Selected topics in cognitive science and biomodelling. L2. Emergence of brain research.

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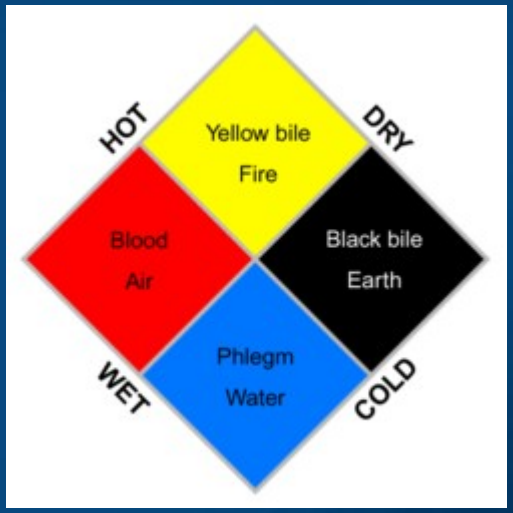
A bit of the brain research history

Ancient History

Trepanation of the scull has been practiced in ancient times all around the world, with some sculls being 7000 years old – it is not clear why they did it.

… from the brain, and from the brain alone, arise our pleasures, joys, laughter and jokes, as well as our sorrows, pains, grief's and tears. Through it, in particular, we think, see, hear, and distinguish the ugly from the beautiful, the bad from the good, the pleasant from the unpleasant…

Attributed to Hippocrates, 5th century BC

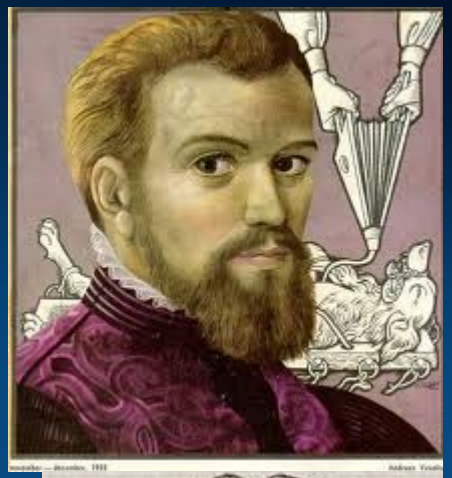


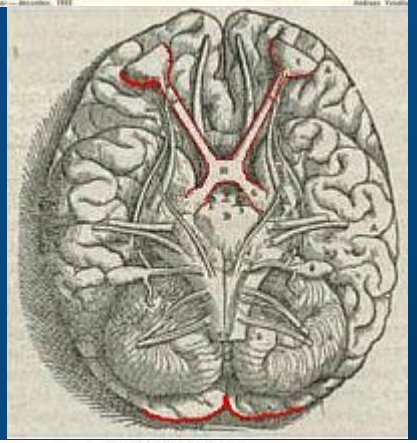
Hippocrates promoted theory of humors, believed by Greek, Roman and Islamic physicians, that survived until the XIX century. The four humors/characters:

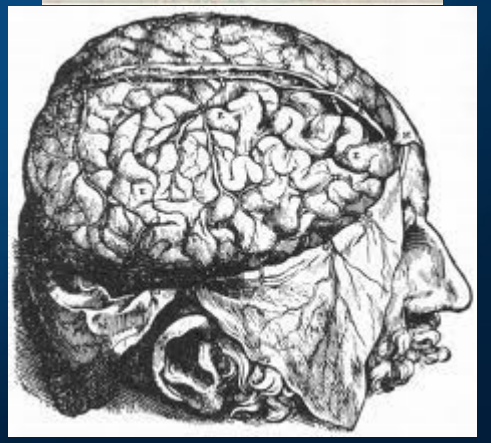
- black bile (gr. melan chole), melancholic, despondent, irritable
- yellow bile (gr. chole), choleric, bad tempered
- white phlegm (gr. phlegma), phlegmatic, calm
- red blood (lat. sanguis), sanguine, courageous, hopeful, amorous

Early History

- **Galen of Pergamon** (129 – 199) was most famous medical researcher, his theories based on dissection of monkeys and pigs dominated for 1500 years, his works were studied even in 19th century! He discovered that brain controls movement through cranial and peripheral nerves.
- *The Canon of Medicine* (1025), encyclopedia of Galenic medicine, compiled by **Ibn Sīnā (Avicenna)**, an example of the great Islamic school of brain surgery.
- **Andreas Vesalius** (1514-1564), a Belgian physician, published 7 volumes of detailed anatomy based on dissections of human body *De humani corporis fabrica* (1543), correcting Aristotle & Galen errors.
- **William Harvey**, *On The Motion Of The Heart And Blood In Animals* (1628): mechanism of blood circulation.







Renaissance

Anatomy lessons (here dr Willem van der Meer by M.J. van Mierevelt) became quite popular in 17th century, students traveled whenever fresh body of an executed criminal was available ...

René Descartes (1596 -1650), a mathematician and philosopher is considered as the originator of modern philosophy of mind.

- He though that animals are automata, only humans can think, have rational souls. His famous statement was: *cogito ergo sum* ("I think, therefore I am").
- The problem of Cartesian dualists: how is the immaterial mind interacting with material body? This has been discussed since antiquity till now.
- **Antonio Damasio's** *Descartes' error. Emotion, Reason, and the Human Brain* discussed connections between emotions and cognition, with body as "canvas for emotional expression", leading to embodied intelligence.

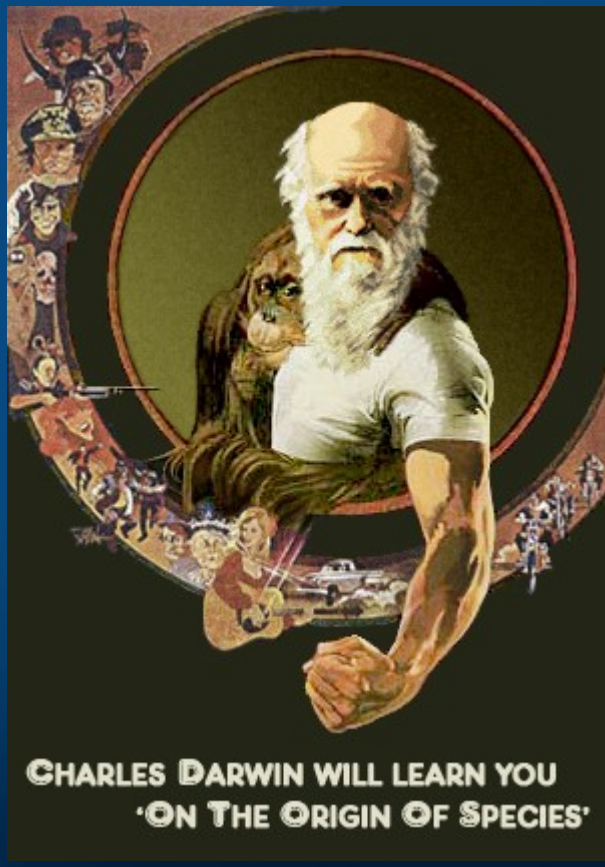
Evolution

Charles Darwin (1809 –1882). Books:
On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life (London, **1859).**

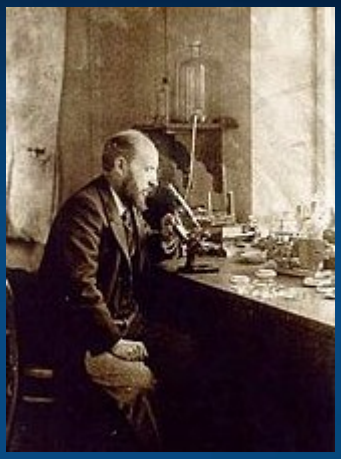
The descent of man, and selection in relation to sex **(London, 1871)**
Expression of emotions in man and animals **(London, 1872)** - emotions are not just a cultural invention, they have biological origins => embodiment ideas.

The mood of his time (1873): "The abdomen, the chest, and the brain will forever be shut from the intrusion of the wise and humane surgeon". Sir John Eric Ericksen, Surgeon-Extraordinary to Queen Victoria.

Psychosurgery started ~ 1935 with lobotomy, cutting thalamus-frontal lobes connections in mentally ill. Antonio Moniz got Nobel prize (1949) for this bad idea.

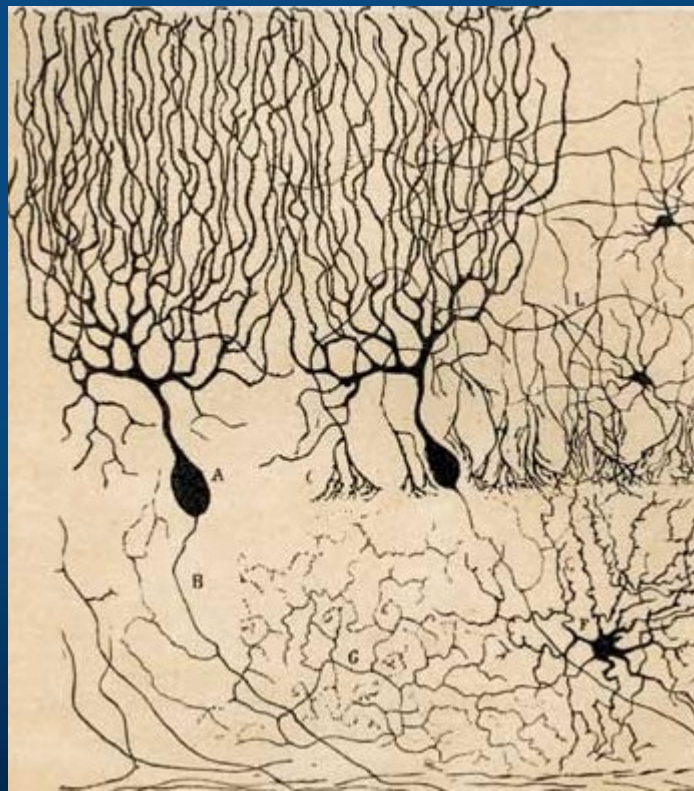


Neurons are coming



In 1838 Theodore Schwann and Matthias Schleiden proposed that organisms have cells, but the brain seemed to have fused cells, a network of tissue, as reticularists believed. The neuronists finally won the dispute, thanks to **Santiago Ramon y Cajal** (1852–1934) who created Neuron Doctrine drawing and describing various types of neurons stained by Golgi's method (Golgi was reticularist).

The term *neuron* was introduced in 1891, *synapse* between nerve and muscle has been described by Charles Sherrington in 1897.



The Neuron Doctrine:

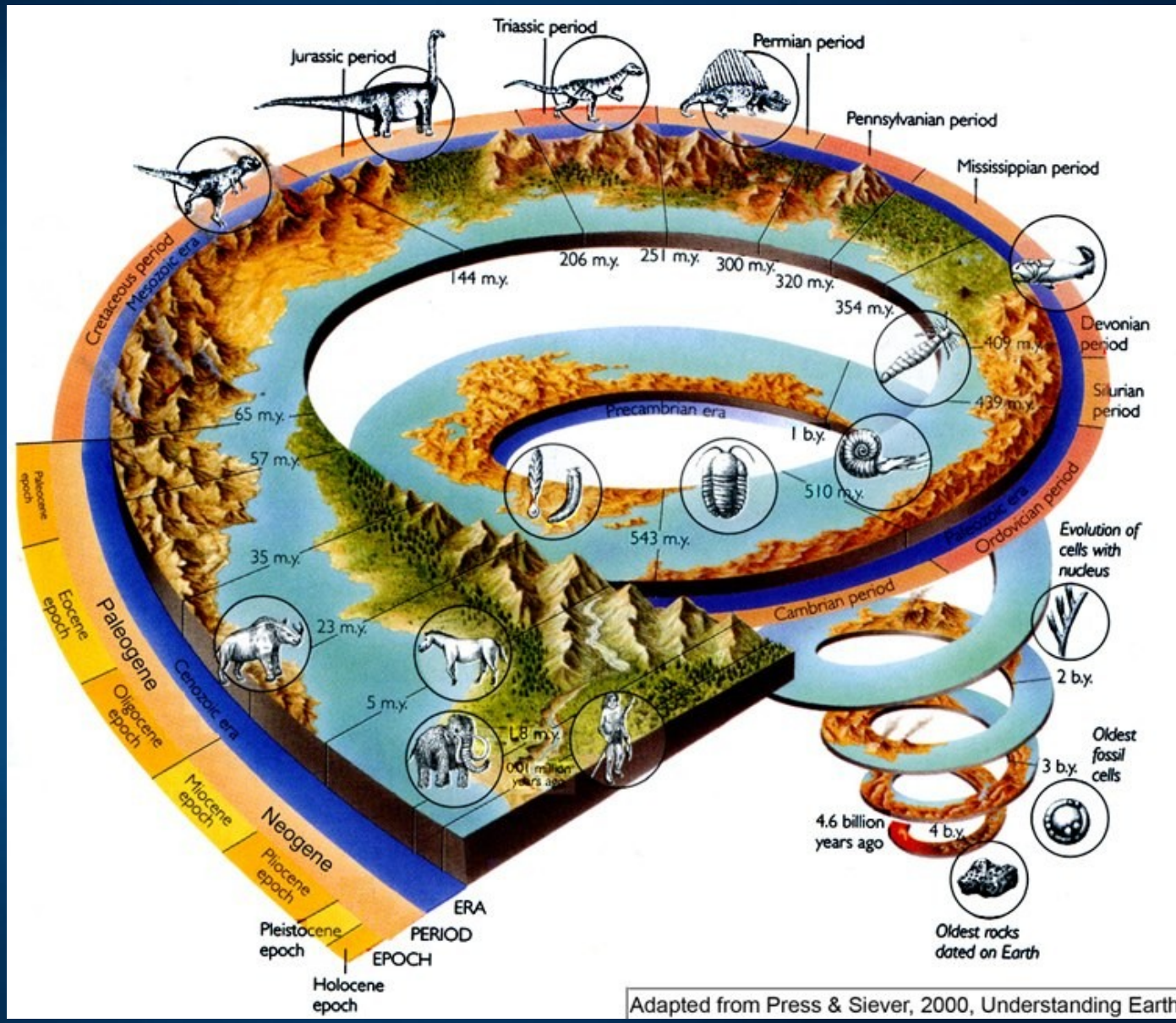
- neurons are functional units of nervous system
- neurons are discrete cells composed of
- the dendrites, axon and cell body,
- information flows along the neuron from the dendrites to the axon, via the cell body.

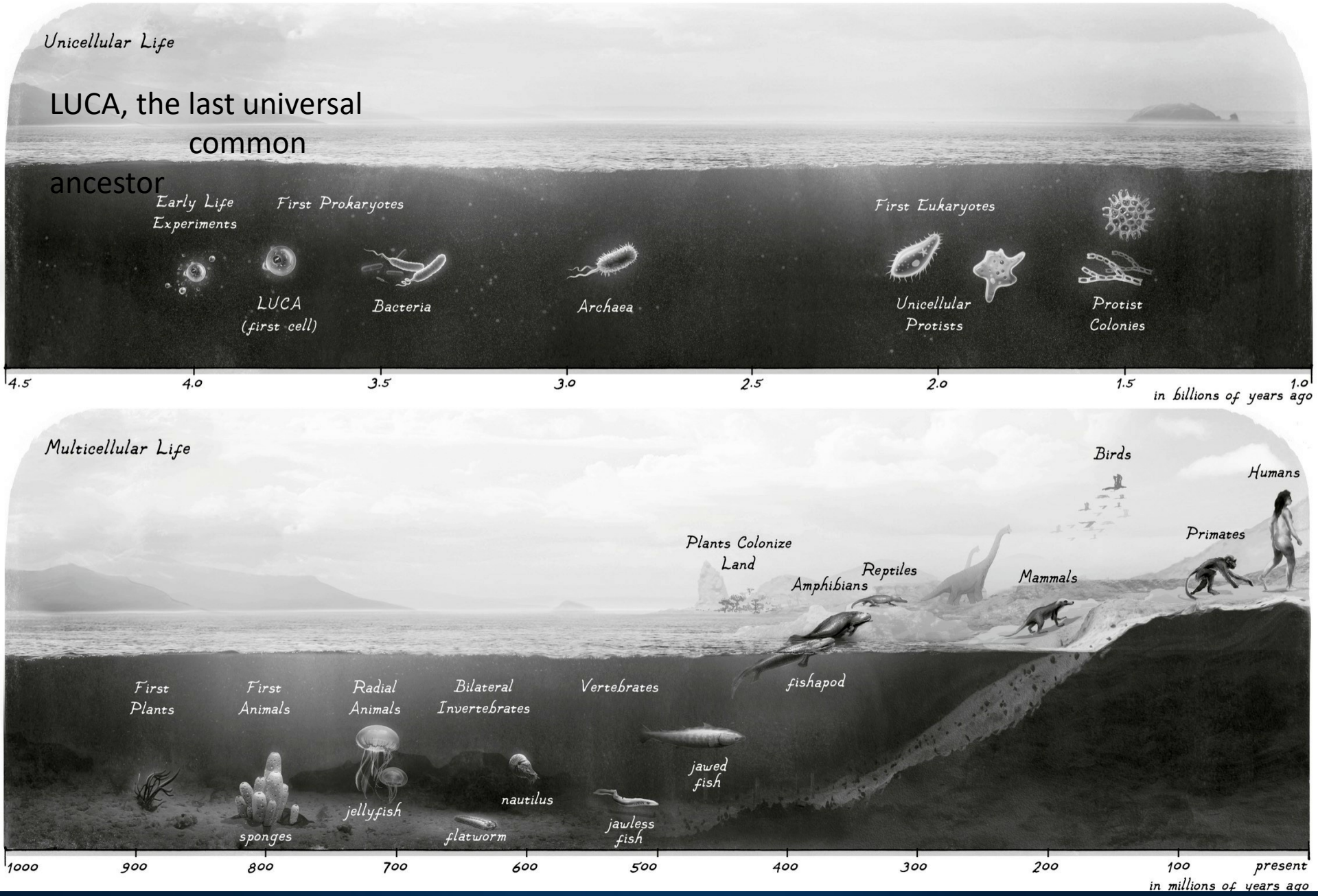
From cells to organisms

Why?
Evolutionary perspective.

D'Arcy Thompson, On Growth and Form (1917). Everything is what it is because it got that way.

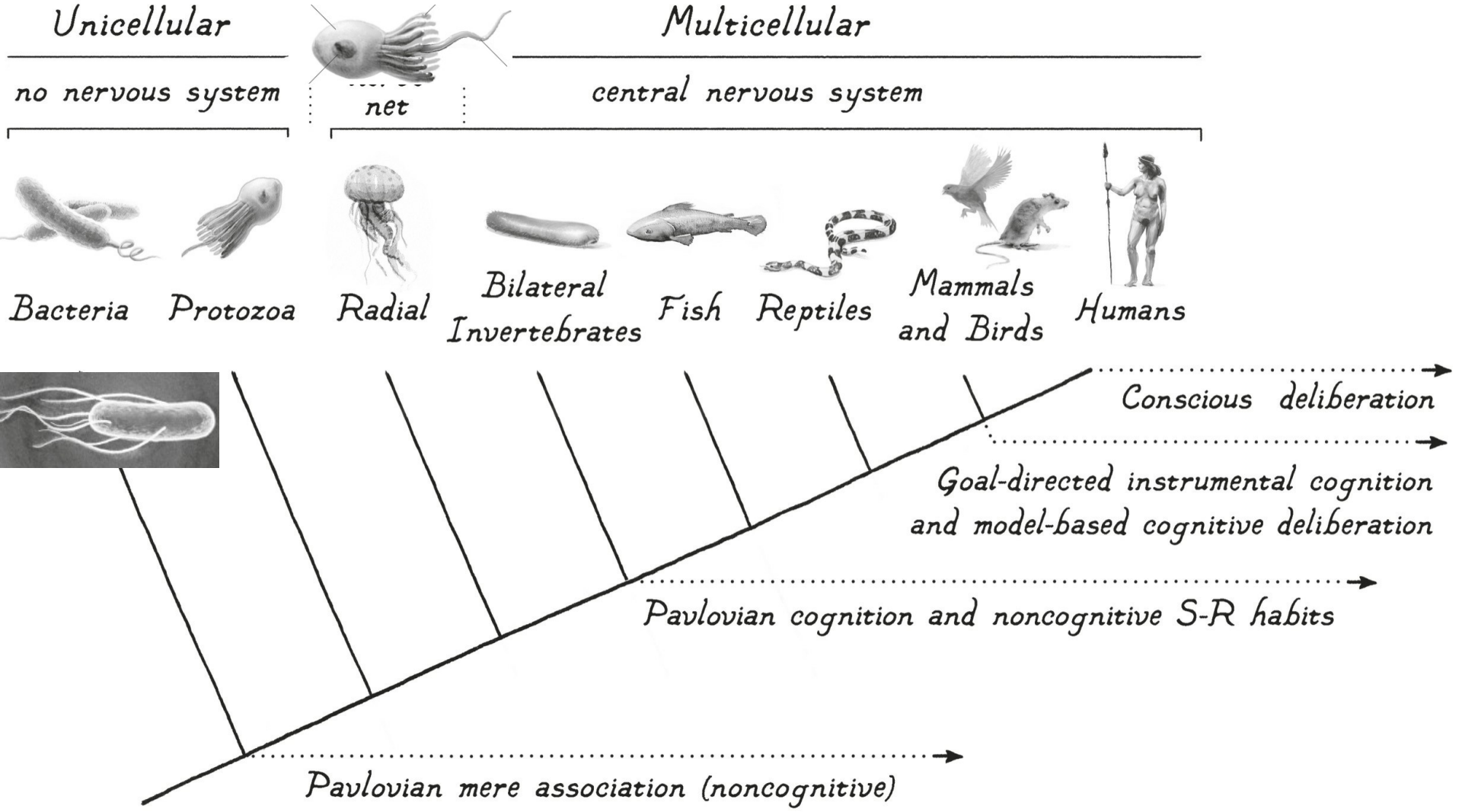
Joseph LeDoux, The Deep History o f Ourselves: The Four-Billion-Year Story of How We Got Conscious Brains. 2019





LUCA, the last universal common ancestor

Bacteria with flagella, protozoa have shorter cilia,
choanoflagellates feed on bacteria, are closest single-cell relatives of animals.



Orientation: receptors

Unicellular organisms (like Paramecium) move towards chemical gradients of nutrients, bacteria, algae, small cells.

Such organisms may learn by altering biochemical cycles.

Reaction to light is quite useful and photoreceptive proteins were relatively easy to create, ex. eyespot apparatus in green algae that can swim towards or away from light, or snails eyes.

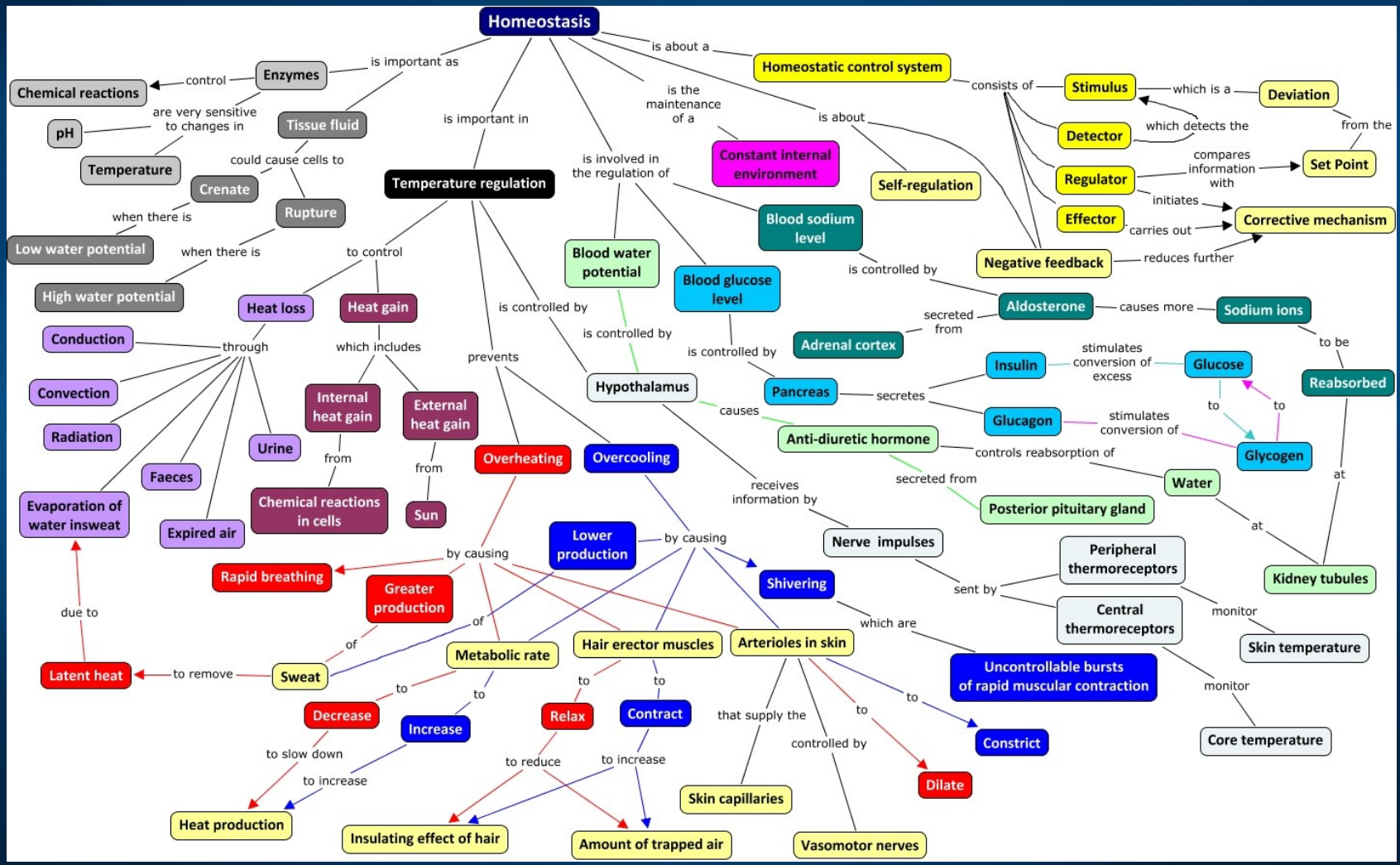
- 10 forms of eyes have evolved from that, based on common genetic mechanisms, with matrices of eyespots,
  to compound eyes of flies and shrimps, to vertebrate eyes
  and more perfect cephalopod (octopus) eyes.

Other useful receptors:

- Chemical sensors, leading to taste, olfaction, thirst and hunger, craving for specific food and substances.
- Mechanical sensors, enabling body orientation and equilibrium, vibration detection, pressure, hearing.

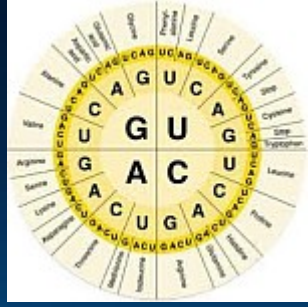
Homeostasis

- What in this map is still missing? And what do we need for robots?



From Homeostasis (ihmc.us)

Evolution rarely looks back



- **Genetic inventions** are preserved in more complex organisms.
- A part of human genome useful in the past, evolved in quite different circumstances, may not be useful or even harmful today: it is called evolutionary baggage.
- During the Ice Age variation in the human leukocyte antigen (HLA) genes lowered the freezing point of the blood by reducing production of insulin, keeping blood sugar levels high: now many Scandinavians who descend from these northern populations suffer from type I diabetes.
- Evolutionary medicine explains how and why bacteria, viruses, microbes, parasites adapt to resist antibiotics, how pathogens learn to cheat the immune system, how organisms evolved to escape from these attacks by inventing sex and evolving faster (see the Red Queen hypothesis).
- Hiccoughs have been connected to the expression of gill ventilation in frogs, originating pattern generators for suckling or regular breathing.
- Freezing behavior: common to many animals (insects) when frightened.
- Left-right crossed connections in the brain is linked to coiling of worms.

Complex behavior

Courtship of the male Maratus speciosus (Coastal peacock spider).
Peacock spider dancing, even house dust mite, not just birds and mammals!

Mind?

In 19th century mental life was considered to be a function of conscious mind, controlled by immaterial soul seated in the brain.

In 1860 neurologist Thomas Laycock in *Mind and Brain, or, the Correlations of Consciousness and Organisation* had to admit that brains also show reflex action, unconscious reaction to stimuli, like other ganglia in nervous system.

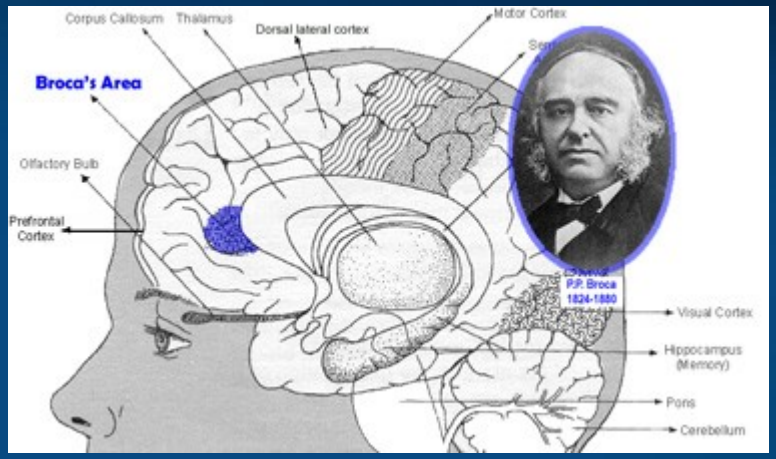
Ivan Mikhaylovich Sechenov published in 1863 *Reflexes of the brain* (in Russian) and in 1866 *Physiology of the nervous system* (in Russian), showing link between brain activity and electric currents, introducing electrophysiology, investigating automatic brain reflexes and claiming that mental life comes from sensory stimulation. He was on trial in 1866 for "spreading materialism and debasing of Christian morality", but not persecuted.

Many British and German scientists came to the same conclusion observing results of brain damage.

Sigmund Freud (1899) created psychoanalysis to understand psychology of unconscious mind, but his theory has never been verified in scientific way.

Localization of language

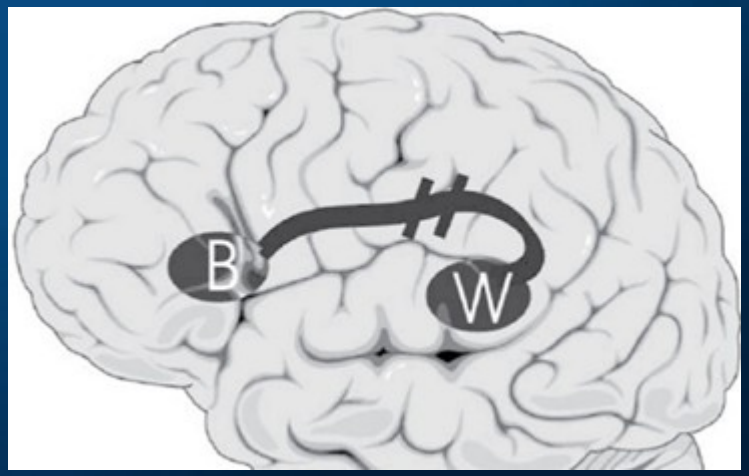
Paul Broca (1824-1880) studying the brains of aphasic patients in 1861 discovered that the damage to left posterior inferior frontal gyrus (called now Broca's area) leads to speech production problems (expressive aphasia, Broca's aphasia).



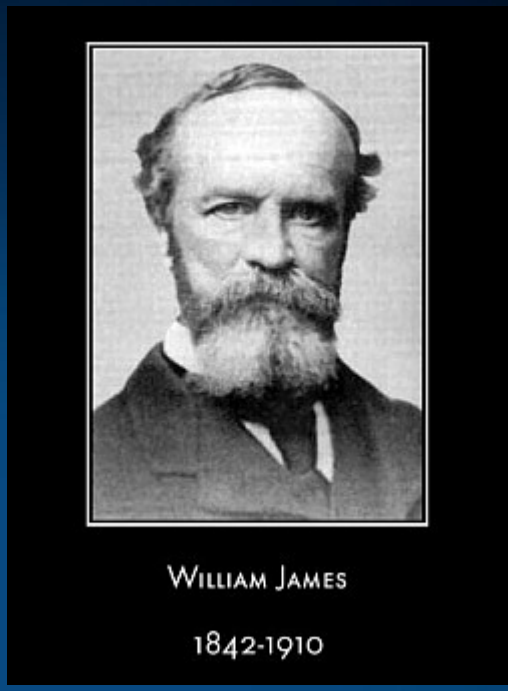
Localization of complex function in the brain was quite surprising, most people had a holistic view of mental functions, although the pseudoscience of phrenology claimed localization of all functions since 1810.

Carl Wernicke (1848-1905) in 1873 noticed that lesion to the left posterior superior temporal gyrus (Wernicke's area) leads to problems with understanding and producing meaningful speech, known as Wernicke's or receptive aphasia.

B & W disconnection => conduction aphasia.



Mind-brain



Psychology was initially understood as the science of mental life, consciousness, psyche+logic.

Introspection, trying to analyze thoughts and mental states in terms of sensations, feelings and images, brought a lot of confusion.

Many scientists (Wundt, Fechner, Helmholtz) developed psychophysics, linking sensory data with percepts.

The **Weber–Fechner law** describes logarithmic relationship between the physical characteristics of stimuli and its perceived intensity. Ex. loudness.

Experimental psychology labs started to investigate memory, animal reflexes.

Pavlov experiments with dogs (1900) on classical conditioning convinced psychologists that all behavior can be derived from simple reflexes.

Behaviorists wanted to change psychology into “objective experimental branch of natural science", removing introspection, leaving only measurable data.

For decades research on consciousness and mind became a taboo.

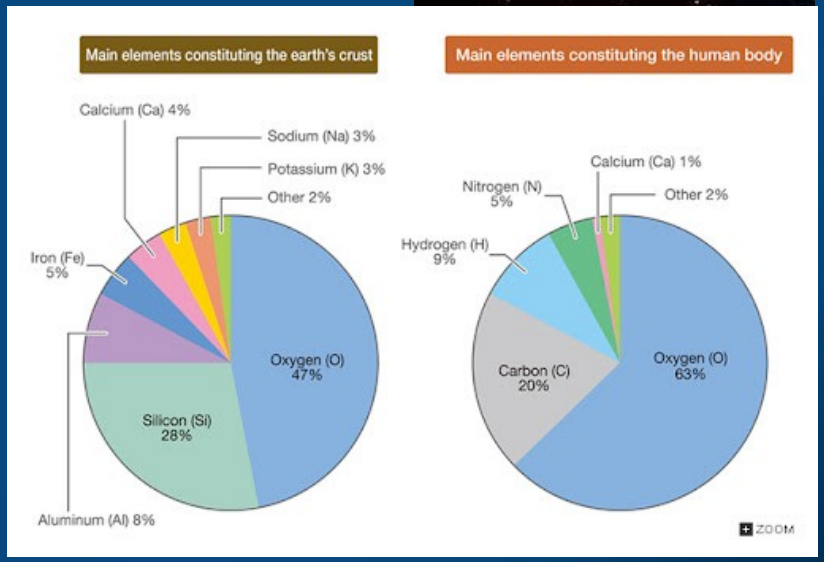
Elements

First: stars form heavy elements from hydrogen.

Then: supernova!
Different elements => different colors.

Earth 4.5 By, crust contains
mostly oxygen and silicon.

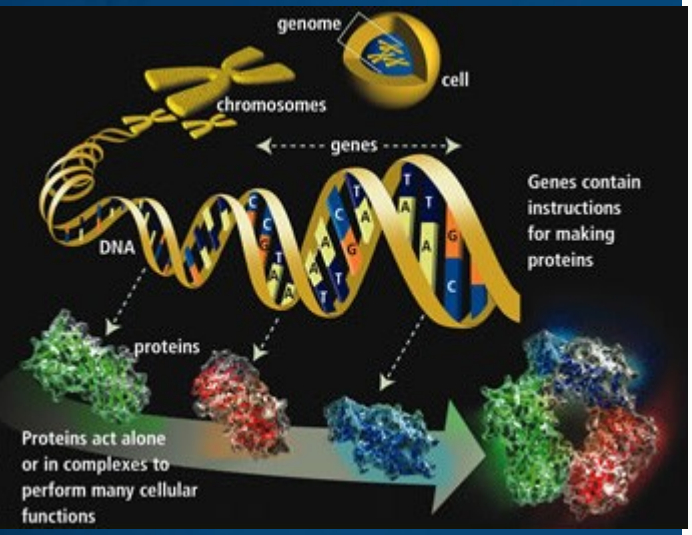
Life, 3.7 By: carbon, nitrogen.

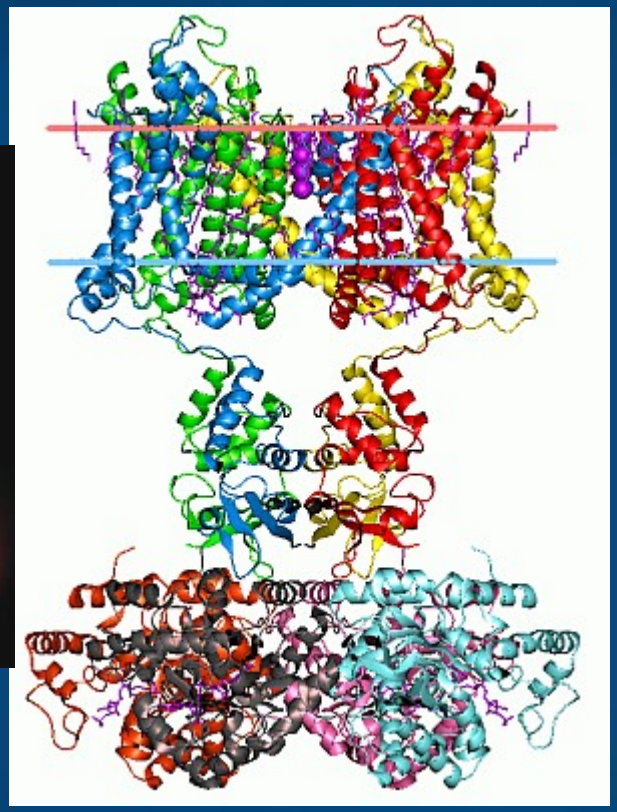


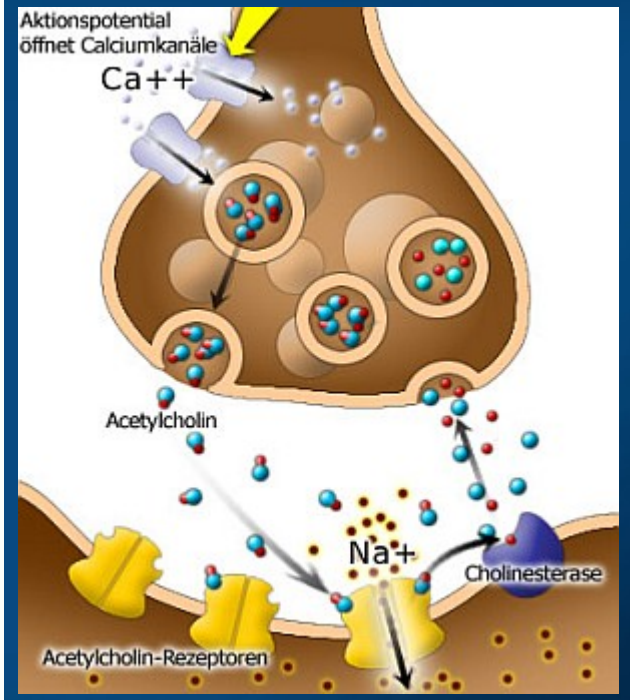
Human body: ~ 10^{27} atoms, most H, O, C.
Carbon 1/10, but 1/5 mass.

Mass of H_2O in human body:
overall 60%, brain 73%, lungs 84%, muscles 79%, bones 31%.
60 elements, half important, some harmful. 1.5% Calcium, 1% Phosphorus, 0.5% Potassium, 0.3% Sulfur, 0.2% Sodium, 0.2% Chlorine, 0.2% Magnesium. Copper only 0.0002% (< 0.1 g), but it is in all proteins.
Lithium, Molybdenum are important elements although it is only 10^{-9} of our mass.
Harmful: arsen, cadmium, mercury, lead.

From Genes to Neurons

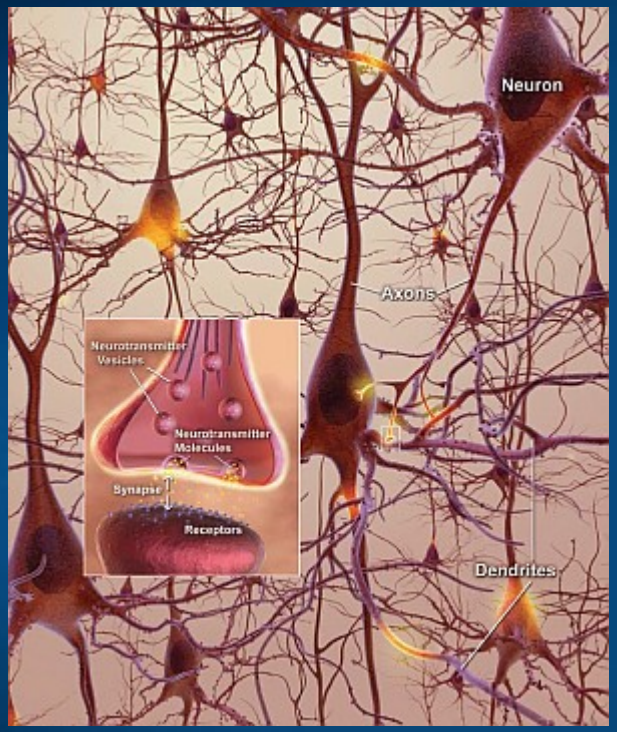


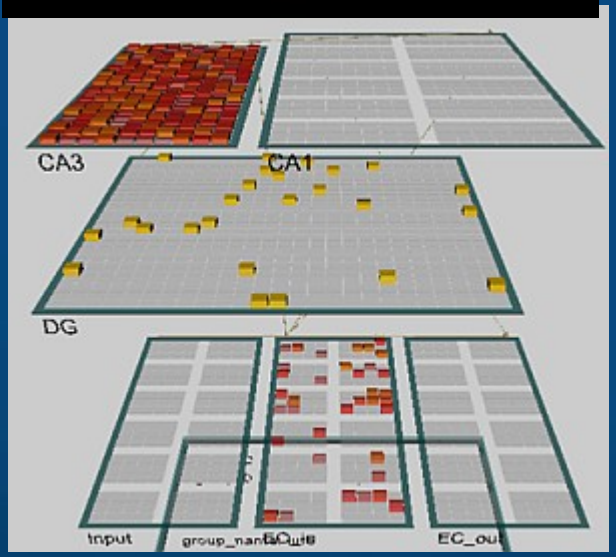




DNA (1953), genes (1972) => proteins => receptors, ion channels, synapses, soma => neuron properties

From neurons to behavior





$\Rightarrow$ network structure **=> neurodynamics** => neuron properties

$\Rightarrow$ behavior (abnormal), cognitive phenotypes,

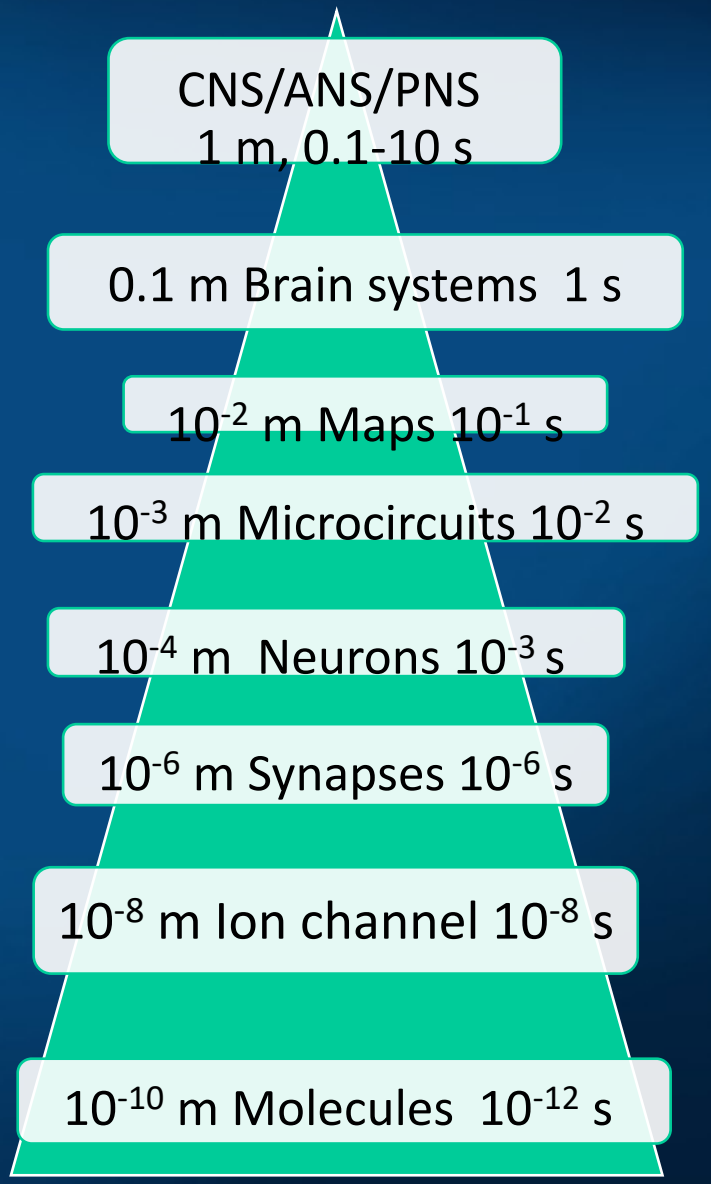
Space/time scales

Spatiotemporal resolution:

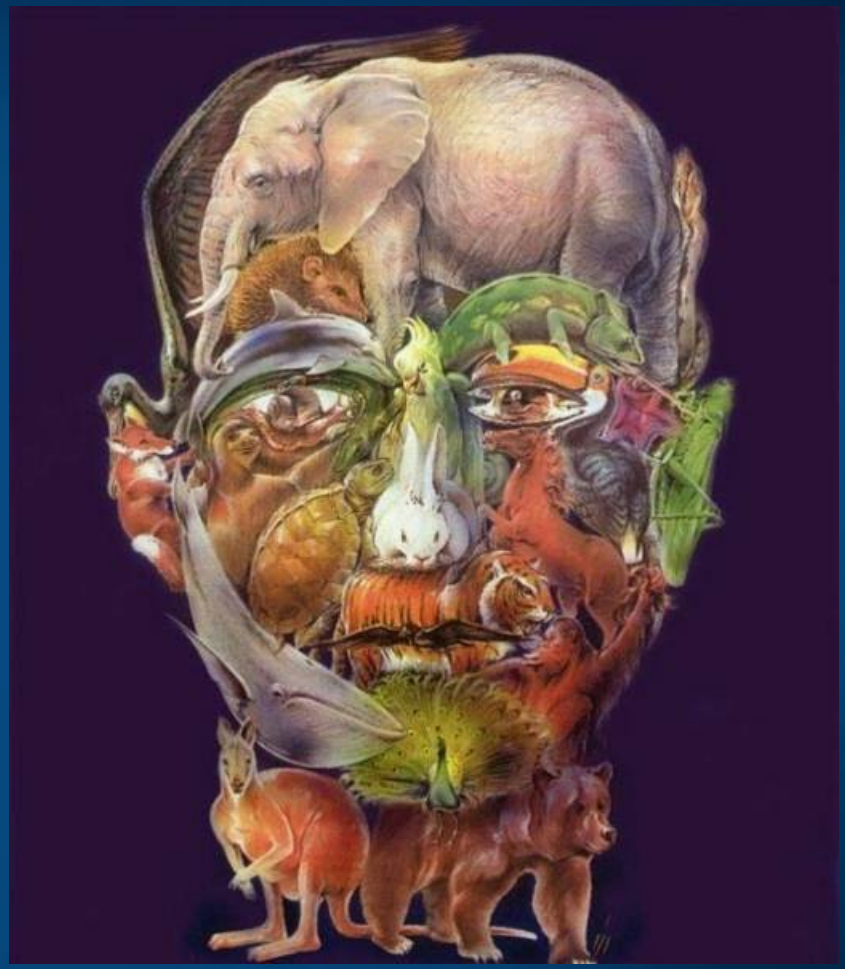
- spatial scale: 10 orders of magnitude, from 10^{-10} m to 1 m.
- temporal scale: 10 or more orders of magnitude, from 10^{-10} s to 1 s.

Architecture:

- hierarchical and modular
- ordered in large scale, chaotic in small;
- specific projections: interacting regions wired to each other;
- diffused: regions interact through hormones and neurotransmitters;
- functional:
  subnetworks dedicated to specific tasks.



Thank you for
synchronization
of your neurons



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