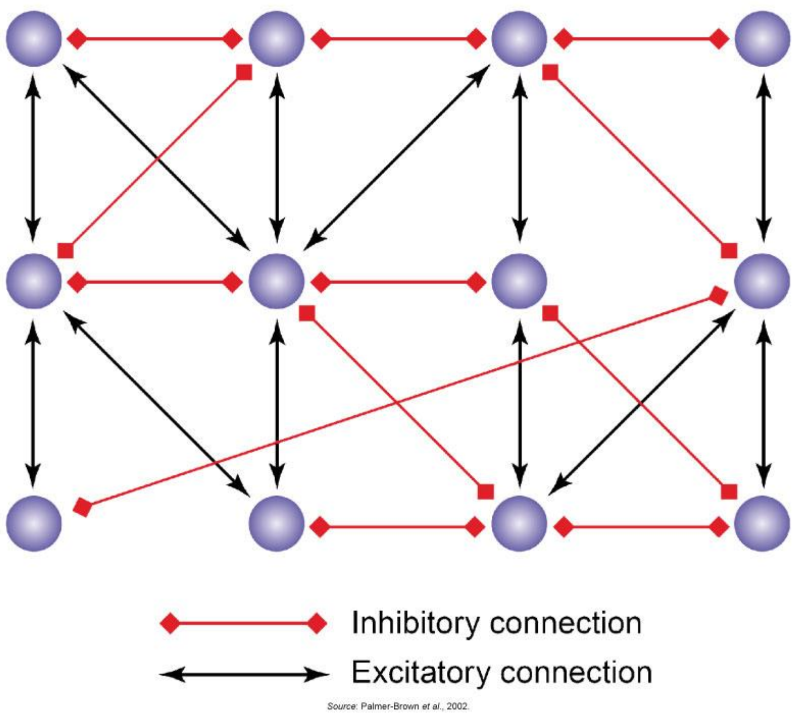
Cognitive neuroscientists focus on *biologically plausible* neural net models, those that are based on the known properties of a specific set of neurons and their connections However, artificial neural nets often provide useful approximations to the reality

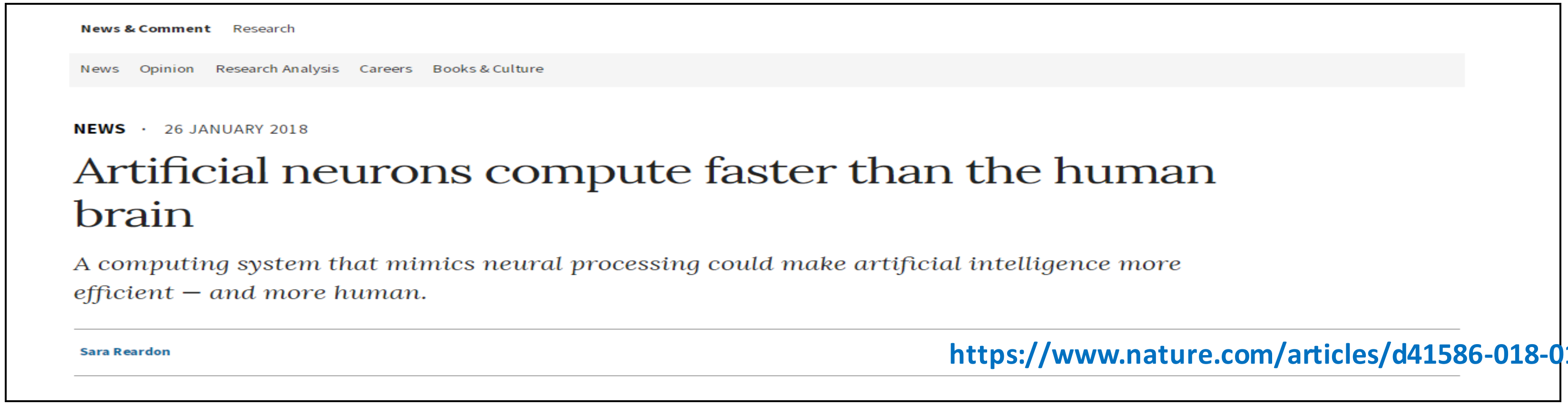
Neural computation

Artificial neural nets (ANNs) have been used to model many of the functions
the brain performs –

- **to recognize patterns**
- **to plan actions in robots**
- **learn new information**
- **and use feedback to improve performance**

- Most ANN simulations are relatively small-scale and limited
- None of them come close to the massive complexity of a living brain. But, for some jobs, ANNs have been more successful in doing human-like tasks

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NEWS · 26 JANUARY 2018

Artificial neurons compute faster than the human brain

A computing system that mimics neural processing could make artificial intelligence more efficient — and more human.

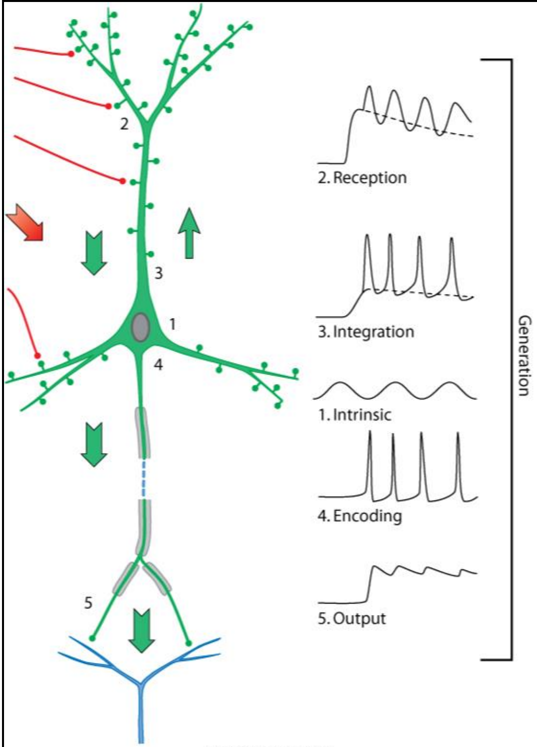
Sara Reardon

https://www.nature.com/articles/d41586-018-01290-0

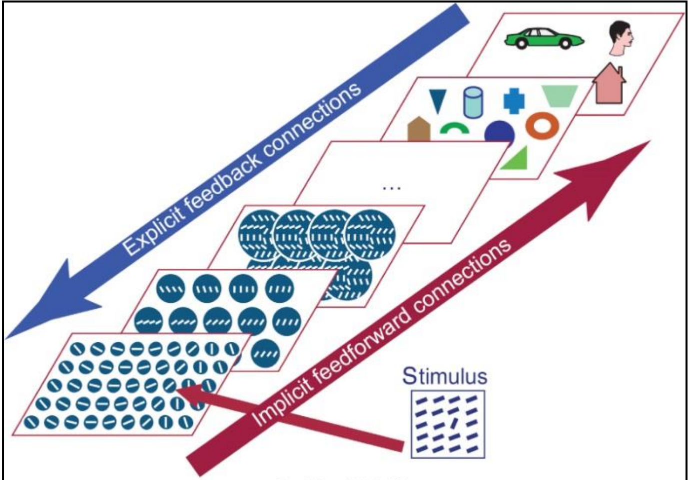
Neurons: Working Assumptions

Six working assumptions:

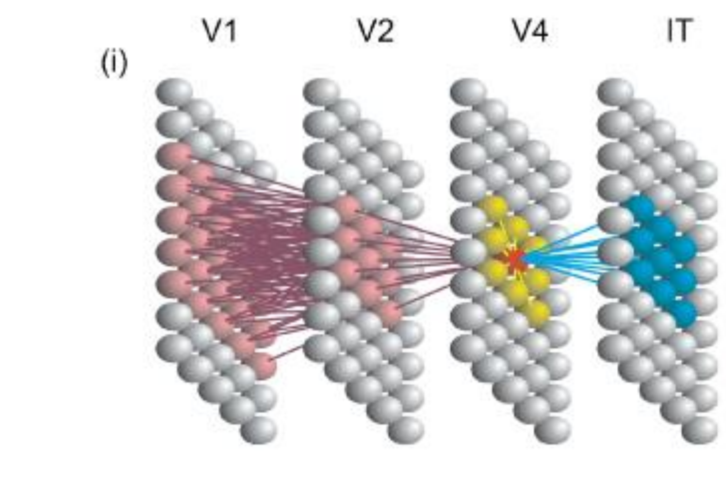
1. Neurons work using an integrate-and-fire action
2. Connections are either excitatory or inhibitory
3. Idealized neurons are used in artificial neural nets to model brain function
4. Neurons typically form two-way pathways, providing the basis for re-entrant connectivity
5. The nervous system is formed into arrays or maps of neurons
6. Hebbian cell assemblies underlie the change from transient to stable, lasting connections



Source: Byrne and Roberts, 2004.



Source: Ahissar and Hochstein, 2004.



Baars and Gage, 2010

Neurons: Working Assumptions

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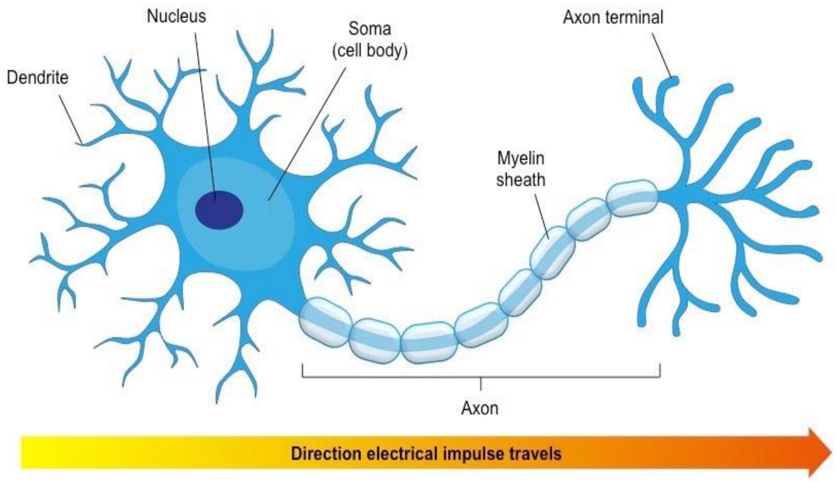
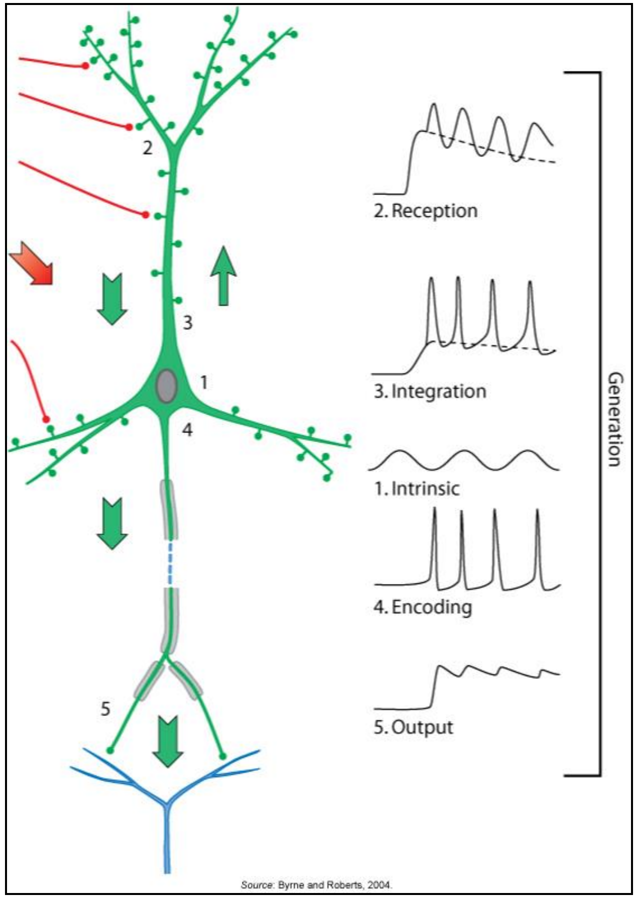


1. Neurons work by adding graded voltage inputs until the total membrane voltage on the target neuron goes past a threshold value (approximately 50 - 70 mV in real neurons) If it does, an all-or-none spike fires down the output branch, the axon

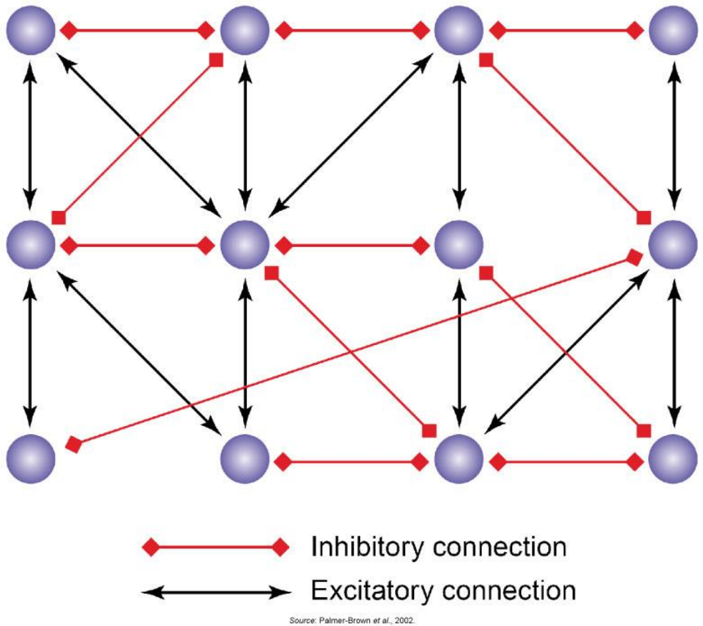
2. If a number is assigned to the probability that neuron A will trigger neuron B. That number is called the *weight* of the connection. As probabilities, connection weights have numbers between +1 and -1. Plus 1 means a 100 per cent certainty of triggering the next neuronal spike, and -1 is 100 per cent certainty of stopping the next neuron from firing

Neurons: Working Assumptions

<u>Working assumptions:</u>
3. Idealized neurons are used in artificial neural nets to model brain function



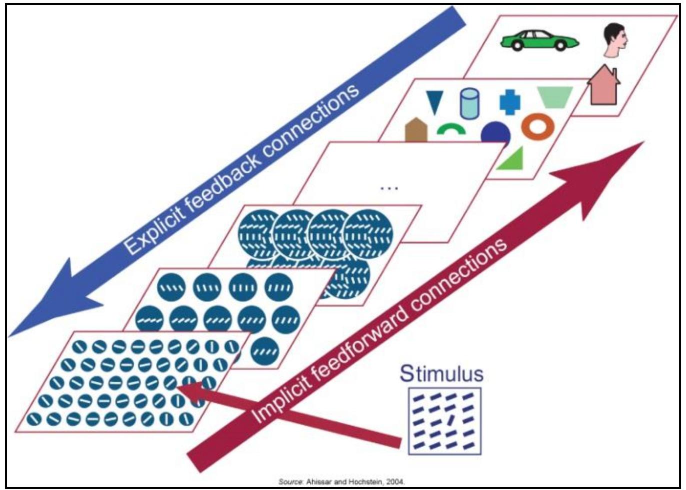
The simplified neuron and synapse is very successful in **simulating cognitive functions**
Neural nets can simulate the kind of pattern recognition that sensory systems perform, although these models are much simpler than any brain mechanism
Neural nets can learn and store information in much the way real neurons are believed to



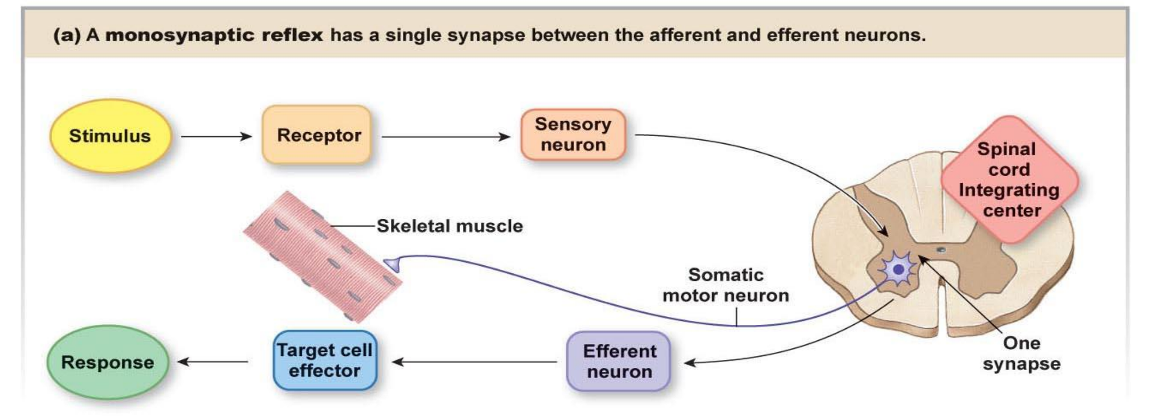
Neurons: Working Assumptions

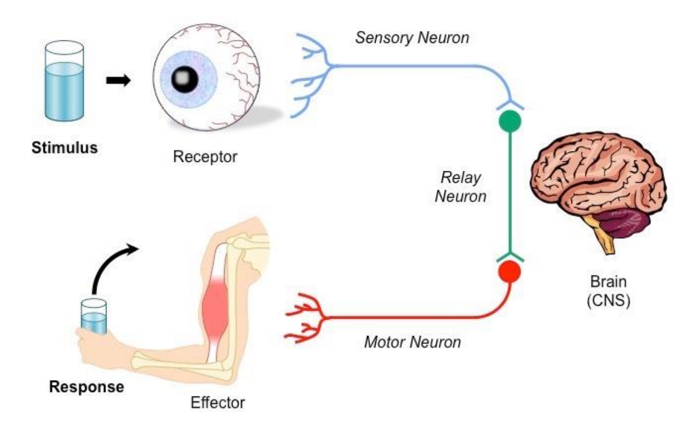
<u>Six working assumptions:</u>

4. Neurons typically form two-way pathways, providing the basis for re-entrant connectivity



- Neurons can form one-way or two-way pathways, such as the optic nerve to the visual thalamus (the lateral geniculate nucleus)
- One-way pathways are quite rare
- More likely, neurons run in two directions, forming two-directional pathways and networks, in which activity at point A triggers activity at point B, and vice versa
- This is called *re-entrant connectivity* (Edelman, 1989)





Neurons: Working Assumptions

Six working assumptions:

5. The nervous system is formed into arrays or maps of neurons
6. Hebbian cell assemblies underlie the change from transient to stable, lasting connections

Hebbian cell assemblies :

- When neurons combine by triggering other neurons, the resulting pattern of activity may be stable or unstable
- Unstable patterns tend to die out, while stable patterns remain for some period of time
- Stable patterns → called *cell assemblies* (Donald O. Hebb, 1949)
- Hebbian cell assemblies may involve neighboring cells, or they may involve cells that are far away from each other

Arrays of neurons or maps :

- The **cerebral cortex** is a massive **six-layer array**, with an estimated 20 billion cells and trillions of synaptic connections between them
- The **retin**a at the back of the eye is another array, this time with **three layers**
- *All* sensory surfaces are arrays of receptors and their closely linked layers of relay and processing cells

- Neuronal *arrays* are widely found in the brain.
- An array is a two dimensional grid of neurons.
- When arrays represent a spatial pattern, they are often called *maps* .
- Spatial maps are a form of spatial coding in neurons. The brain performs temporal as well as spatial coding and may have several other ways of representing and processing information.
- Nevertheless, spatial maps are the most obvious kind of neural code.
- The retina itself is a three-layered map of light receptors and their neighboring neurons, (including ganglion cells), which send their axons from the retina to the visual relay cells of the thalamus (**the lateral geniculate nucleus**)
- The thalamic visual cells then project their fibers to the first visual area of the cortex, area V1 of the occipital lobe V1 also looks like a detailed map of the visual input, with different quadrants of the visual field projected to different parts of this region.
- From area V1, most of the visual information projects to other ‘ maps ’ in the cortex, some of them in the visual cortex itself, but also beyond it.
- While the resolution of spatial details tends to blur after V1, higher-level visual maps respond to more complex and abstract stimuli, like faces, objects, it captures a good deal of evidence

The body senses, like touch and pain perception, also project to map-like regions of cortex. Other senses like hearing, smell, and taste are less spatial in nature, but the auditory cortex has map-like regions organized by pitch, like the strings of a harp. Thus, even the non-spatial senses show regular neuronal arrays and map-like regions. Finally, information from specific sensory systems is combined in the parietal cortex, using spatial arrays that combine auditory, visual, touch information into map-like regions

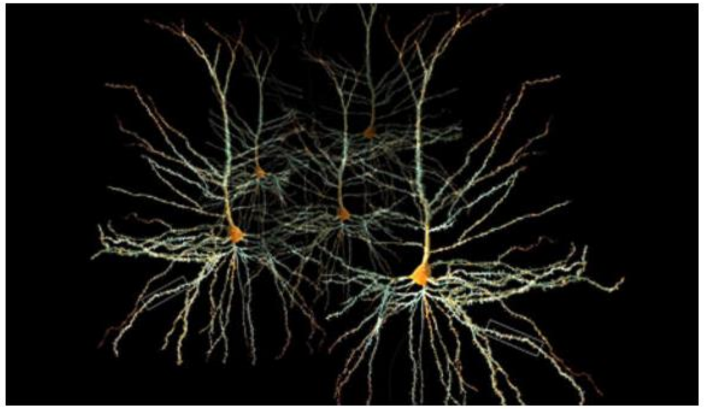
Neurons and Human cognition

High-order thinking depends upon our ability to generate mental representations in our brains without any sensory stimulation from the environment. These cognitive abilities arise from highly evolved circuits in the prefrontal cortex

YaleNews EXPLORE TOPICS ▼

Human cognition depends upon slow-firing neurons, Yale researchers find

By Bill Hathaway | FEBRUARY 20, 2013



(Illustration courtesy of John H. Morrison, Mt. Sinai School of Medicine)

Neurons and Human cognition

Science News *from research organizations*

Waves move across the human brain to support memory

Columbia Engineers discover a new fundamental feature of brain oscillations: These traveling waves reflect patterns of neuronal activity that move across the cortex and are important for memory and cognition

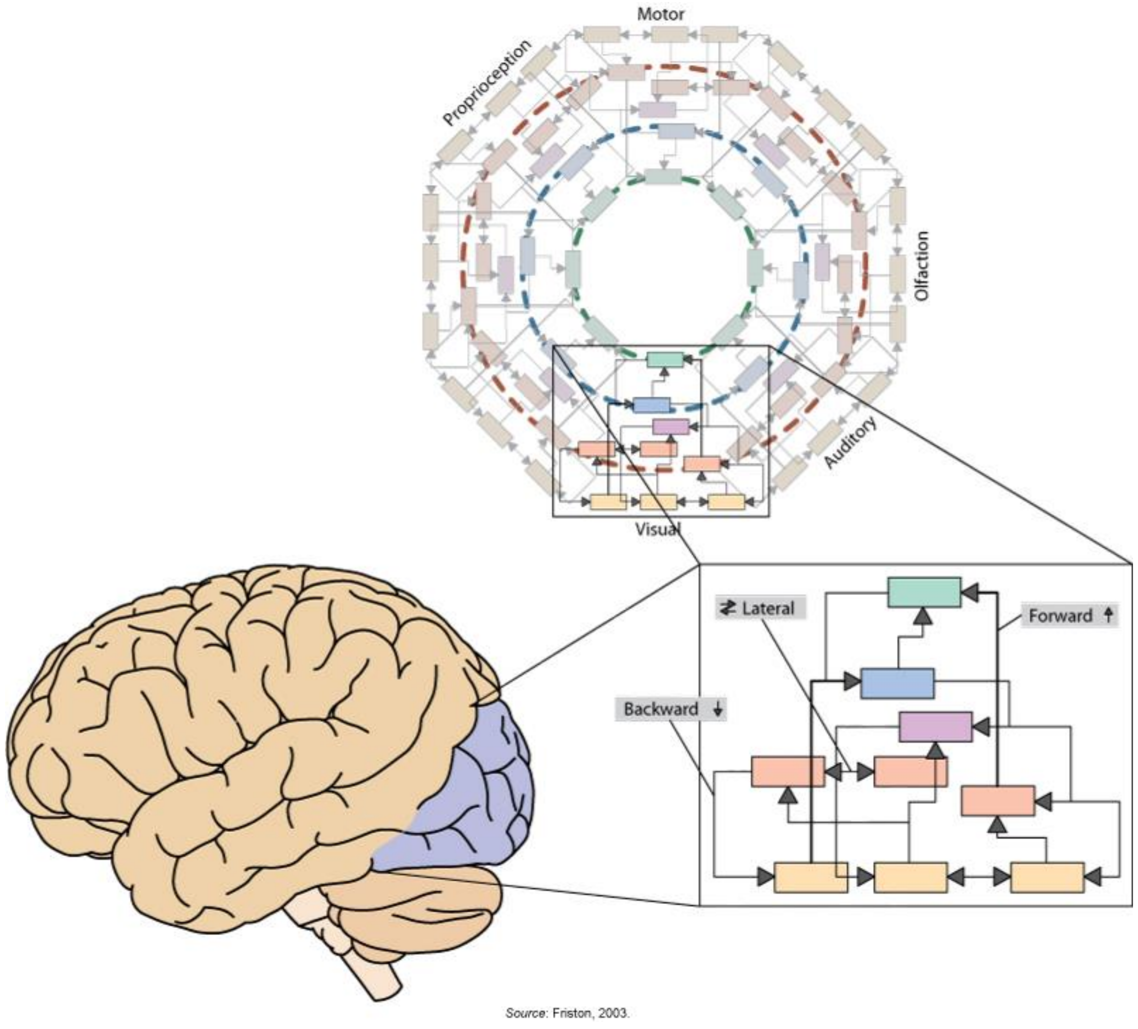
Date: June 7, 2018

Source: Columbia University School of Engineering and Applied Science

Summary: Engineers have discovered a new fundamental feature of brain oscillations: they actually move rhythmically across the brain, reflecting patterns of neuronal activity that propagate across the cortex. The researchers also found that the traveling waves moved more reliably when subjects performed well while performing a working memory task, indicating traveling waves are important for memory and cognition: the waves play a significant role in supporting brain connectivity.

Summary

- How do nerve cells combine to perform complex cognitive functions such as perception, memory, and action?
- While neurons form the basic building block of cognition, how do they work both as individual cells and in synchrony in large scale arrays?
- Some working assumptions about how neurons work -- such as the integrate-and-fire neuron, two-way pathways, cell assemblies and artificial neural nets -- have allowed scientists to begin to model the complex and dynamic activity in the brain that underlies human cognition



Source: Baars and Gage, 2010