ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Cognitive Neuroscience: Bridging the Gap Between Brain and Mind

Cognition and Neuroscience
Academic year 2024/2025

Francesca Starita

francesca.starita2@unibo.it

Learning objectives

- Define neuroscience, cognition and cognitive neuroscience.

- Explain the relationship between neuroscience and artificial intelligence (AI).
- Discuss the arguments for and against using the human brain as a model for AI.
- Describe the different levels of brain emulation in AI.

- Trace the historical development of cognitive neuroscience, examining key figures and their contributions.
- Evaluate the contributions of key researchers and different schools of thought in understanding brain structure and function.
- Explain the relationship between brain structure and function.
- Explain how cognitive neuroscience bridges the gap between brain structure and function to understand the mind.

- Critically evaluate scientific claims.

What is neuroscience?

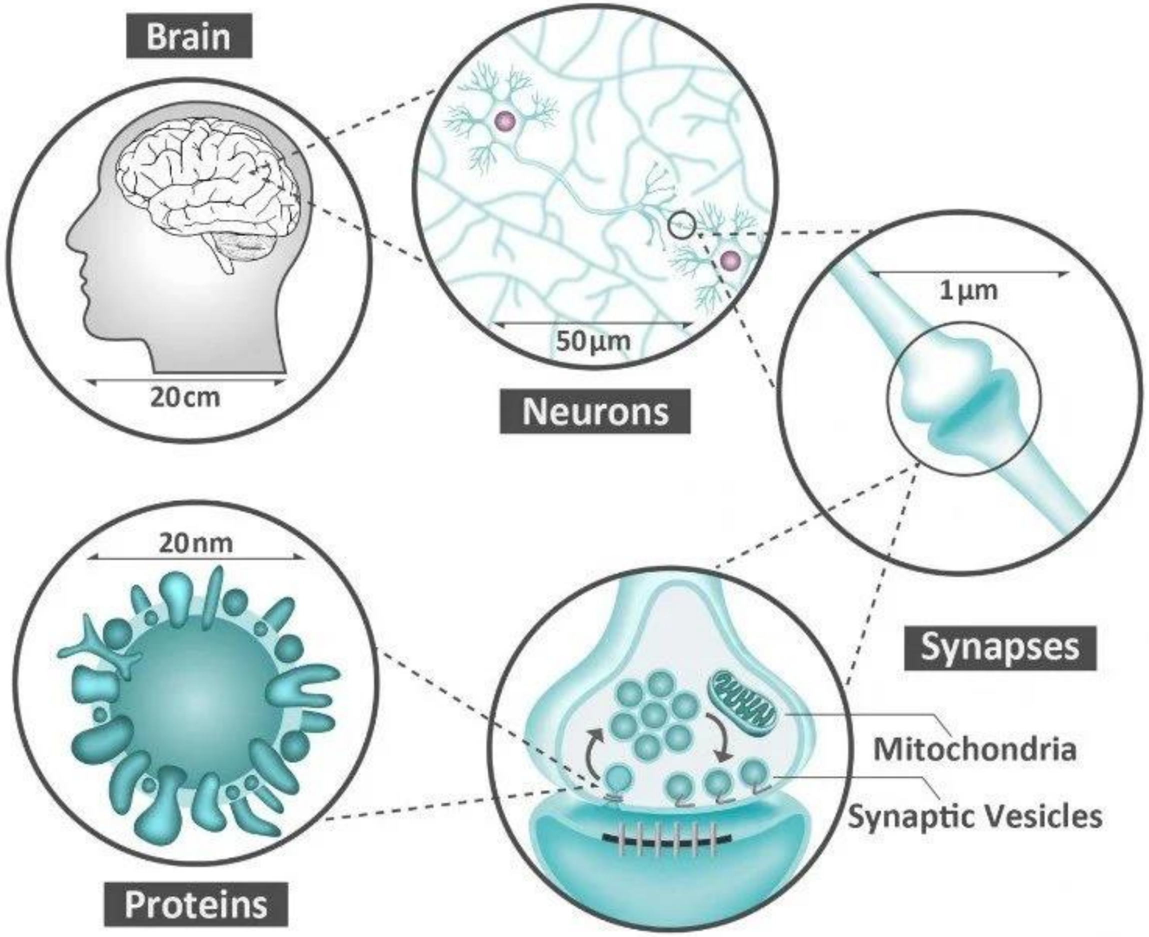
wooclap

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

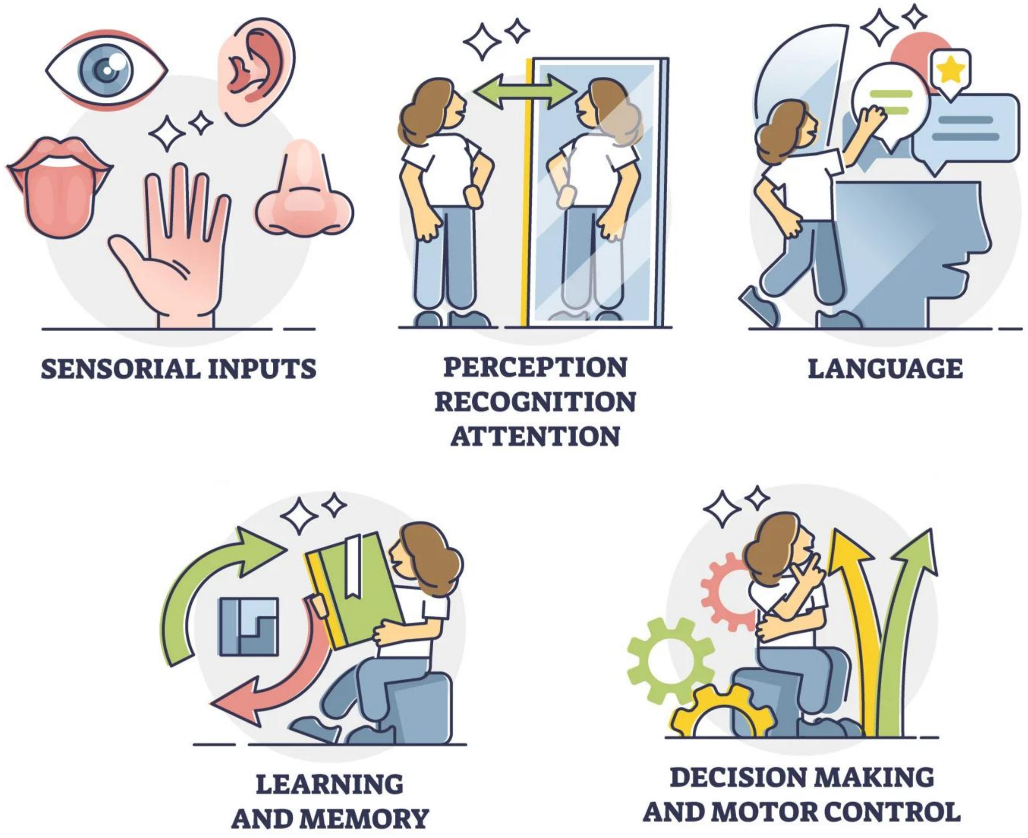
What is cognition?

wooclap

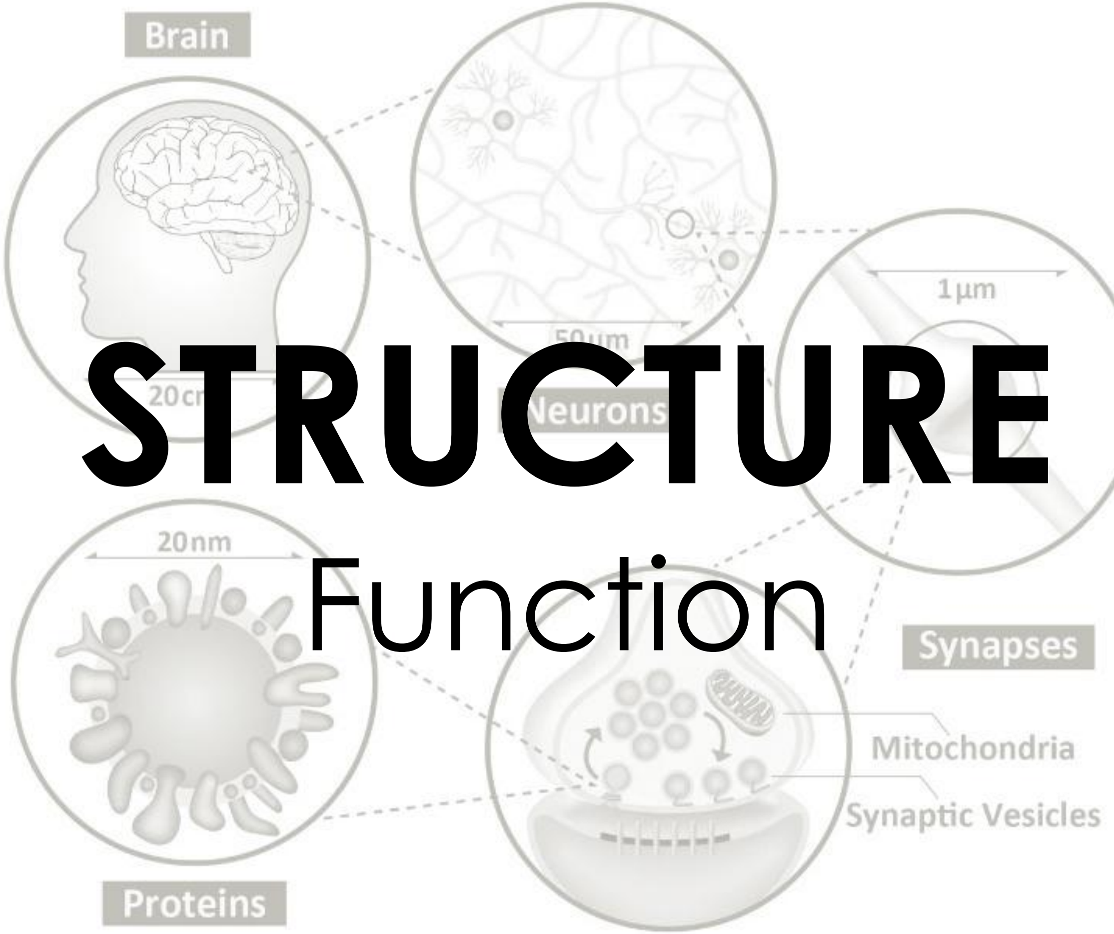
Neuroscience



Cognition



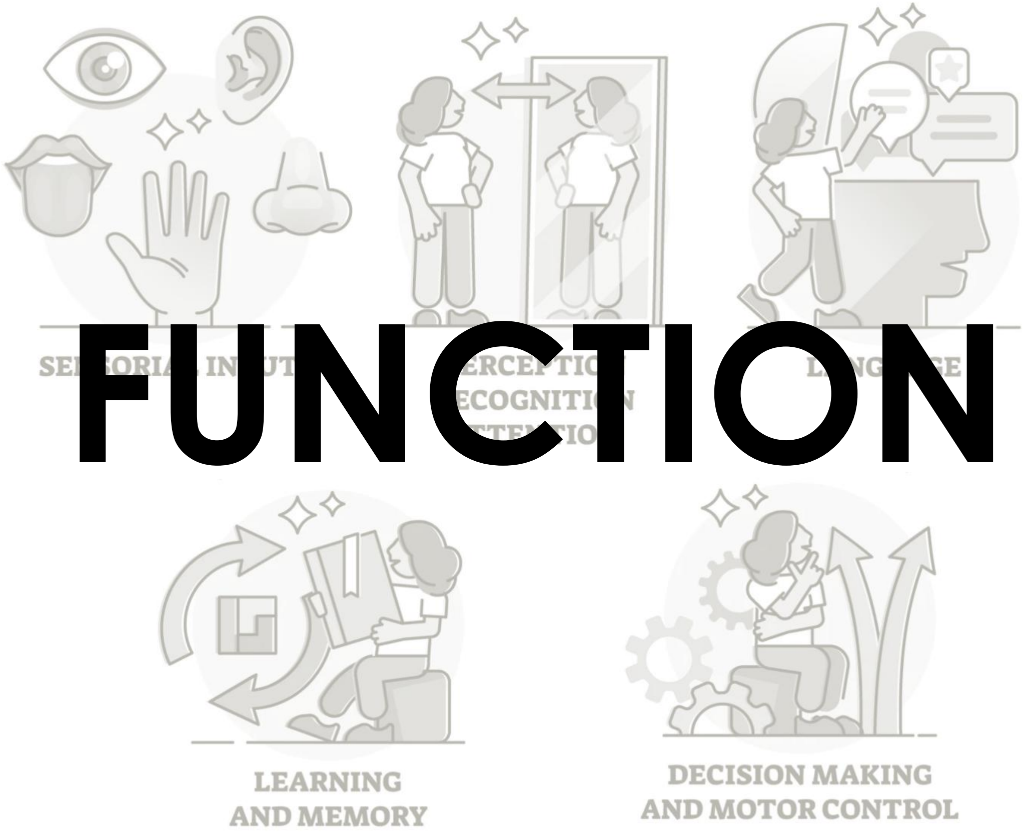
Neuroscience



STRUCTURE

Function

Cognition

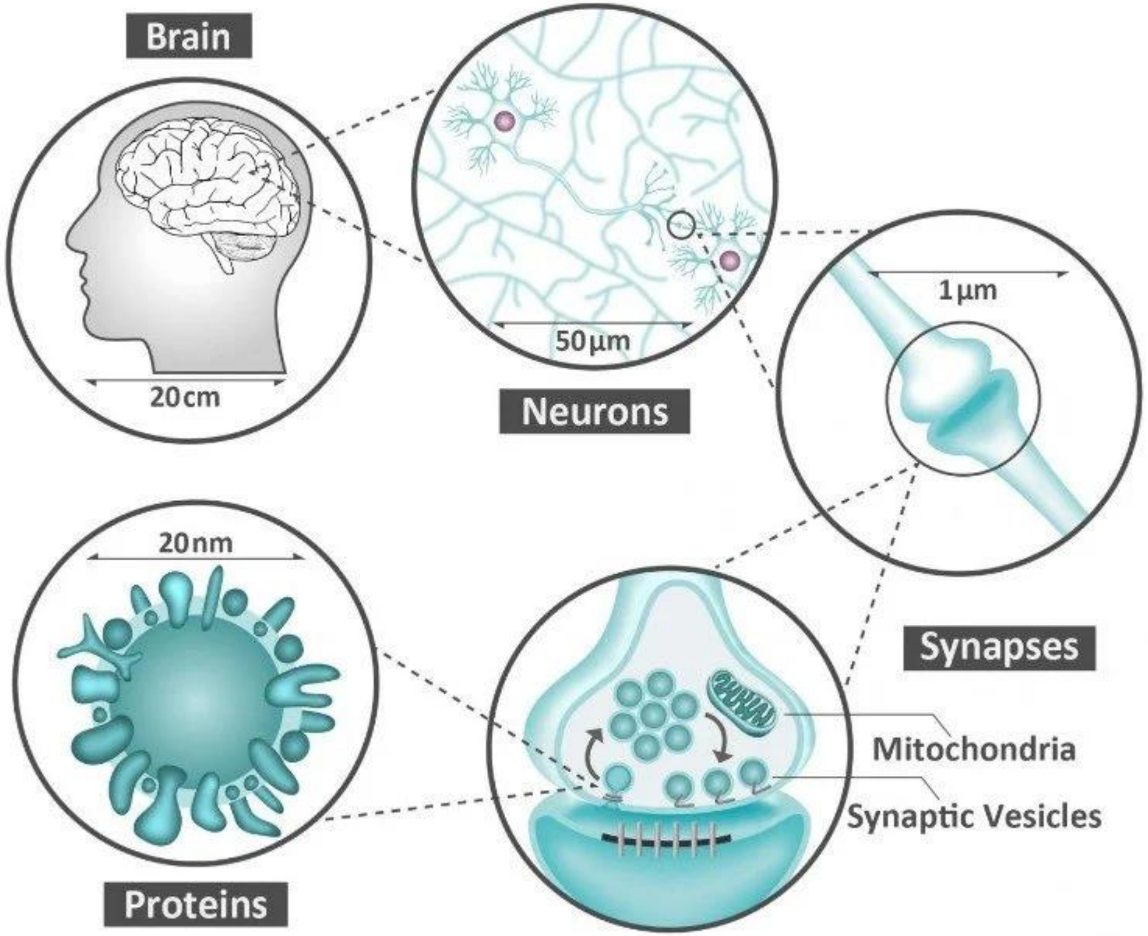


FUNCTION

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Neuroscience

The study of how the nervous system is organized and functions

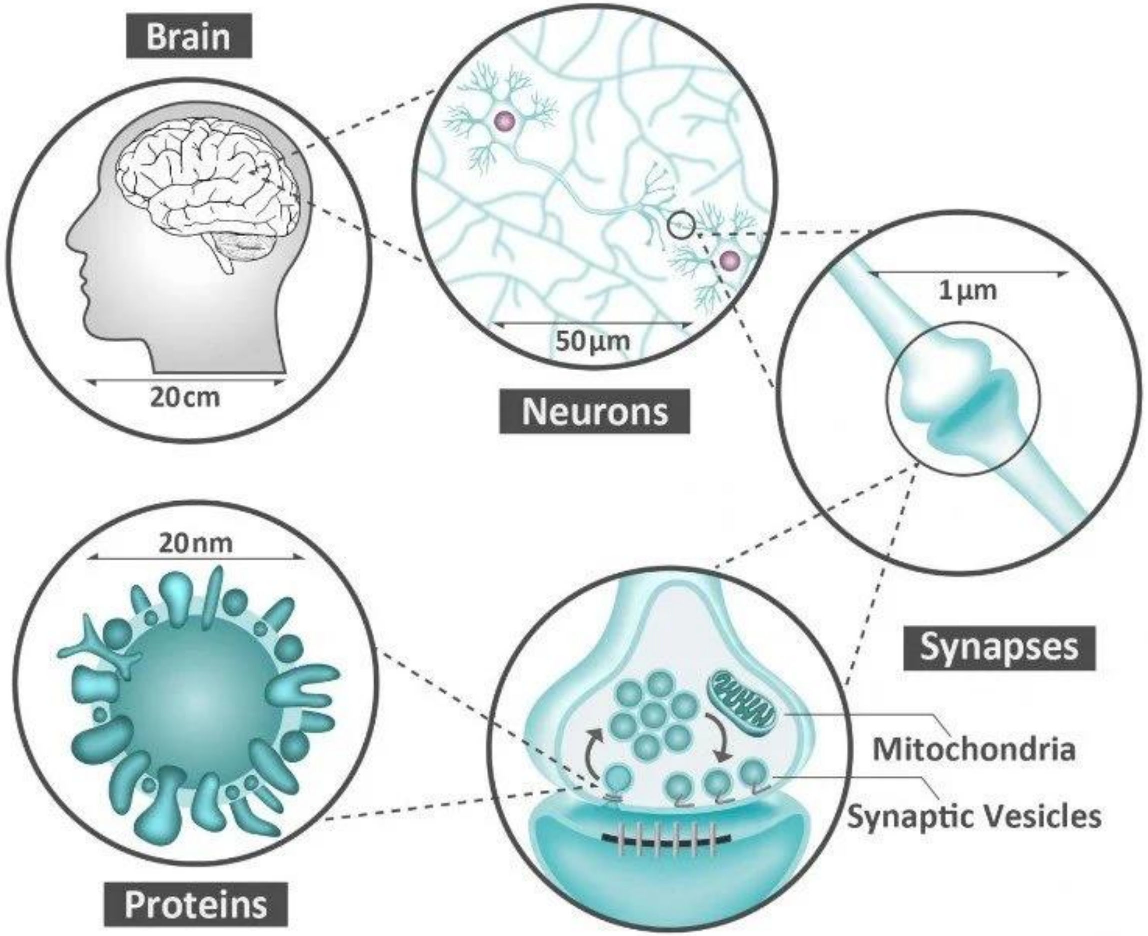


Neuroscience

The study of how the nervous system is organized and functions

Multidisciplinary science:

- Physiology
- Anatomy
- Molecular biology
- Developmental biology
- Cytology
- Computer science
- Mathematical modeling



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Neuroscience

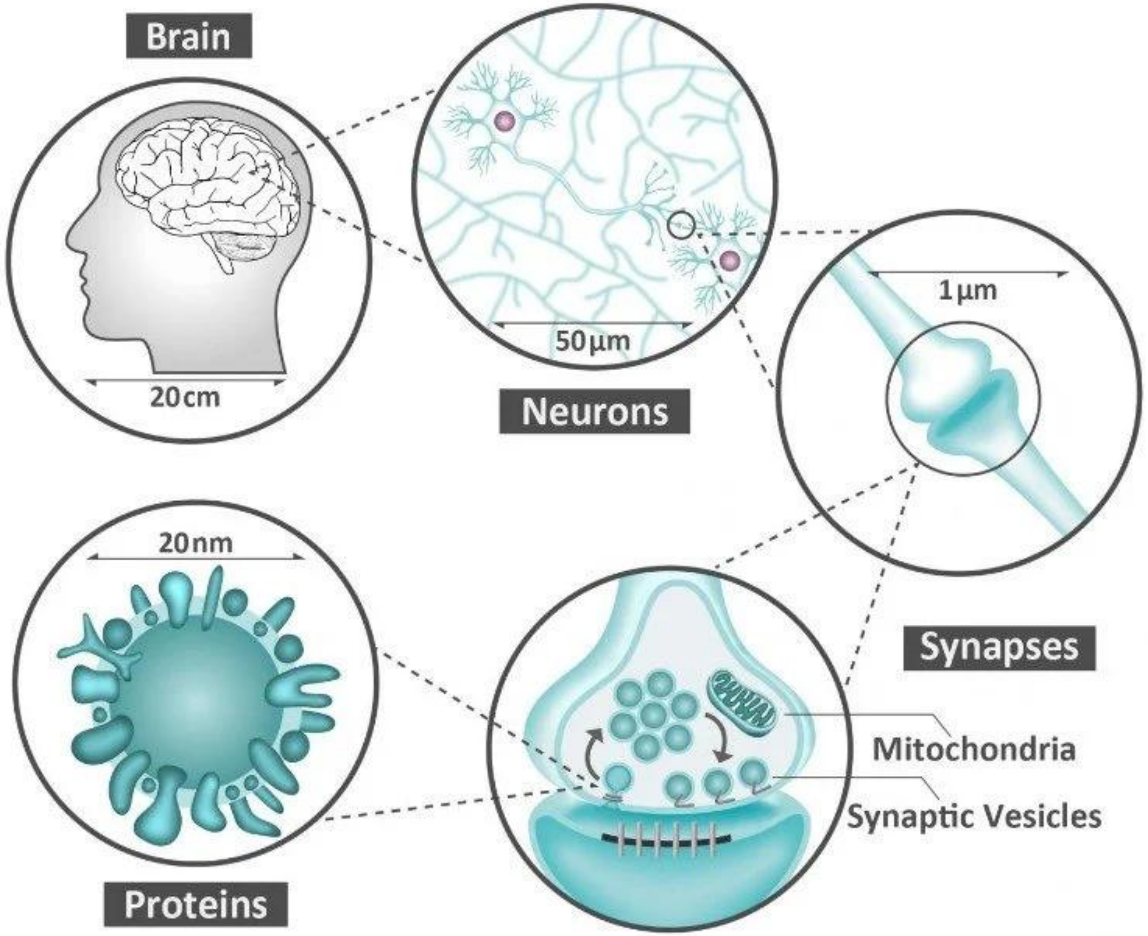
Includes different levels of investigation:

Molecular: molecular neuroanatomy, mechanisms of molecular signaling in the nervous system

Cellular: study of neurons at a cellular level including morphology and physiological properties

Neural circuits and systems: how neural circuits are formed and function anatomically and physiologically to generate behaviors, such as

- sensory perception (somatosensory, visual auditory etc.) & multisensory integration
- motor reflexes and actions



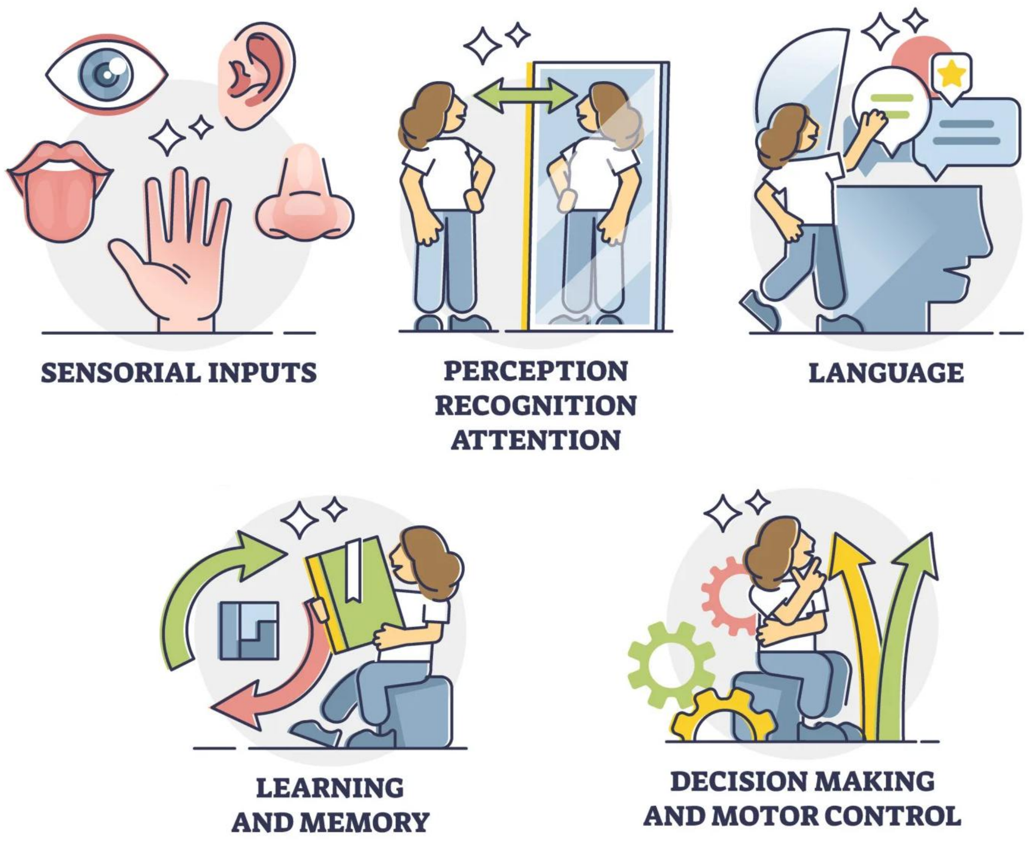
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Cognition

Range of mental processes relating to the

- Acquisition
- Storage
- Manipulation
- Retrieval

of information



Cognition includes multiple processes

Perception: take in information from environment through the senses (sensation)

Attention: allows to focus on a specific stimulus in the environment

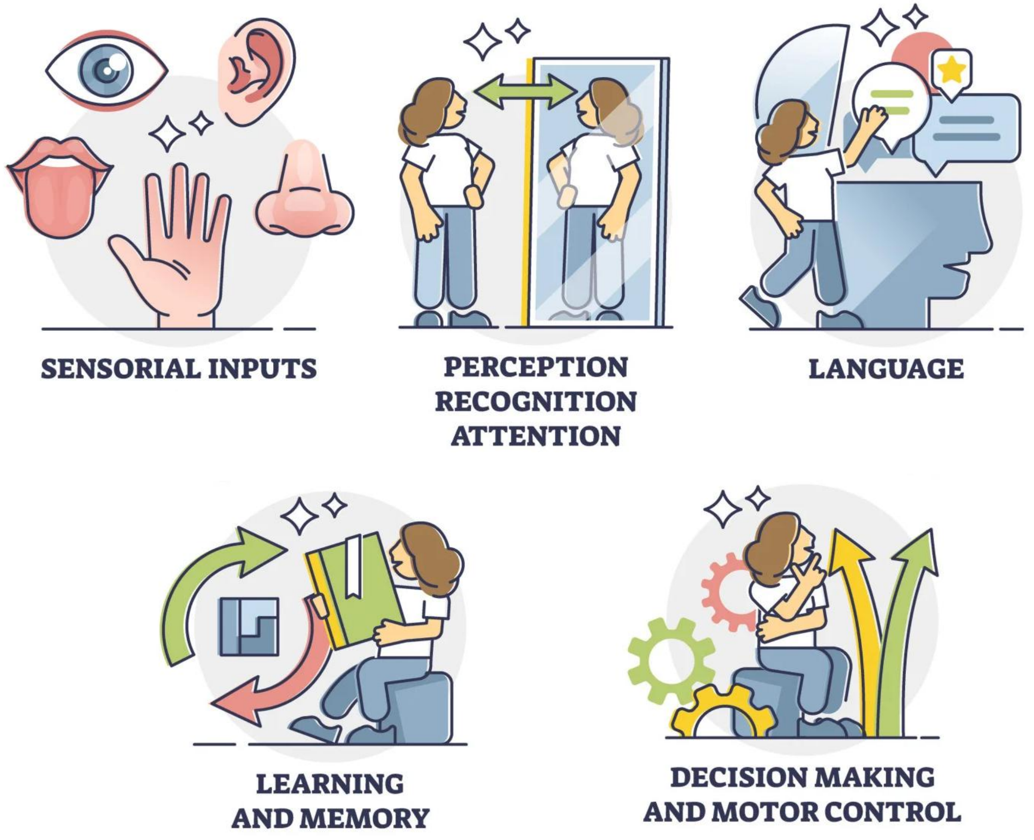
Learning: manipulating new information, and integrating it with prior knowledge

Memory: encode, store, and retrieve information. It is a critical component in the learning process.

Action: use perceived information to interact with the environment

Language: the ability to understand and express thoughts through spoken and written words. It allows communication with others.

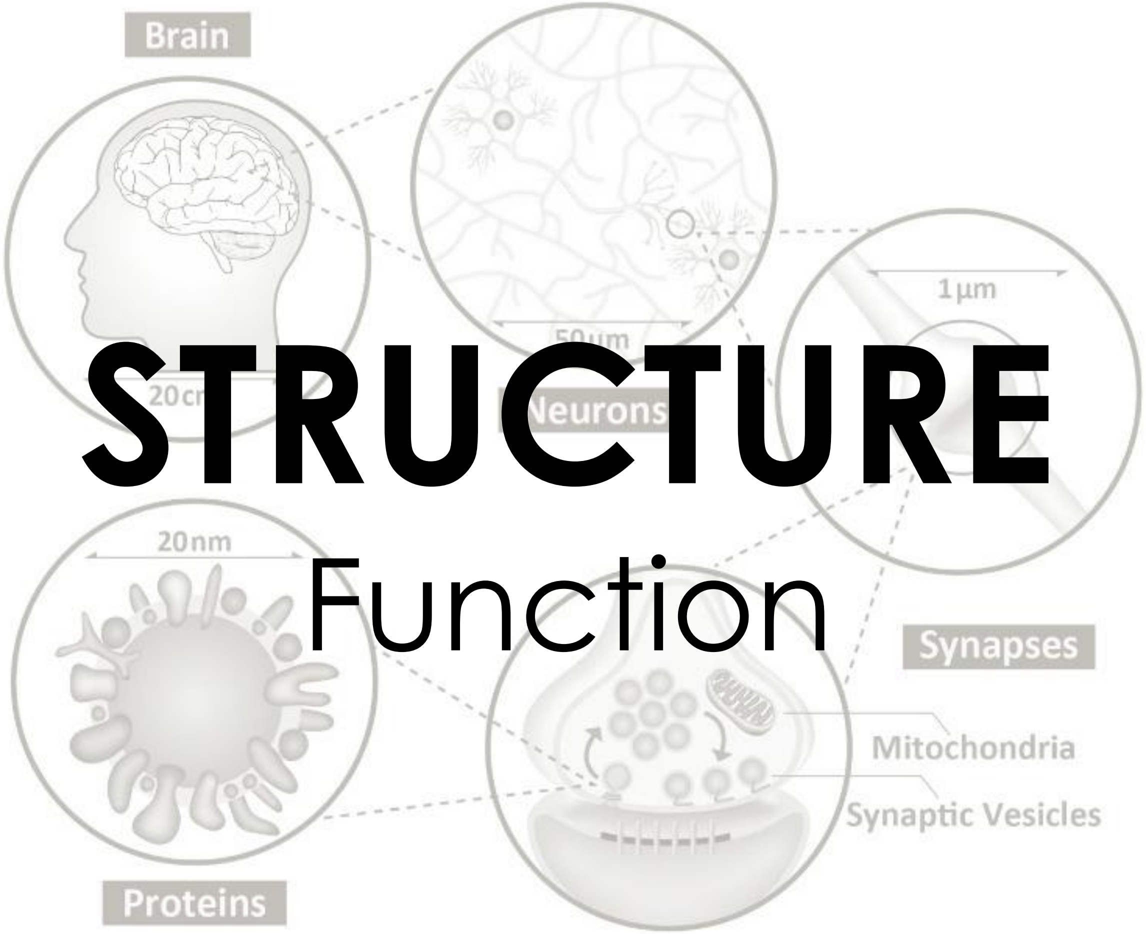
Thought/higher reasoning: allows to engage in decision-making and problem-solving



Cognitive Neuroscience

The interdisciplinary field that studies the neural basis of cognition, seeking to understand how the nervous system gives rise to mental processes.

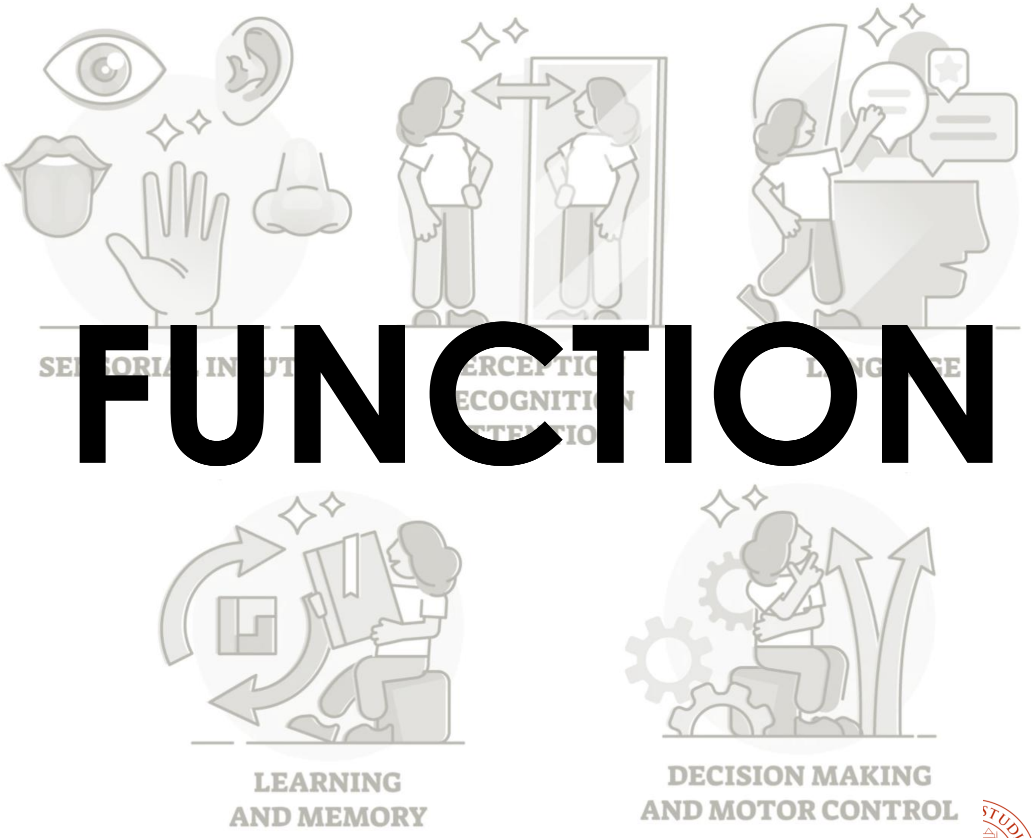
Neuroscience



STRUCTURE

Function

Cognition

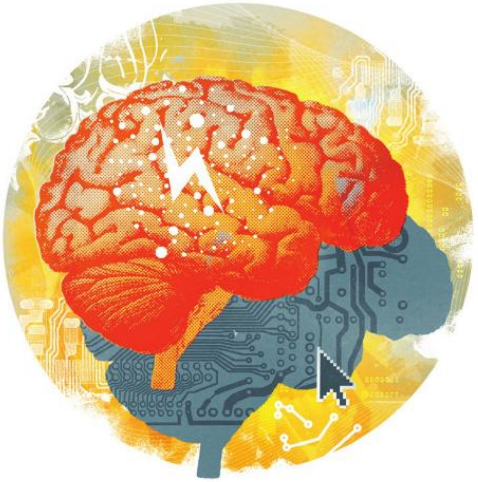


FUNCTION

Why is there a cognitive neuroscience course in an AI degree?

Is the brain a good model for machine intelligence?

Is the brain a good model for machine intelligence?



Is the brain a good model for machine intelligence?

To celebrate the centenary of the year of Alan Turing's birth, four scientists and entrepreneurs assess the divide between neuroscience and computing.

RODNEY BROOKS
Avoid the cerebral blind alley

Emeritus professor of robotics, Massachusetts Institute of Technology

I believe that we are in an intellectual cul-de-sac, in which we model brains and computers on each other, and so prevent ourselves from having deep insights that would come with new models.

The first step in this back and forth was made by Alan Turing. In his 1936 paper[1] laying the foundations of computation, Turing used a person as the basis for his model. He abstracted the actions of a human 'computer' using paper and pencil to perform a calculation (as the word meant then) into a formalized machine, manipulating symbols on an infinite paper tape.

But there is a worry that his version of computation, based on functions of integers, is limited. Biological systems clearly differ. They must respond to varied stimuli over long periods of time; those responses in turn alter their environment and subsequent stimuli. The individual behaviours of social insects, for example, are affected by the structure of the home they build and the behaviour of their siblings within it.

Nevertheless, for 70 years, those people working in what is now called computational neuroscience have assumed that the brain is a computer — a machine that is equivalent to Turing's finite-state machine with an infinite tape and a finite symbol set, and that does computation.

In 1943, Warren McCulloch and Walter Pitts[2] noted the "all-or-none" nature of the firing of neurons in a nervous system, and suggested that networks of neurons could be modelled as logical propositions. They modelled a network of neurons as circuits of logic gates, noting that these may "compute only such numbers as can a Turing machine". But more, they proposed that everything at a psychological level happens in these networks. Over the decades, such ideas begat more studies in neural networks, which in turn begat computational neuroscience. Now those metaphors and models pervade explanations of how the brain 'computes'. But these binary abstractions do not capture all the complexities inherent in the brain.

So now I see circles before my eyes. The brain has become a digital computer; yet we are still trying to make our machines intelligent. Should those machines be modelled on the brain, given that our models of the brain are performed on such machines? That will probably not be enough.

When you are stuck, you are stuck. We will get out of this cul-de-sac, but it will take some brave and bright souls to break out of our circular confusions of models.

DEMIS HASSABIS
Model the brain's algorithms

Neuroscientist, computer-game producer and chess master, University College London

Alan Turing looked to the human brain as the prototype for intelligence. If he were alive today, he would surely be working at the intersection of natural and artificial intelligence.

Yet to date, artificial intelligence (AI) researchers have mostly ignored the brain as a source of algorithmic ideas. Although in Turing's time we lacked the means to look inside this biological 'black box', we now have a host of tools, from functional magnetic resonance imaging to optogenetics, with which to do so.

Neuroscience has two key contributions to make towards progress in AI. First, the many structures being discovered in the brain — such as grid cells used for navigation, or hierarchical cell layers for vision processing — may inspire new computer algorithms and architectures. Second, neuroscience findings may validate the plausibility of existing algorithms being integral parts of a general AI system.

To advance AI, we need to better understand the brain's workings at the algorithmic level — the representations and processes that the brain uses to portray the world around us. For example, if we knew how conceptual knowledge was formed from perceptual inputs, it would crucially allow for the meaning of symbols in an artificial language system to be grounded in sensory 'reality'.

AI researchers should not only immerse themselves in the latest brain research, but also conduct neuroscience experiments to address key questions such as: "How is conceptual knowledge acquired?" Conversely, from a neuroscience perspective, attempting to distil intelligence into an algorithmic construct may prove to be the best path to understanding some of the enduring mysteries of our minds, such as consciousness and dreams.

TURING AT 100
A legacy that spans science:
nature.com/turing

DENNIS BRAY
Brain emulation requires cells

Department of Physiology, Development and Neuroscience, University of Cambridge

Machines can match us in many tasks, but they work differently from networks of nerve cells. If our aim is to build machines that are ever more intelligent and dexterous, then we should use circuits of copper and silicon. But if our aim is to reproduce the human brain, with its quirky brilliance, capacity for multitasking and sense of self, we have to look for other materials and different designs.

Computers outperform us in complex mathematical calculations and are better at storing and retrieving data. We accept that they can beat us at chess — once regarded as the apogee of human intellect. But the success of a computer called Watson in US television quiz show *Jeopardy!* in 2011 was a nail in the coffin of human superiority. The machine beat two human contestants by answering questions posed in colloquial English, making sense of cultural allusions, metaphors, puns and jokes. If Alan Turing had been given a transcript of the show, would he have spotted the odd one out?

Watson may be the latest vindication of Turing's view of intellectual processes as a series of logical states. But its internal workings are not based on the human brain. Broad similarities in organization might be imposed by the nature of the task, but most software engineers neither know nor care about anatomy or physiology. Even biologically inspired approaches such as cellular automata, genetic algorithms and neural networks have only a tenuous link to living tissue.

In 1944, Turing confessed his dream of building a brain, and many people continue in that endeavour to this day. Yet any neurobiologist will view such attempts as naive. How can you represent a neuronal synapse — a complex structure containing hundreds of different proteins, each a chemical prodigy in its own right and arranged in a mare's nest of interactions — with a single line of code? We still do not know the detailed circuitry of any region of the brain well enough to reproduce its structure. Brains are special. They steer us through the world, tell us what to do or say, and perform myriad vital functions. Brains are the source of our emotions, motivation, creativity and consciousness. Because no one knows how to reproduce any of these features in an artificial machine, we must consider that something important is missing from the canonical microchip.

Brains differ from computers in a number of key respects. They operate in cycles rather than in linear chains of causality, sending and receiving signals back and forth. Unlike the hardware and software of a machine, the mind and brain are not distinct entities. And then there is the question of chemistry.

Living cells process incoming sensory information and generate not just electrical signals but subtle biochemical changes. Cells are soft, malleable and built from an essentially infinite variety of macromolecular species quite unlike silicon chips. Organisms encode past experiences in distinct cellular states — in humans these are the substrate of goal-oriented movements and the sense of self. Perhaps machines built from cell-like components would be more like us.

AMNON SHASHUA
Speed will trump brain's advantages

Sachs Professor of Computer Science, Hebrew University of Jerusalem, and co-founder and chairman of Mobileye

The saying that "people who are really serious about software should make their own hardware", attributed to computer scientist Alan Kay in the 1980s, still rings true today. The idea that the function and form of computing architecture should serve each other is at the root of algorithms in signal processing, image rendering, gaming, video compression and streaming. I believe that it is also true for the human brain — meaning that the brain does not implement 'intelligence' in the same way as a computer.

Two of the many fundamental differences between the brain and the computer are memory and processing speed. The analogue of long-term memory in a computer is the hard disk, which can store practically unlimited amounts of data. Short-term information is held in its random access memory (RAM), the capacity of which is astronomical compared with the human brain. Such quantitative differences become qualitative when considering strategies for intelligence.

> "Signals in the brain are transmitted at a snail's pace."

Intelligence is manifested by the ability to learn. Machine-learning practitioners use 'statistical learning' which requires a very large collection of examples on which to generalize. This 'frequentist' approach to probabilistic reasoning needs vast memory capacity and algorithms that are at odds with available data on how the brain works. For example, IBM computer Watson needed to consume terabytes of reference material to beat human contestants on *Jeopardy!*. Volvo's pedestrian-detection system (developed by Mobileye) learned to identify people by using millions of pictures. In both cases, the human brain is considerably more parsimonious in the reliance on data — something that does not constrain the computer.

In terms of processing power, the brain can reach about 10–50 petaflops — equivalent to hundreds of thousands of the most advanced Intel Core i7 CPUs. Yet signals in the brain are transmitted at a snail's pace — five or six orders of magnitude slower than modern CPUs. This huge difference in communication speed drives vastly different architectures.

The brain compensates for the slow signal speed by adopting a hierarchical parallel structure, involving successive layers with increasing receptive field and complexity. By comparison, a computer architecture is usually flat and, because of its much faster clock rate, can employ brute-force techniques. Computer chess systems such as Deep Blue use pattern-recognition strategies, such as libraries of opening moves and completely solved end-games, complemented by their ability to evaluate the outcomes of some 200 million moves per second. This is way beyond the best grandmaster.

An intimate understanding of how cognitive tasks are performed at an algorithmic level would allow artificial intelligence to grow in leaps and bounds. But we must bear in mind that the vastly different architecture of the computer favours strategies that make optimal use of its practically unlimited memory capacity and brute-force search. ■

1. Turing, A. M. *Proc. Lond. Math. Soc.* **s2-42**, 230–265 (1936–37).
2. McCulloch, W. S. & Pitts, W. H. *Bull. Math. Biophys.* **5**, 115–133 (1943).

© 2012 Macmillan Publishers Limited. All rights reserved

Nature, 2012

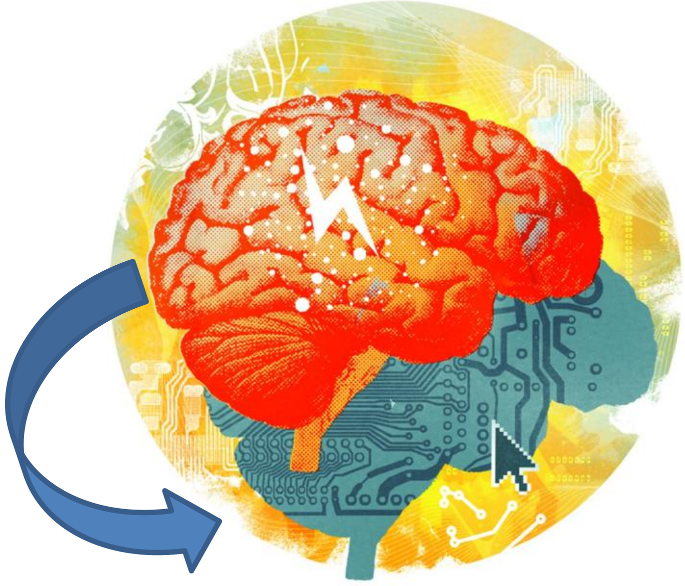
Celebrating 100 years from Alan Turing birth

Brooks R, Hassabis D, Bray D, Shashua A. Turing centenary: Is the brain a good model for machine intelligence? Nature. 2012 Feb 22;482(7386):462-3. doi: 10.1038/482462a. PMID: 22358812.

Why use the (human) brain as model for artificial intelligence?

- The **human brain** is the existing **proof that general intelligence is even possible**

- Studying **animal cognition** and its **neural implementation** can provide a **window into** different aspects of higher-level **general intelligence**



Functional similarities

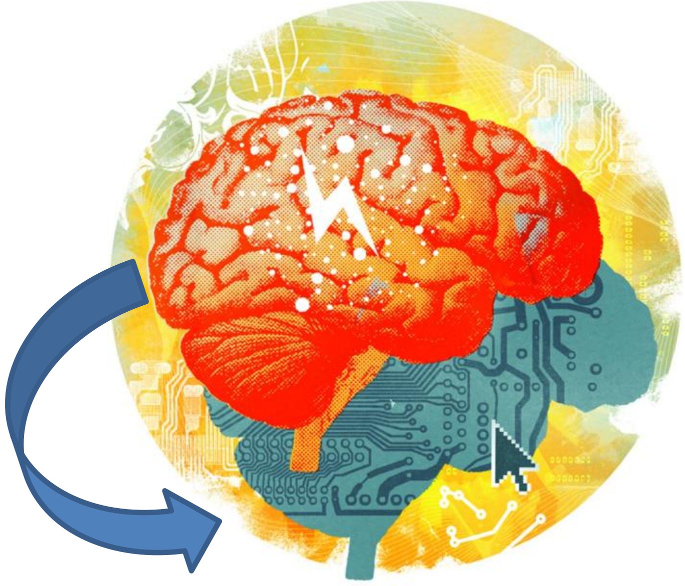
- The "all-or-none" nature of the firing of neurons in a nervous system is analogous to binary computations
    - But these binary abstractions do not capture all the complexities inherent in the brain.

Why use the (human) brain as model for artificial intelligence?

Neuroscience can provide

- **inspiration for new** types of **algorithms and architectures**
  - independent of and complementary to the mathematical and logic-based methods and ideas that have largely dominated traditional approaches to AI

- **validation of AI** techniques that already exist
  - A known algorithm that is found to be implemented in the brain gives strong support for its plausibility as an integral component of an overall general intelligence system



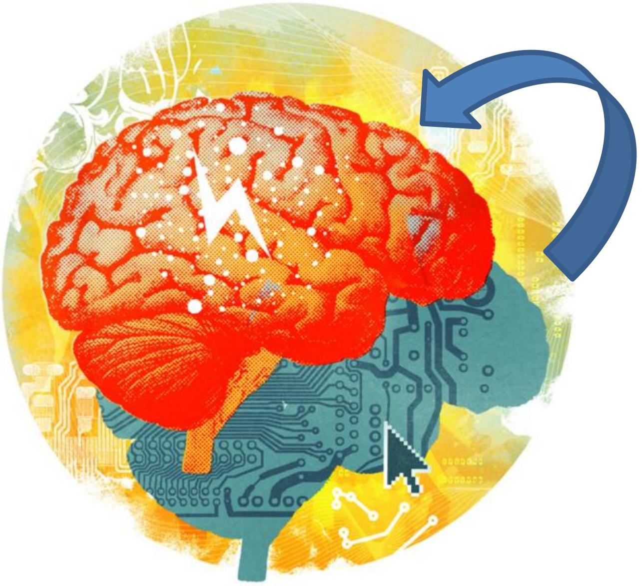
Note that…also AI can provide insights on the functioning of brains

ARTICLES
https://doi.org/10.1038/s41593-018-0147-8
nature neuroscience

Prefrontal cortex as a meta-reinforcement learning system

Jane X. Wang[1,5], Zeb Kurth-Nelson[1,2,5], Dharshan Kumaran[1,3], Dhruva Tirumala[1], Hubert Soyer[1], Joel Z. Leibo[1], Demis Hassabis[1,4] and Matthew Botvinick[1,4*]

Over the past 20 years, neuroscience research on reward-based learning has converged on a canonical model, under which the neurotransmitter dopamine 'stamps in' associations between situations, actions and rewards by modulating the strength of synaptic connections between neurons. However, a growing number of recent findings have placed this standard model under strain. We now draw on recent advances in artificial intelligence to introduce a new theory of reward-based learning. Here, the dopamine system trains another part of the brain, the prefrontal cortex, to operate as its own free-standing learning system. This new perspective accommodates the findings that motivated the standard model, but also deals gracefully with a wider range of observations, providing a fresh foundation for future research.



Biomimicry: Technologies inspired by nature

Emulation of the models, systems, and elements of nature for the purpose of solving complex human problems.

Living organisms have evolved well-adapted structures and materials over geological time through natural selection.

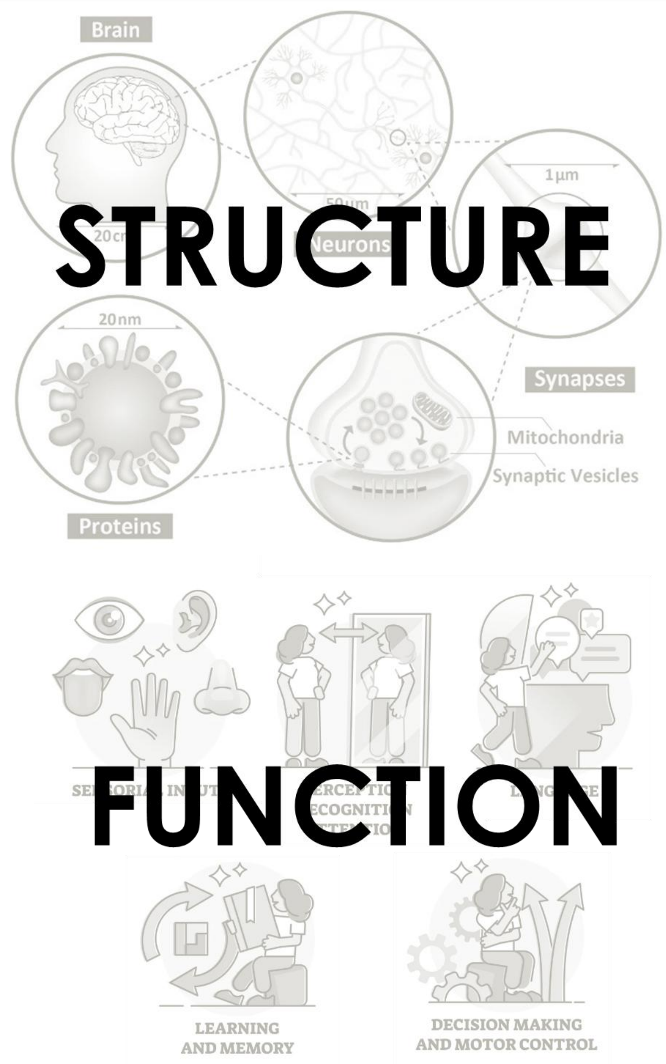
https://youtu.be/iMtXqTmfta0

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

BUT the animal brain is not necessarily a good model for AI

Brains differ from computers in several key respects

- Unlike the **hardware and software** of a machine, the mind and brain are not distinct entities.
- The **human brain does not implement 'intelligence' in the same way as a computer**
  - **Machine-learning** practitioners use '**statistical learning'** which requires a very large collection of examples on which to generalize --> **vast memory capacity.** [But see meta-reinforcement learning]
  - The **brain has limited memory capacity**, yet humans **excel at generalizing** or transferring generalized knowledge gained in one context to novel, previously unseen domains



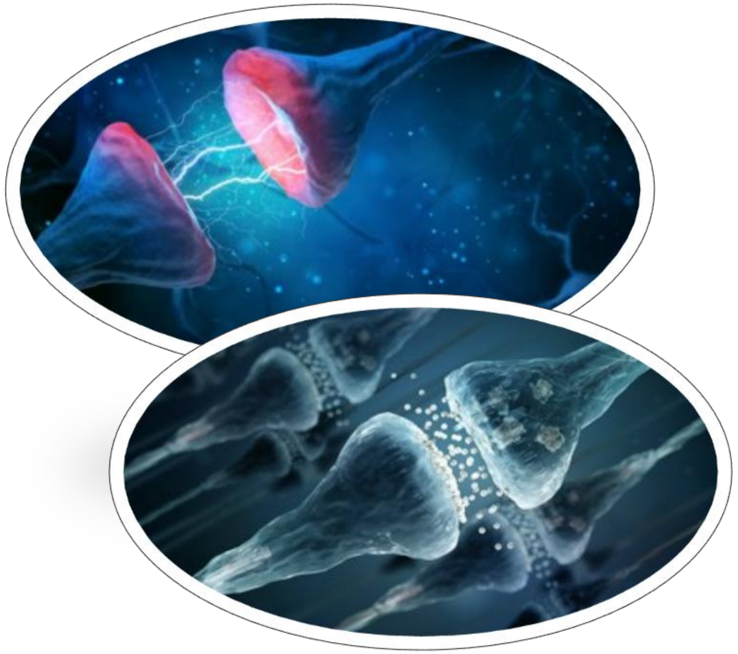
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

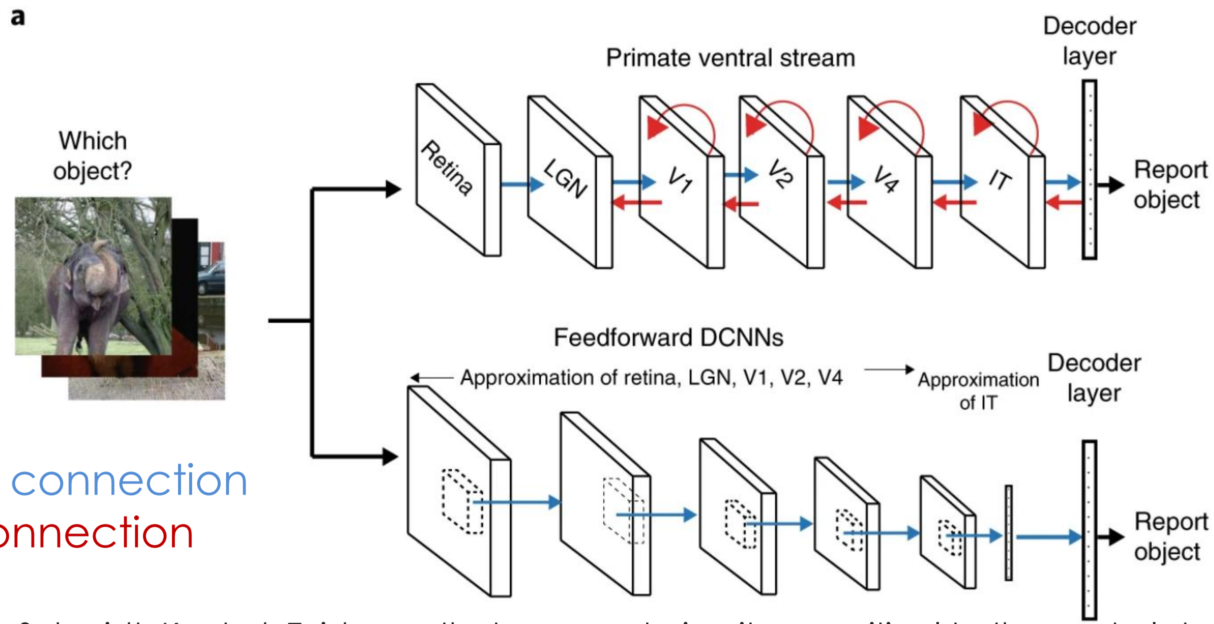
BUT the animal brain is not necessarily a good model for AI

Brains differ from computers in several key respects

- Living cells process incoming sensory information and generate not just **electrical signals** but subtle **biochemical changes**.
- They operate in **cycles** rather than in linear chains of causality, sending and receiving signals back and forth.

  --> recurrent components to neural networks





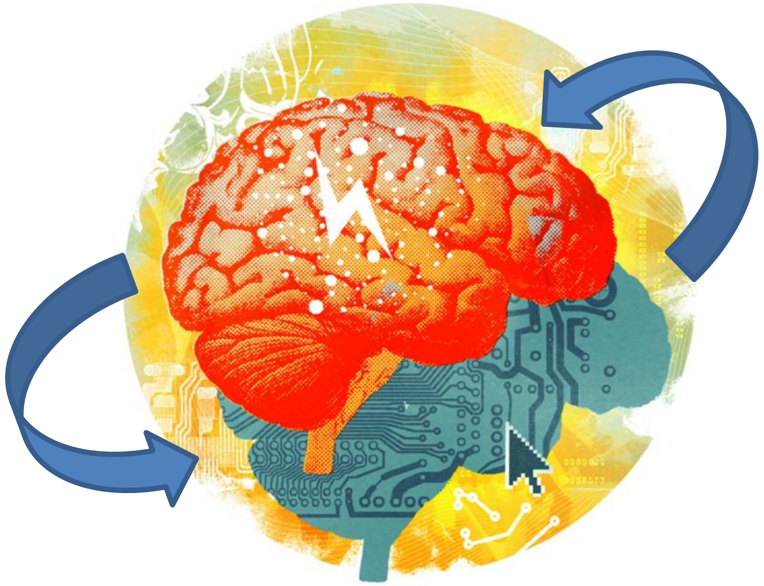
Feedforward connection
Feedback connection

Kar, K., Kubilius, J., Schmidt, K. *et al.* Evidence that recurrent circuits are critical to the ventral stream's execution of core object recognition behavior. *Nat Neurosci* **22**, 974–983 (2019). https://doi.org/10.1038/s41593-019-0392-5

BUT the animal brain is not necessarily a good model for AI

- We **model brains and computers on each other**, and so prevent ourselves from having deep insights that would come with new models.

- **From an engineering perspective, what works is ultimately all that matters.**
    - We need not slavishly enforce adherence to biological plausibility.
    - We still do not know the detailed circuitry of any region of the brain well enough to reproduce its structure.



Different levels of brain emulation

STRUCTURE

Closely **mimic or directly reverse engineer the specifics of neural circuits**

Blue Brain Project (Markram, 2006) aims to build biologically detailed digital reconstructions and simulations of the mouse brain

Biologically-detailed digital reconstructions and simulations of the mammalian brain to identify the fundamental principles of brain structure and function

FUNCTION

Mimic the **computational and algorithmic levels of neural systems**, to gain transferrable insights into general mechanisms of brain function

Deep Mind (Hassabis, Legg, 2010)aims to create a general-purpose AI

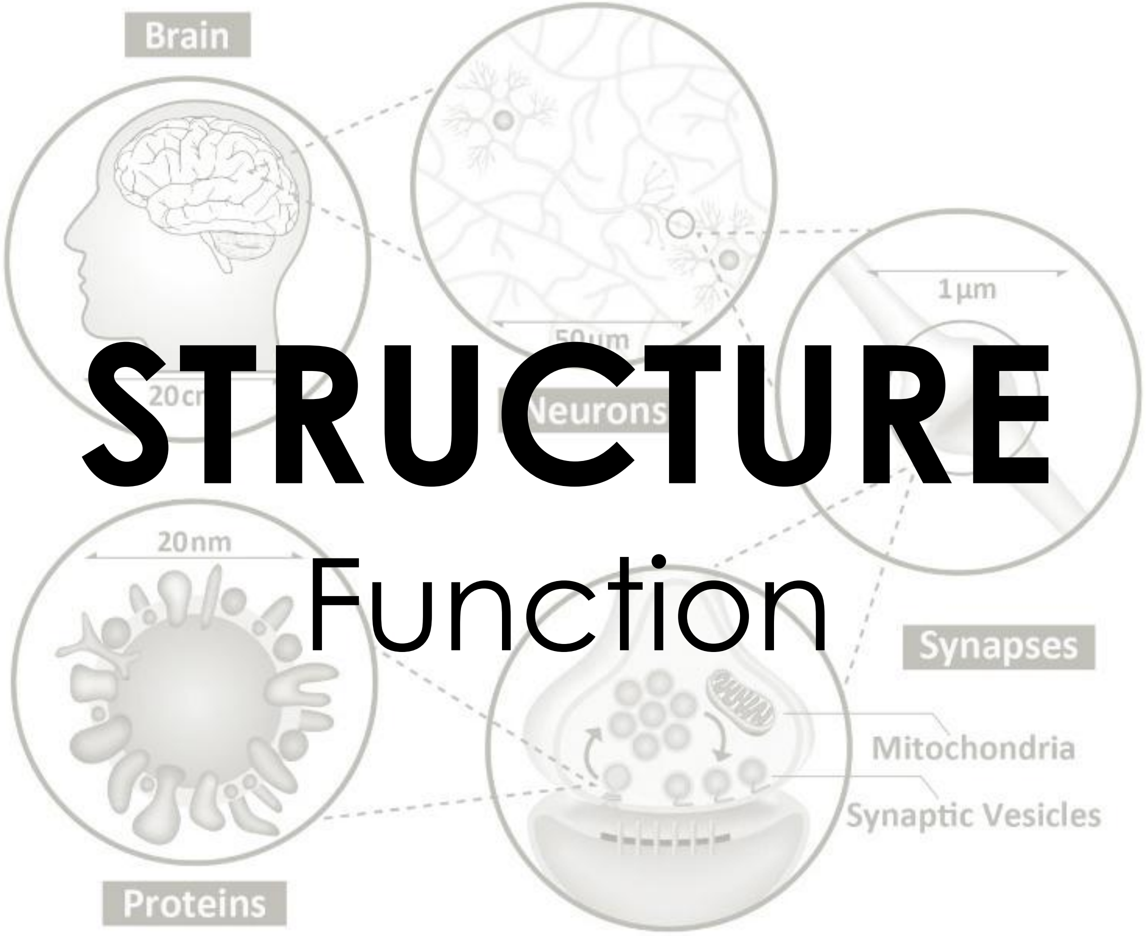
Systems neuroscience-level understanding of the brain, namely the algorithms, architectures, functions, and representations it utilizes.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

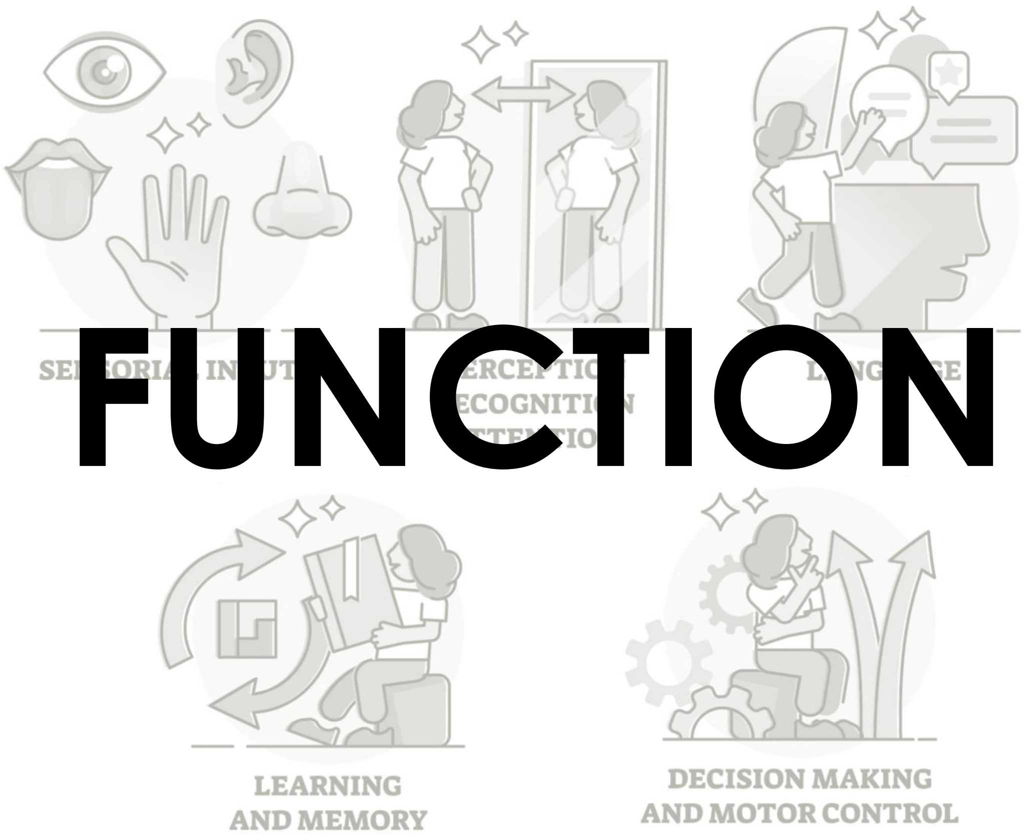
We will look at both

STRUCTURE

Function

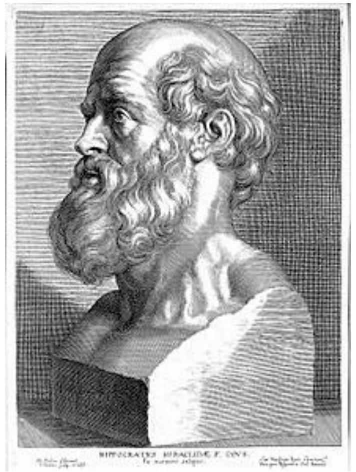


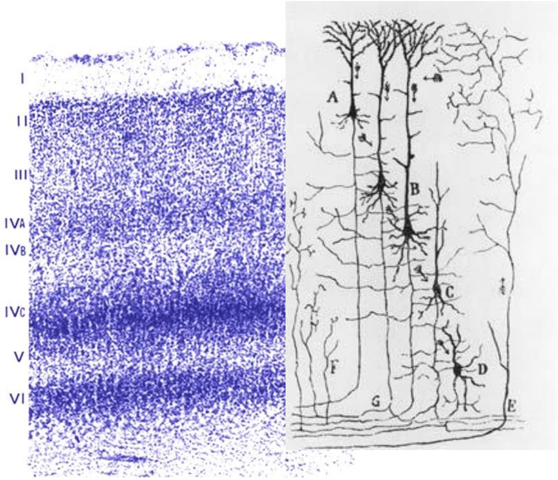
FUNCTION

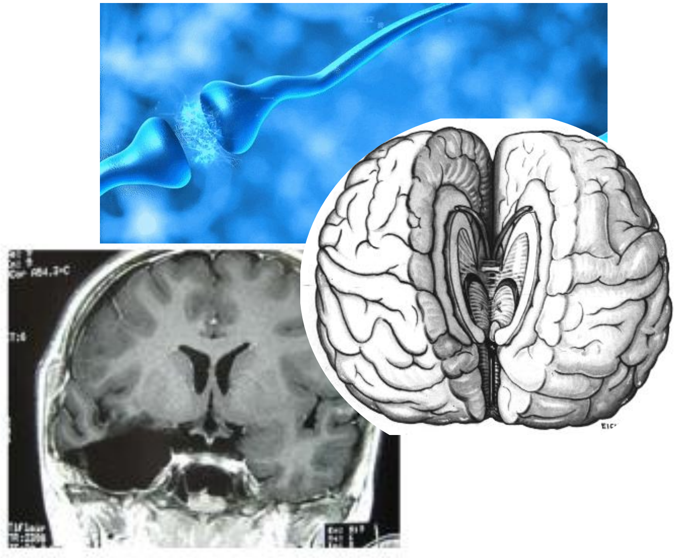


What is the evidence that structure and function are intimately related?

The history of cognitive neuroscience







800-500 BC

Late 1700-
Early 1800

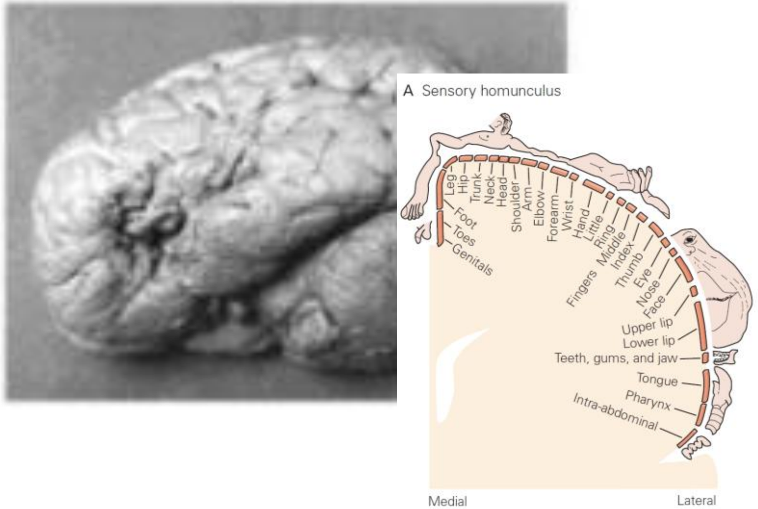
Late 1800s-
Early 1900s

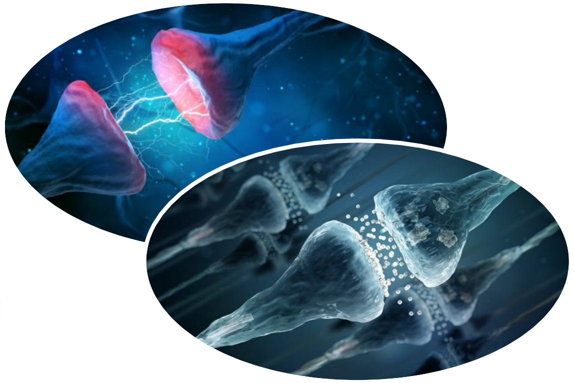
Mid-late
1900s

1650

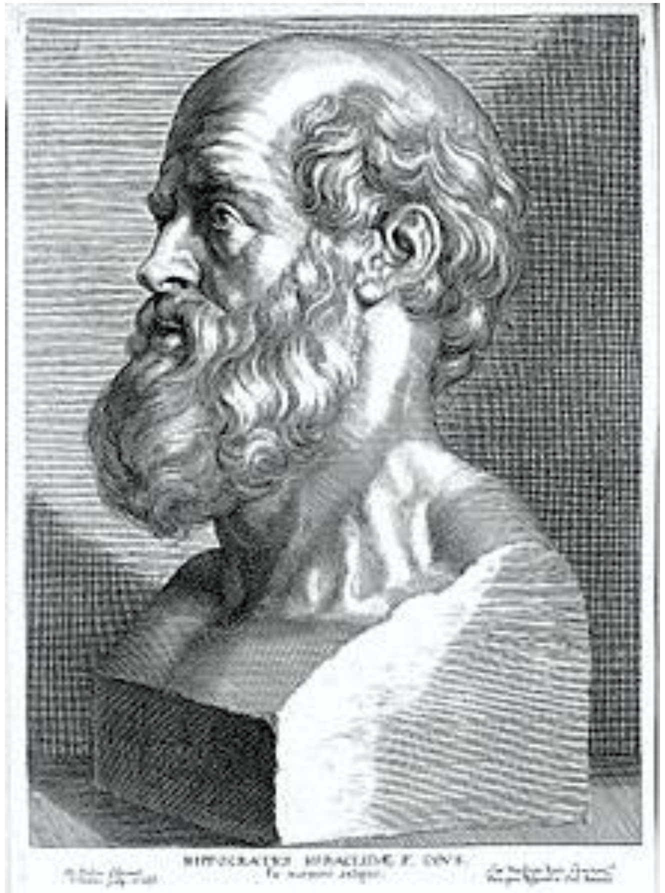
1830s-1870s

1930s





The Greeks



800 BC. The Homeric Greeks --> multiple souls were associated with different aspects of cognition, each located in different parts of our body

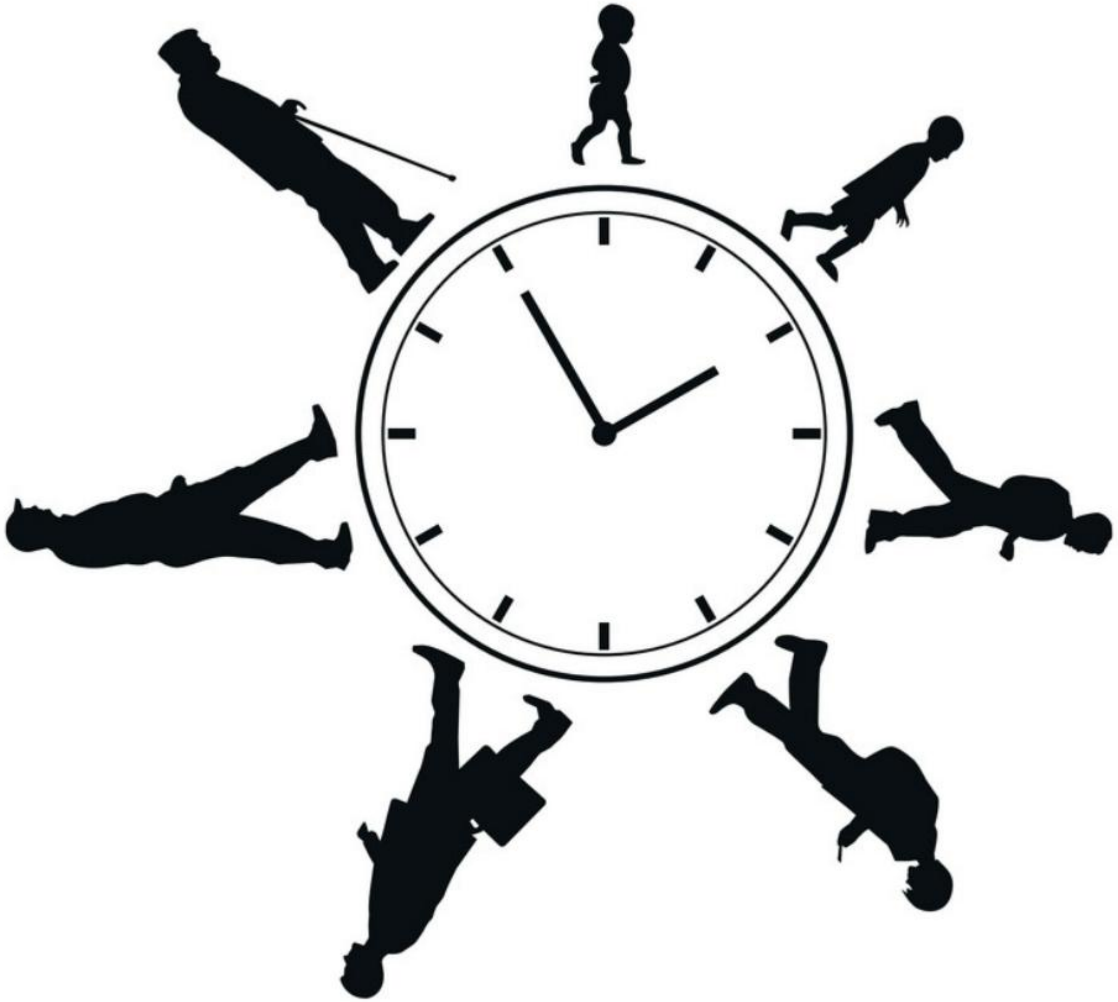
500 BC. 2 camps of though:

Cardiocentrism

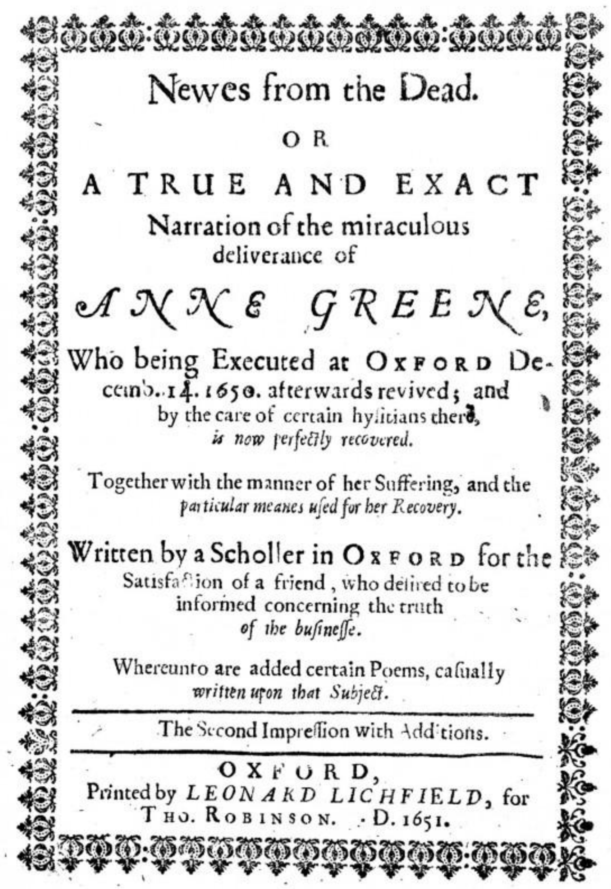
Encephalocentrism

- Theon of Croton dissected animals and noticed that the nerves were sending information to the brain
- Hippocrates noticed that brain injuries affected mental abilities → localized intellect and neurological diseases in the brain

Many many many years later...



The story of Anne Green



Newes from the Dead.

OR

A TRUE AND EXACT
Narration of the miraculous
deliverance of

ANNE GREENE,

Who being Executed at OXFORD Decemb. 14. 1650. afterwards revived; and by the care of certain Physitians there, is now perfectly recovered.

Together with the manner of her Suffering, and the particular meanes used for her Recovery.

Written by a Scholler in OXFORD for the Satisfaction of a friend, who desired to be informed concerning the truth of the businesse.

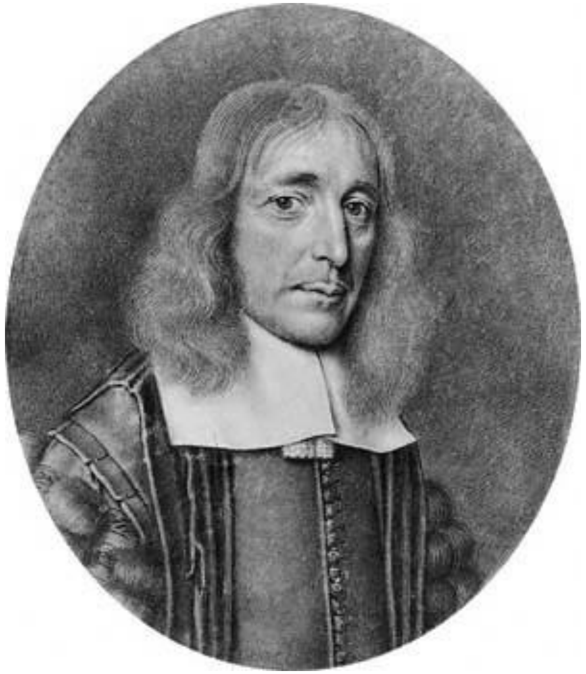
Whereunto are added certain Poems, casually written upon that Subject.

The Second Impression with Additions.

OXFORD,
Printed by LEONARD LICHFIELD, for
THO. ROBINSON. A. D. 1651.

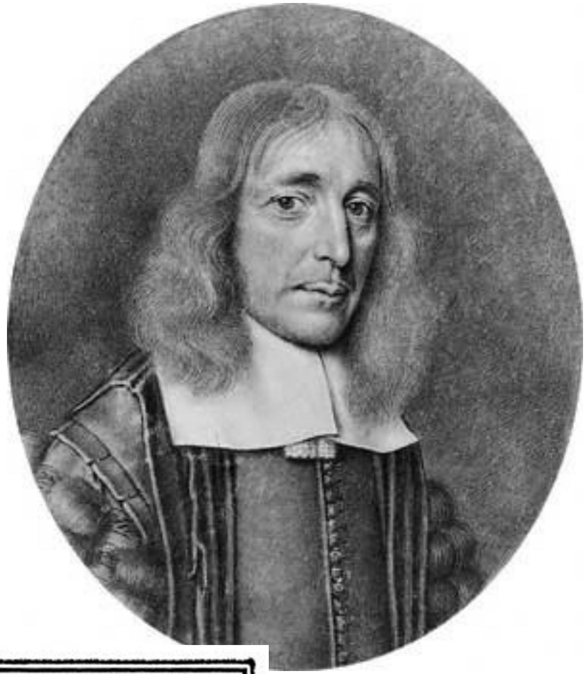
1650, Oxford, England

Thomas Willis (1621-1675)

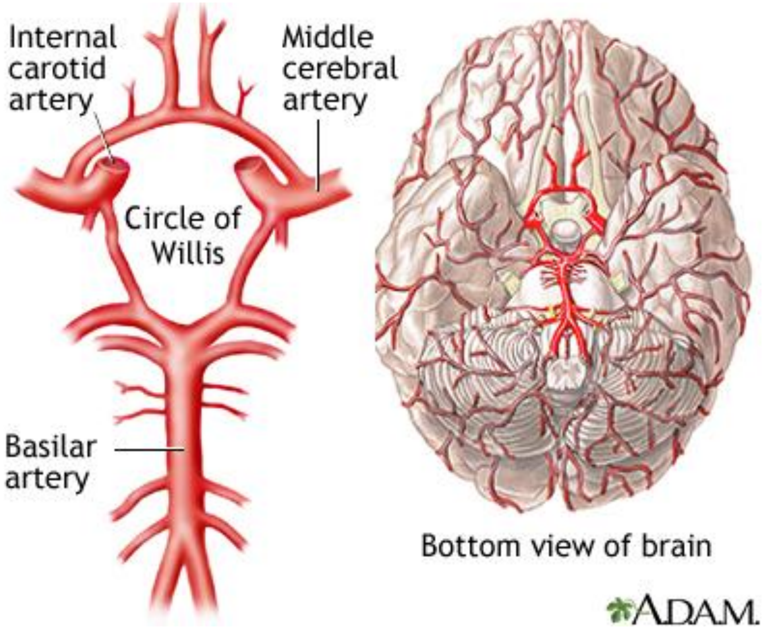


Thomas Willis (1621-1675)

Brain structure gives rise to function



- He was the **first** anatomist **to link abnormal human behaviors to changes in brain structure**. Foreshadowed cognitive neuroscience with the notion that isolated brain damage (neurology) could affect behavior (psychology)
- He coined the term neurology
- A pioneer in research into the anatomy of the brain, nervous system and muscles



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Brain structure gives rise to function

The brain was the organ of the mind and that innate faculties were localized in specific regions of the cerebral cortex → **localizationism**

Hypothesized that if a person used one of the faculties with greater frequency than the others, the part of the brain representing that function would grow,

Franz Joseph Gall (1758–1828)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Brain structure gives rise to function

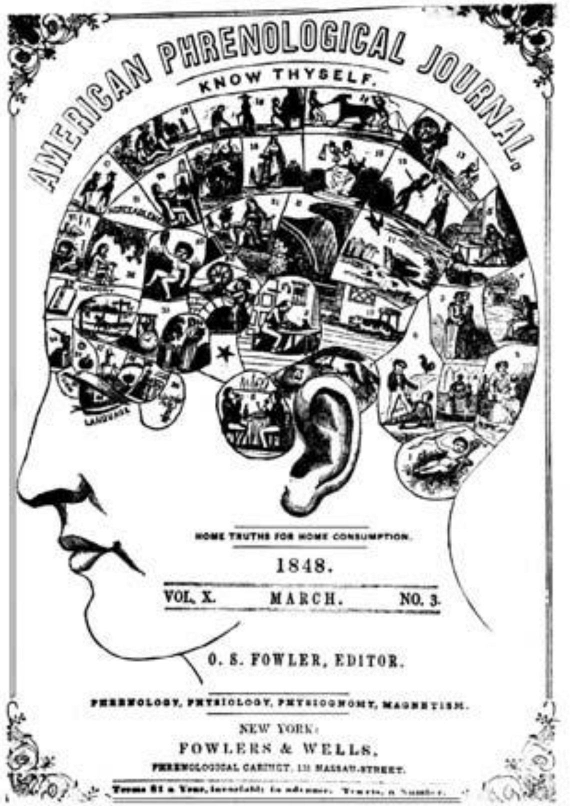
The brain was the organ of the mind and that innate faculties were localized in specific regions of the cerebral cortex → **localizationism**

Hypothesized that if a person used one of the faculties with greater frequency than the others, the part of the brain representing that function would grow, *causing a bump in the skull*.

Thus, a careful analysis of the skull could describe the personality of the person inside the skull.

Gall was the **father of ...**

Franz Joseph Gall (1758–1828)



Brain structure gives rise to function

The brain was the organ of the mind and that innate faculties were localized in specific regions of the cerebral cortex → **localizationism**

Hypothesized that if a person used one of the faculties with greater frequency than the others, the part of the brain representing that function would grow, *causing a bump in the skull.*

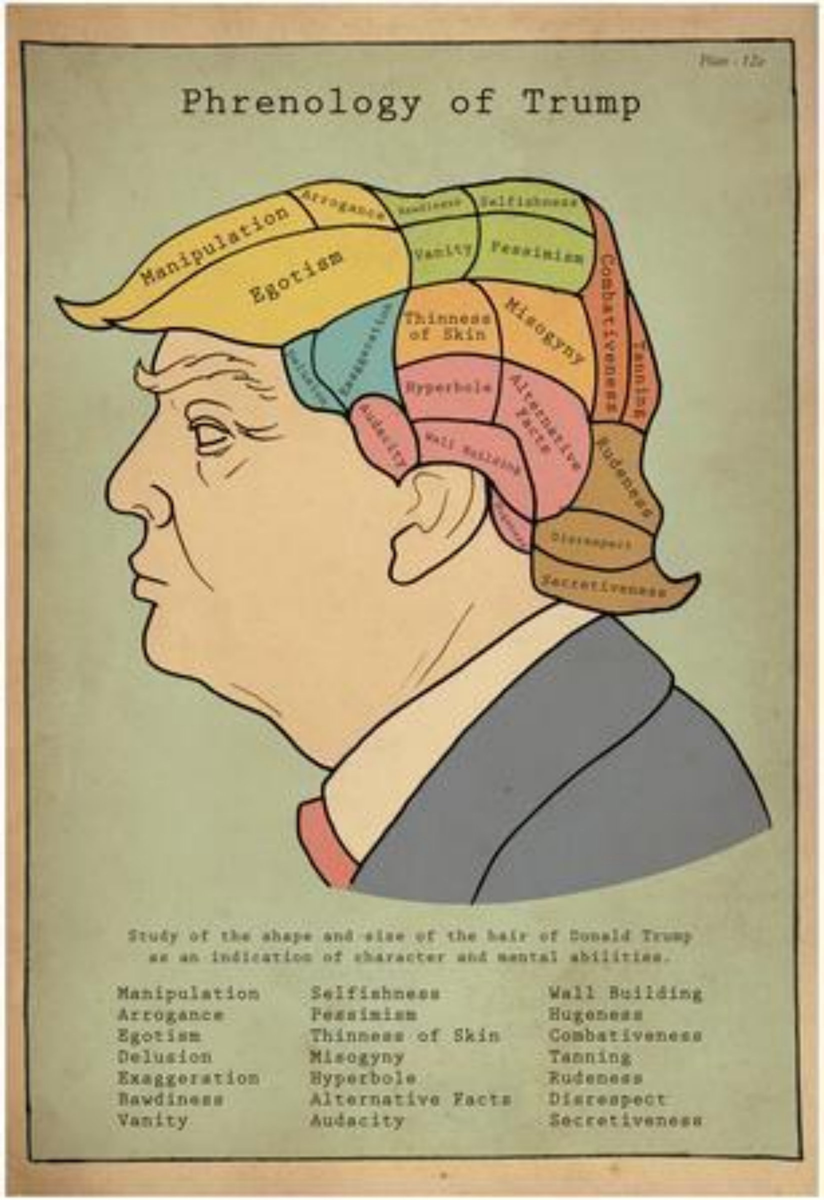
Thus, a careful analysis of the skull could describe the personality of the person inside the skull.

Gall was the **father of** … **Phrenology**

Phrenology is a pseudoscience

Gall was not a scientist.

He used only a **correlational approach** and sought to **confirm his hypotheses** rather than to disprove them.



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Napoleon
Bonaparte
(1769-1821)

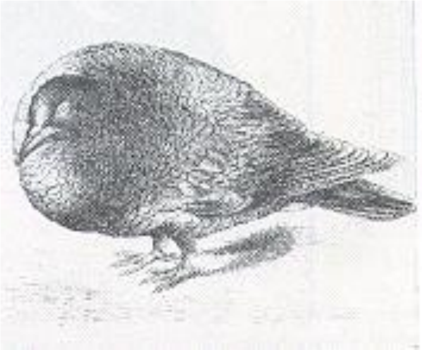
A scientific approach: causal inferences

Napoleonic government asked physiologist Marie-Jean-Pierre Flourens to test the validity of phrenology by collecting evidence using the scientific method.

He used a **causal approach**: he destroyed parts of the brains of pigeons (1814-1822) and rabbits and observed what happened. He was the first to show that indeed **certain parts of the brain were responsible for certain functions**.

He could not, however, find **any specific area for advanced abilities** such as memory or cognition, concluding that the whole brain participated in behavior → **aggregate field theory**

Napoleon Bonaparte (1769-1821)



Marie-Jean-Pierre Flourens (1794–1867)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Aggregate field theory & localizationism

Aggregate field theory

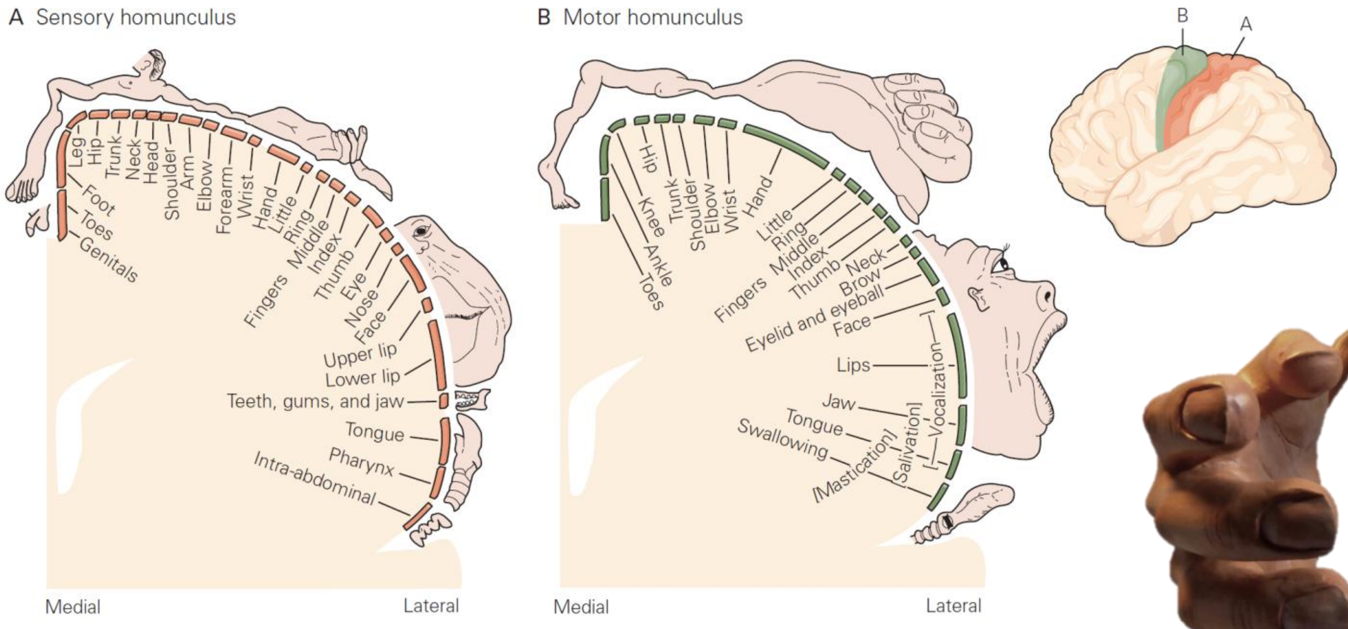
+

localizationism

Evidence in favor of localizationism

John Hughlings Jackson (1835–1911)

- **Epilepsy** progressed in an orderly manner from one part of the body to another
- Proposed a **topographic organization of the cortex**



John Hughlings Jackson (1835–1911)

Focal brain damage causes specific behavioral deficits

1836 **Marc Dax** reported about 3 patients, noting that each had speech disturbances and similar left–hemisphere lesions found at autopsy.

1861 **Paul Broca** published the results of his autopsy on a patient who had been nicknamed Tan

Paul Broca (1824–1880)

Tan had a lesion in his left hemisphere in the inferior frontal lobe

Tan had developed **expressive aphasia**

- Impaired language production (non-fluent aphasia)
- Preserved language comprehension
- usually aware of their communication deficits

A

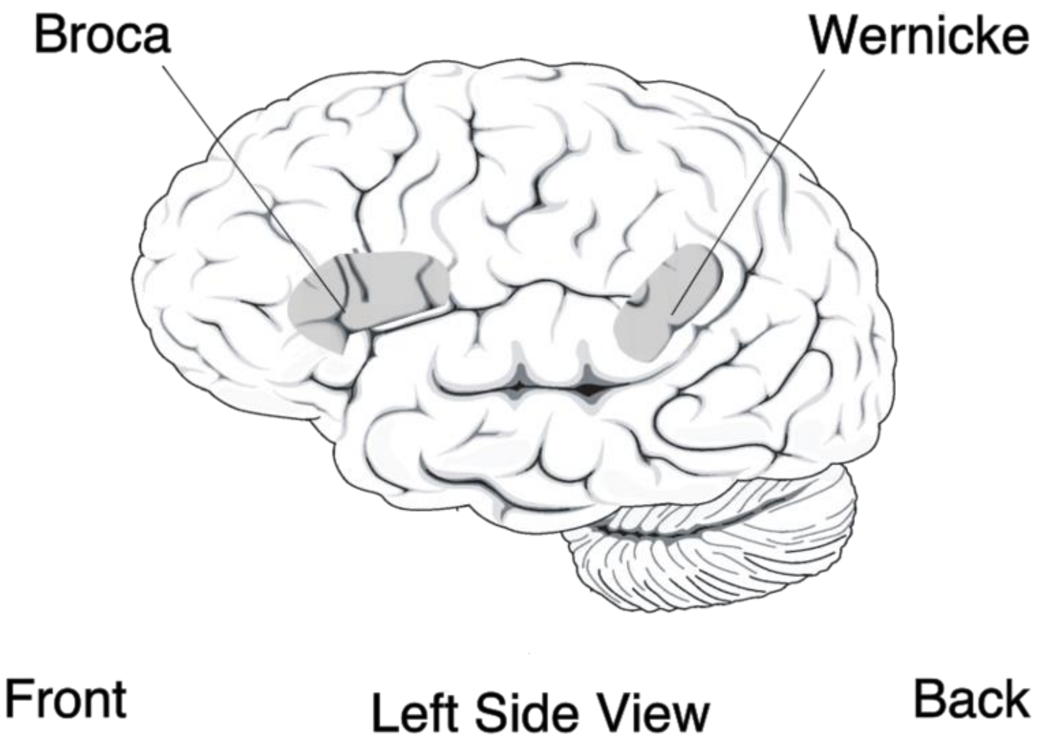
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

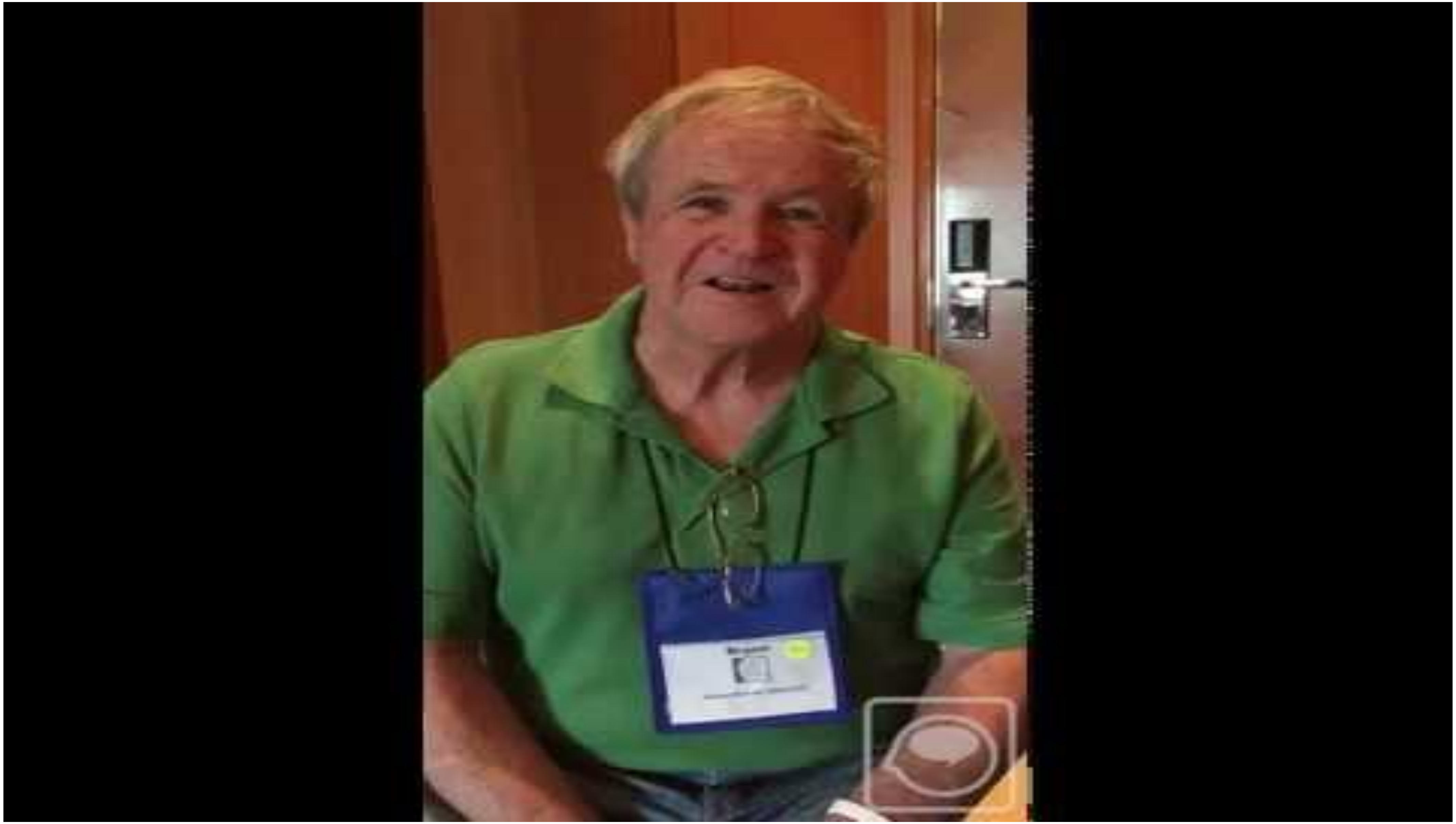
https://youtu.be/JWC-cVQmEmY

Focal brain damage causes specific behavioral deficits

1876 Carl Wernicke in Germany reported on a stroke victim who had **receptive aphasia**

- Impaired language comprehension
- Preserved - jumbled- language production (fluent aphasia)
- Often not aware of their incorrect productions



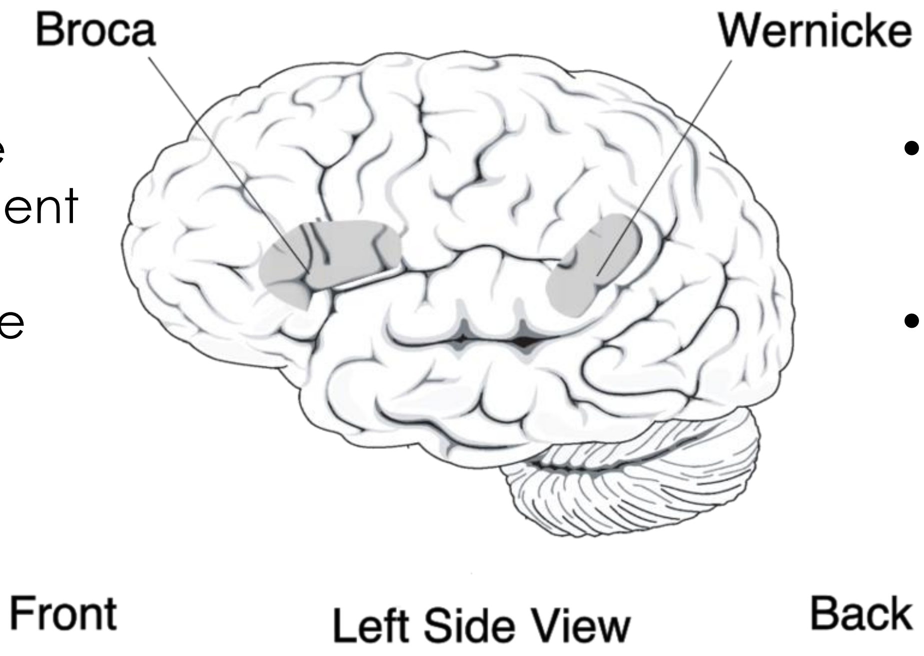


https://youtu.be/3oef68YabD0

Focal brain damage causes specific behavioral deficits

A specific aspect of language that was impaired by a specific lesion

- Impaired language production (non-fluent aphasia)
- Preserved language comprehension



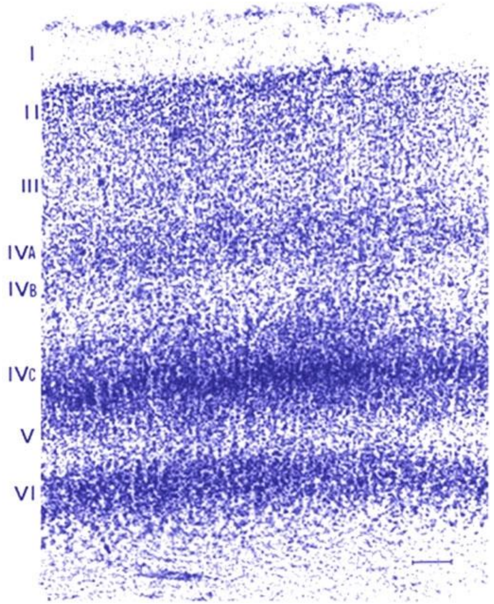
- Preserved - jumbled- language production (fluent aphasia)
- Impaired language comprehension

Double dissociation: group 1 is impaired on task X (but not task Y) and group 2 is impaired on task Y (but not task X)

The rise of molecular neuroscience

Given that different regions perform different functions, do they look different also in their structure?

Different regions of the brain are made of different neurons

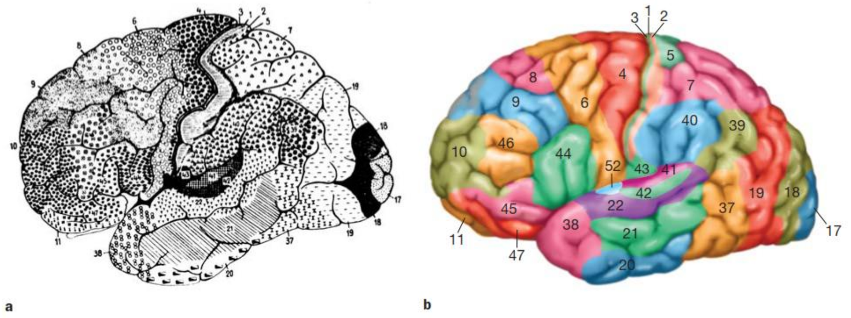


Korbinian Brodmann
1868-1918

Used tissue stains that permitted him to visualize the different cell types in different brain regions

Characterized 52 distinct regions

Cytoarchitectonics: the study of cellular architecture or how cells differ between regions



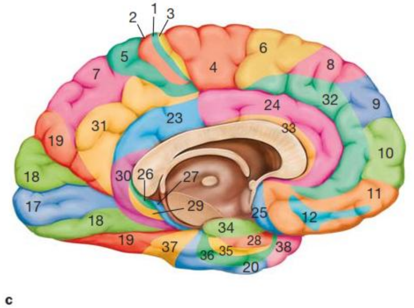


FIGURE 2.31 Cytoarchitectonic subdivisions of the human cerebral cortex.
(a) Brodmann's original cytoarchitectonic map from his work around the start of the 20th century. Different regions of cortex have been demarcated by histological examination of the cellular microanatomy. Brodmann divided the cortex into about 52 areas. **(b)** Lateral view of the right hemisphere showing Brodmann's areas color coded. Over the years, the map has been modified, and the standard version no longer includes some areas. **(c)** Medial view of the left hemisphere showing Brodmann's areas. Most of Brodmann's areas are symmetrical in the two hemispheres.

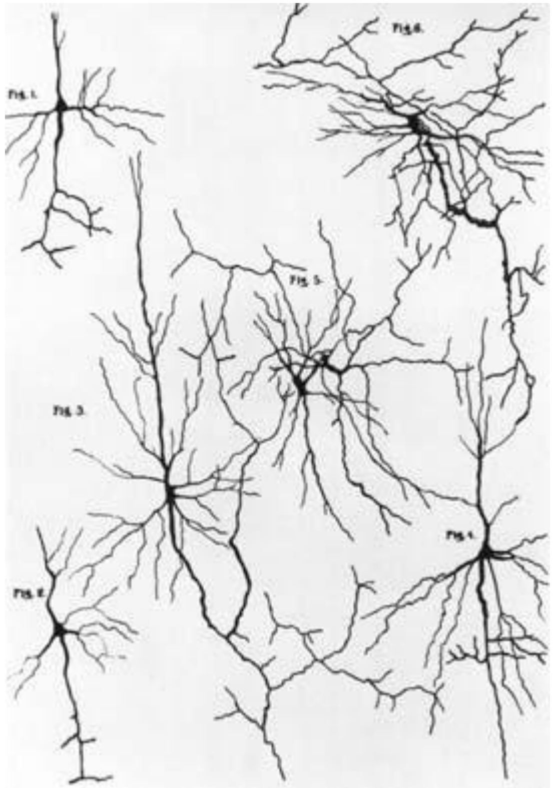
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

The rise of molecular neuroscience

The silver method for staining neurons— la reazione nera , “the black reaction,” that impregnated **individual neurons** with silver chromate

Stain **permits visualization of individual neurons** in their entirety

Camillo Golgi (1843–1926)



Golgi’s drawings of different types of ganglion cells in dog and cat.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

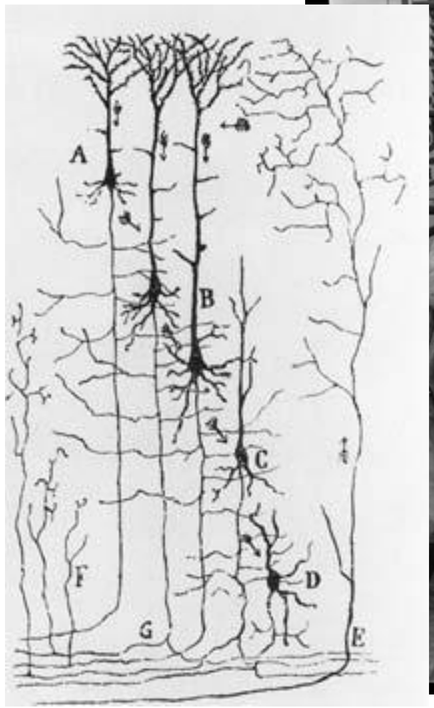
The neuron doctrine

Using Golgi's method, Cajal was the first to identify **the unitary nature of neurons**.

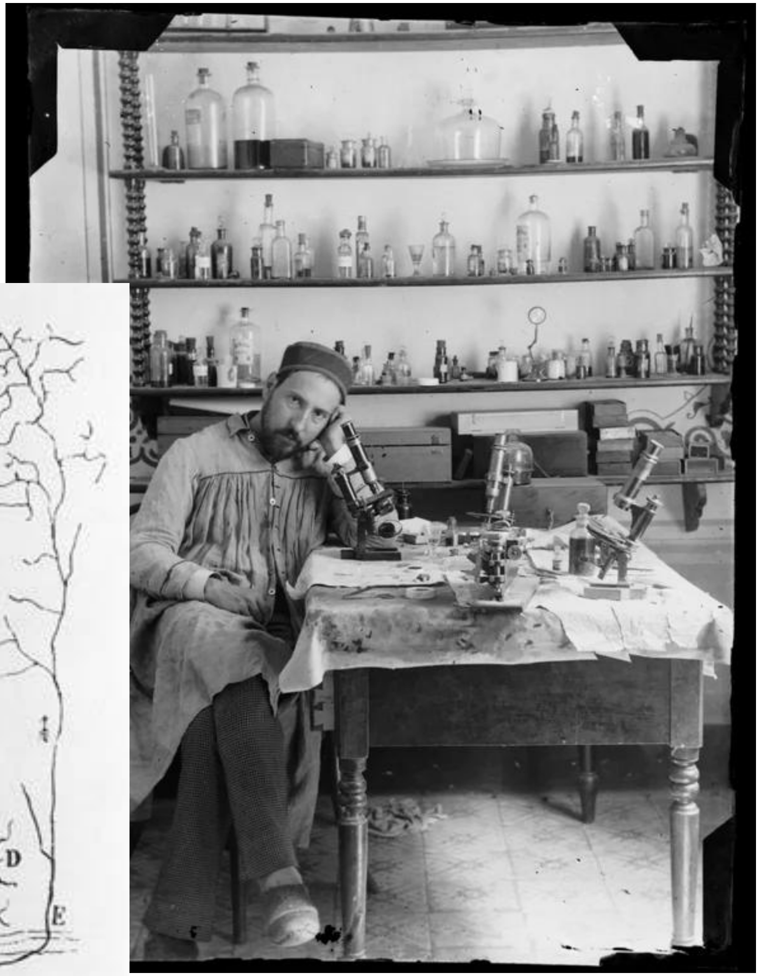
Neuron doctrine: the nervous system is made up of individual cells. Neurons are discrete entities.

Challenged Golgi who had believed that the whole brain was a **syncytium**, a continuous mass of tissue that shares a common cytoplasm.

Realized that the feature that most distinguishes one type of neuron from another is form, specifically the **number of the processes** arising from the cell body



Ramón y Cajal's drawing of the afferent inflow to the mammalian cortex

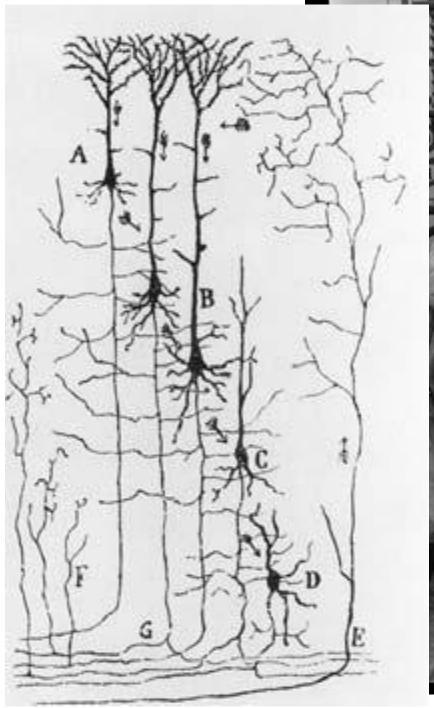


Santiago Ramón y Cajal (1852–1934)

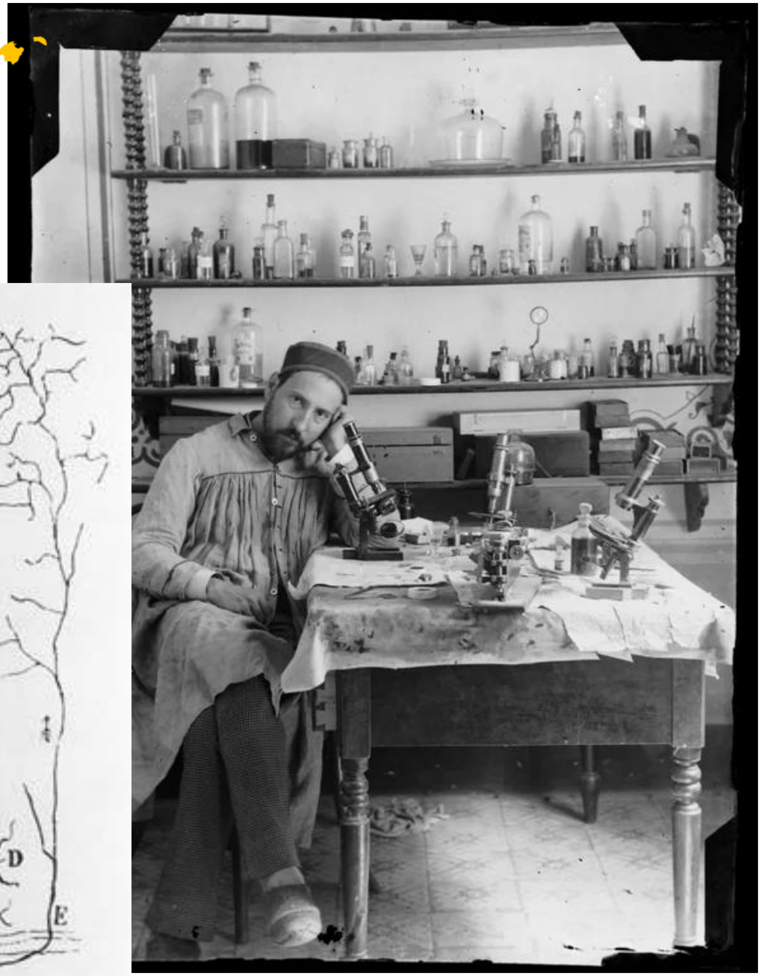
Two other principles of neural organization

1. **Principle of dynamic polarization:** electrical signals within a nerve cell **flow only in one direction**: from the receiving sites of the neuron, to its trigger region.

2. **Principle of connectional specificity:** nerve cells do not connect randomly with one another in the formation of networks. Rather, each cell makes **specific connections - at particular contact points -** with certain postsynaptic target cells but not with others.



Ramón y Cajal's drawing of the afferent inflow to the mammalian cortex

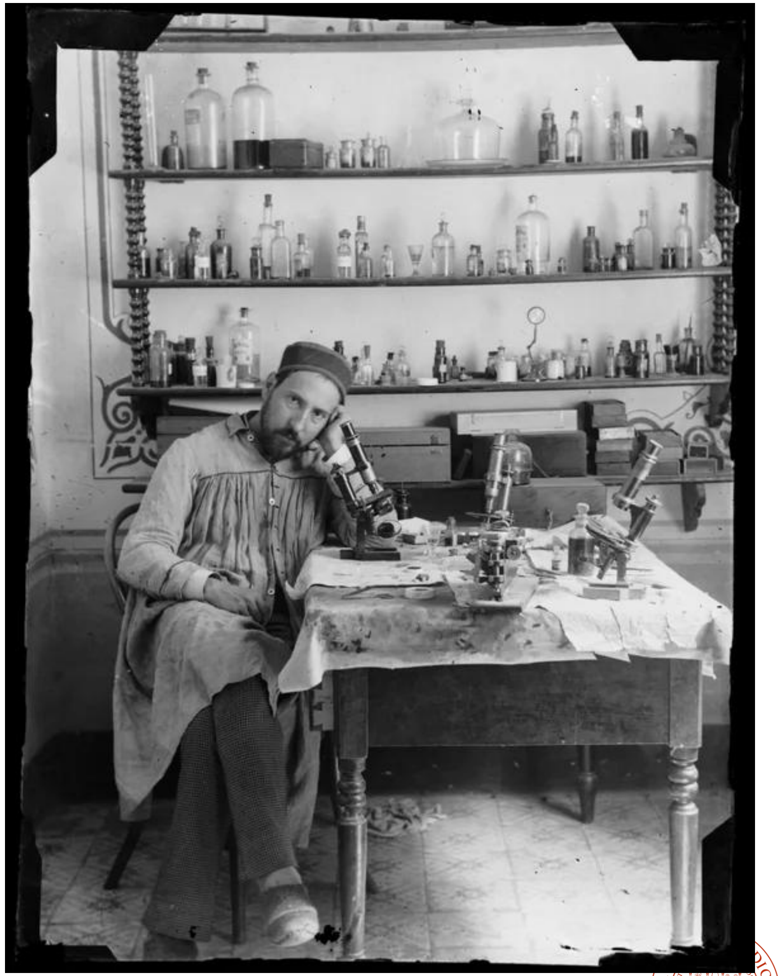


Santiago Ramón y Cajal (1852–1934)

The rise of molecular neuroscience

1906 Nobel Prize in Medicine

Camillo Golgi (1843–1926)

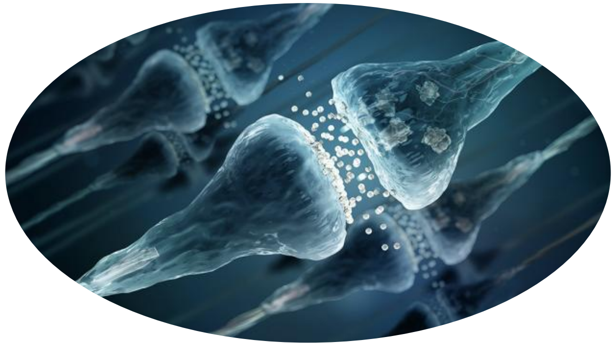


Santiago Ramón y Cajal (1852–1934)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

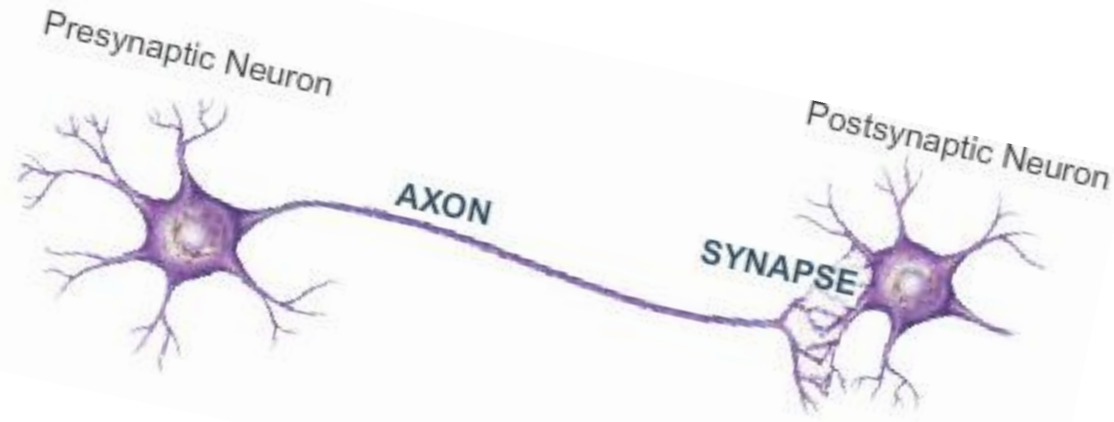
The synapse enables neuronal communication

Chemical synapse



Charles Sherrington realized that reflexes were not as fast as they should be if the nervous system was a continuous mass of tissue (syncytium) → Coined the term **synapse**

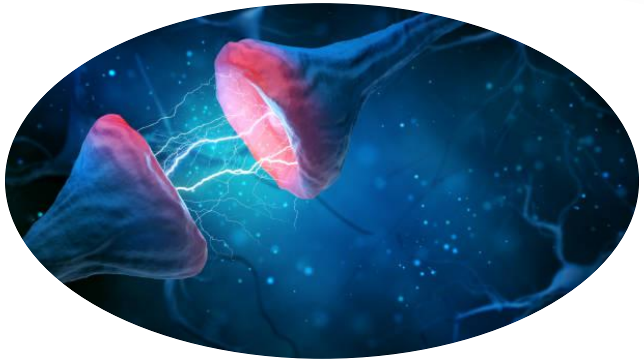
1930s **synaptic transmission "fight"**

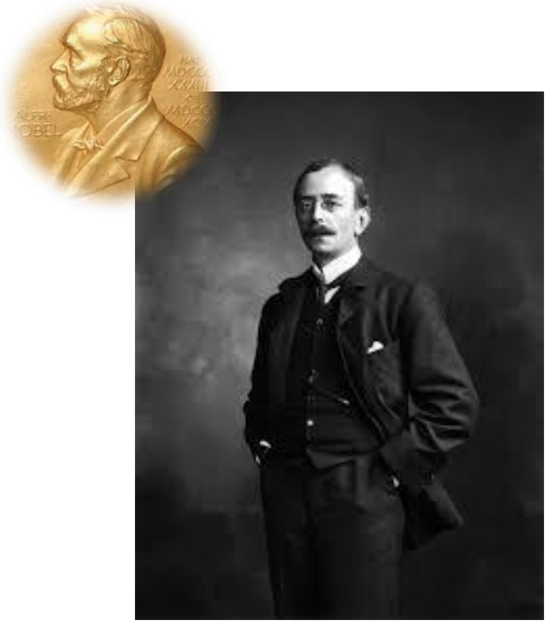


Henry Dale

Jhon Eccles

Electrical synapse

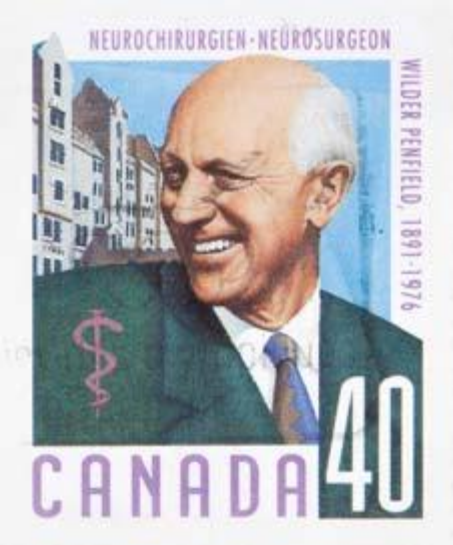




Charles Sherrington

Bridging brain structure and behavioral function

Surgically induced lesions: the Montreal procedure to treat epilepsy

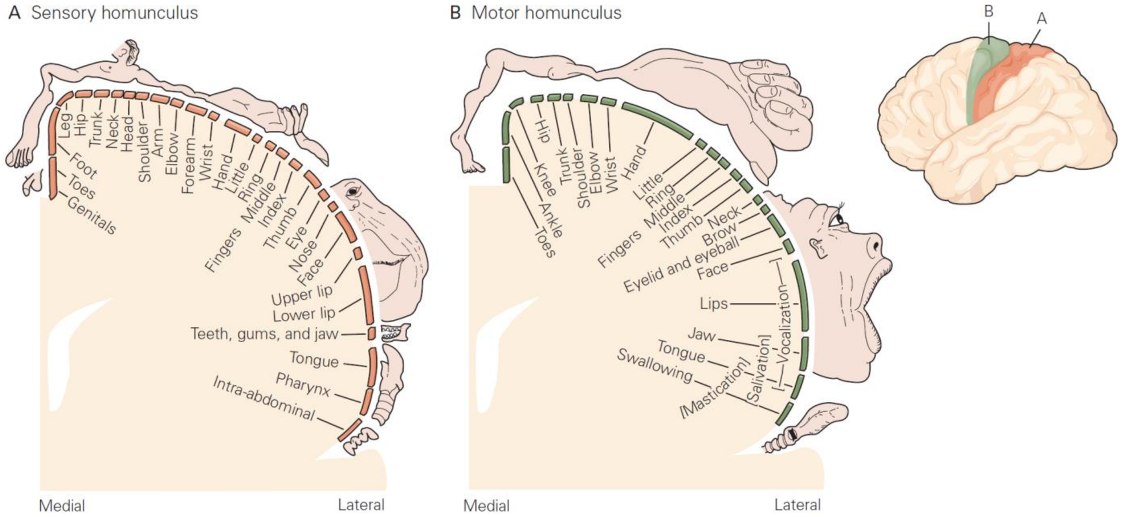


Wilder Penfield
(1891–1976)

Montreal procedure to treat epilepsy

- surgically destroyed the neurons in the brain that produced the seizures.
- Stimulated various parts of the brain with electrical probes and observed the results on the patients, to determine which cells to destroy

From these observations, he created maps of the sensory and motor cortices in the brain (Penfield & Jasper, 1954)



The Montreal procedure is still used today

https://youtu.be/BfdY_7KHSos

Surgically induced lesions

- Worked with Penfield studying the effects of brain surgery and injury on the functioning of the brain.

- Hebb thought that the workings of the brain explained behavior and that the **psychology and biology of an organism could not be separated**.

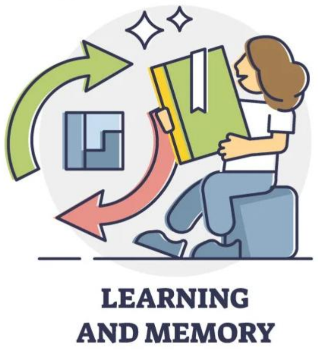
- Learning has a biological basis: **“cells that fire together, wire together”** neurons can combine together into a single processing unit and the connection patterns of these units make up the ever-changing algorithms determining the brain’s response to a stimulus

- Hebb’s theory was subsequently used in the design of artificial neural networks.

Donald O. Hebb
(1904–1985)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Surgically induced lesions: the hippocampus & memory



Brenda Milner
(1918–)

Penfield's patients began to complain about mild memory loss after surgery

Brenda Milner

- provided anatomical and physiological proof that there are **multiple memory systems**
- Showed that the extent of a memory deficit depended on how much of the medial temporal lobe had been removed

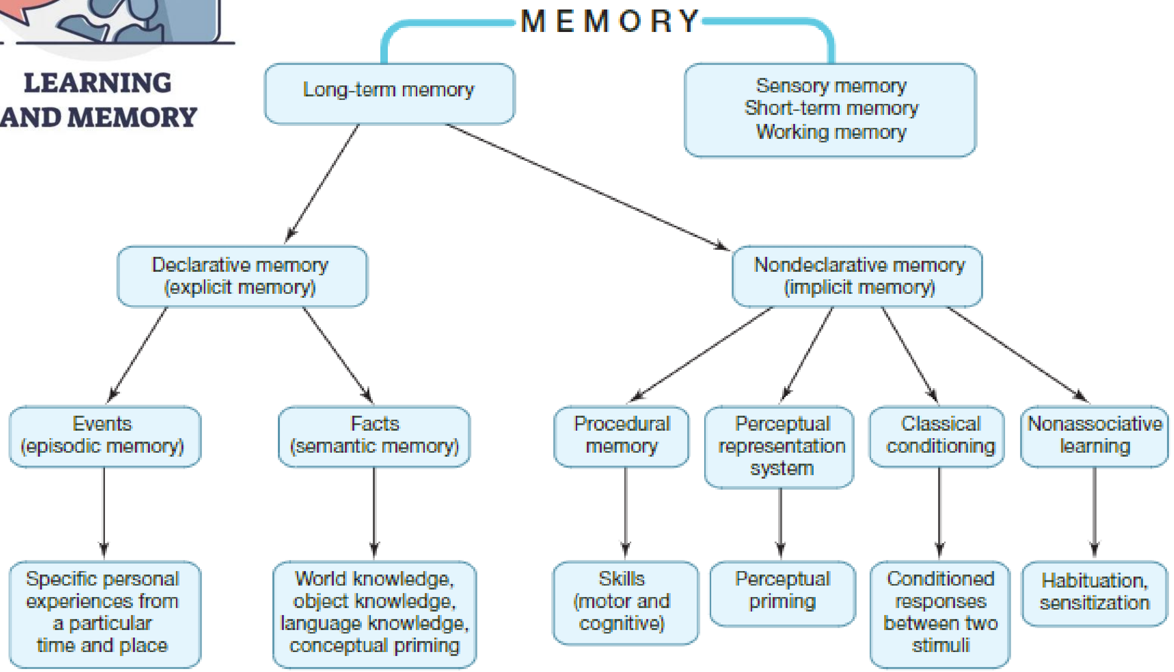
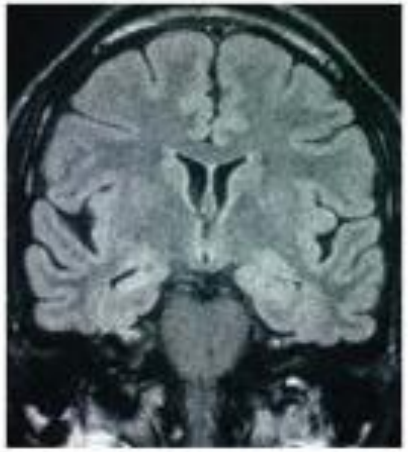
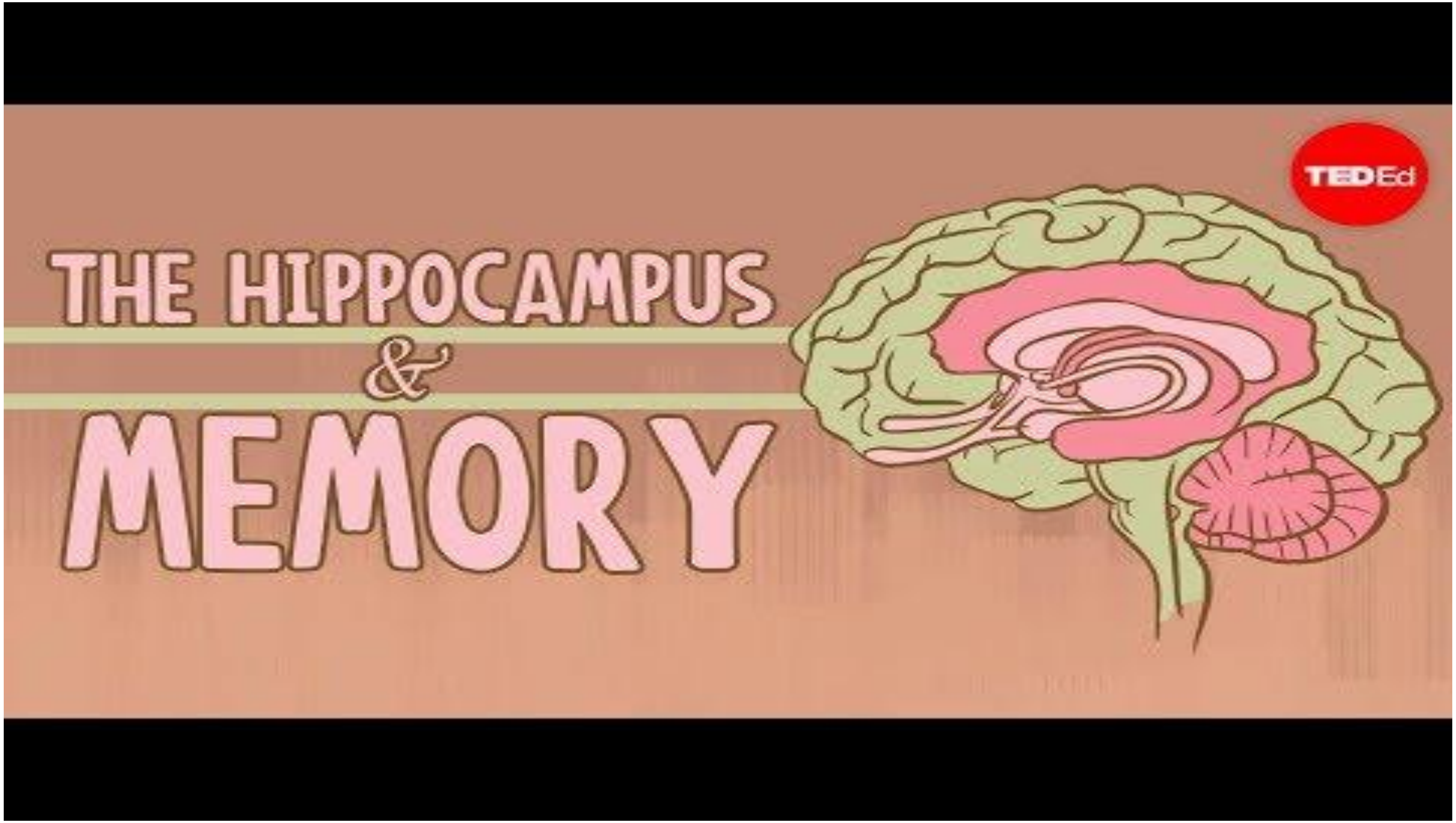


FIGURE 9.2 The hypothesized structure of human memory, diagramming the relationships among different forms of memory.



b

The hippocampus & memory: Patient H.M.

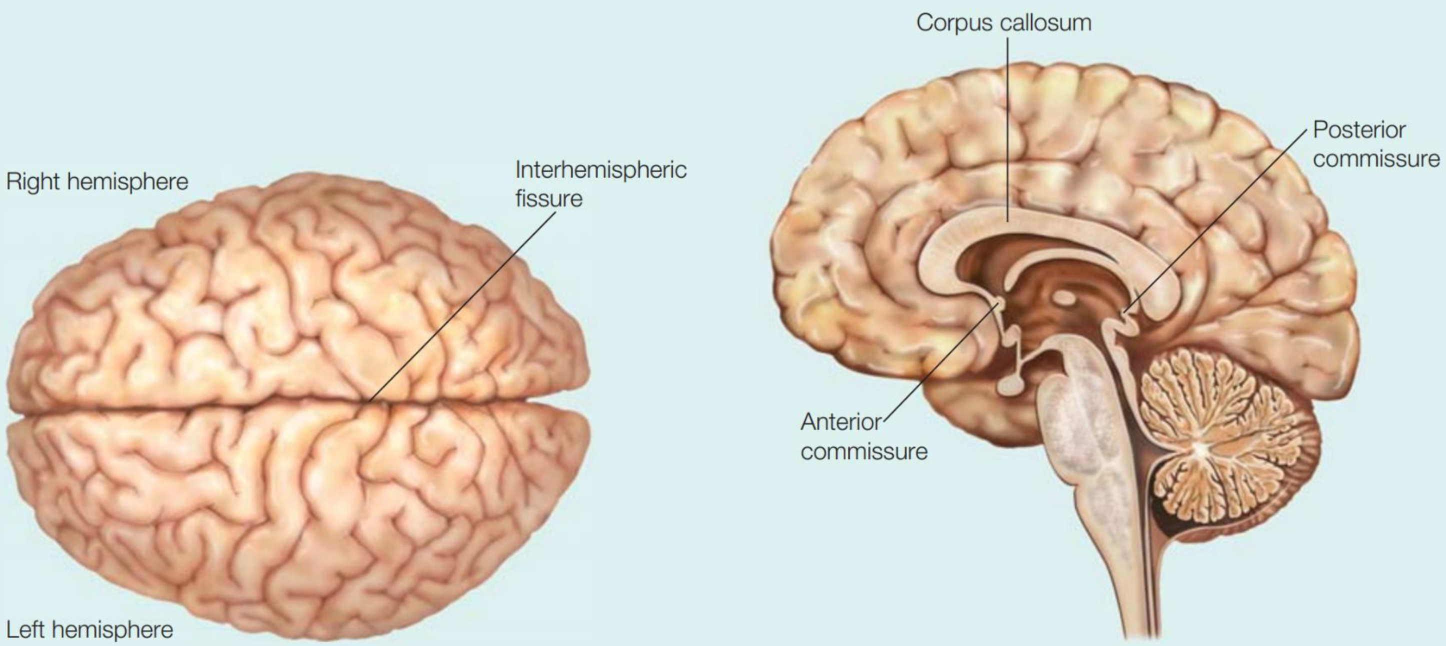


https://youtu.be/KkaXNvzE4pk

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

The study of split brains: hemispheric specialization

The hemispheres of the brain



The hemispheres of the brain are distinct yet connected. In the medial view are seen the commissures, the large white matter fiber tracts that connect the hemispheres.

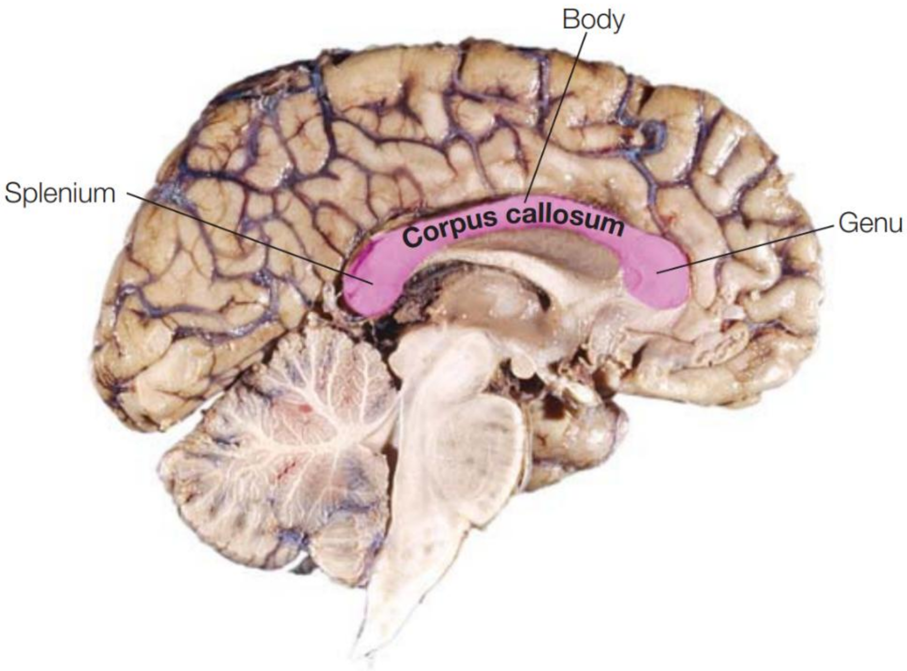


FIGURE 4.7 The corpus callosum.
A sagittal view of the left hemisphere of a postmortem brain. The corpus callosum is the dense fiber tract located below the folds of the cortex. The anterior portion is the genu, the middle portion is the body, and the posterior portion is the splenium.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

The study of split brains: hemispheric specialization

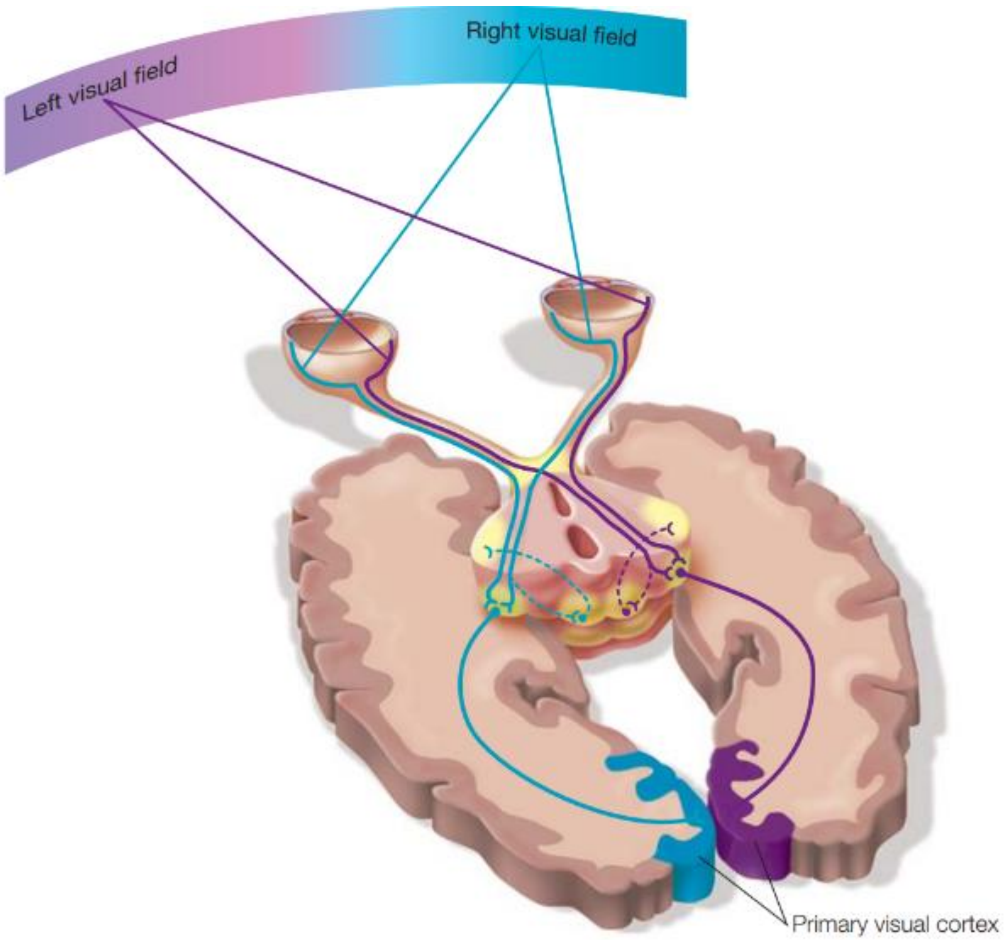
The study of
how the physical brain
can yield the thoughts
and ideas of an
intangible mind

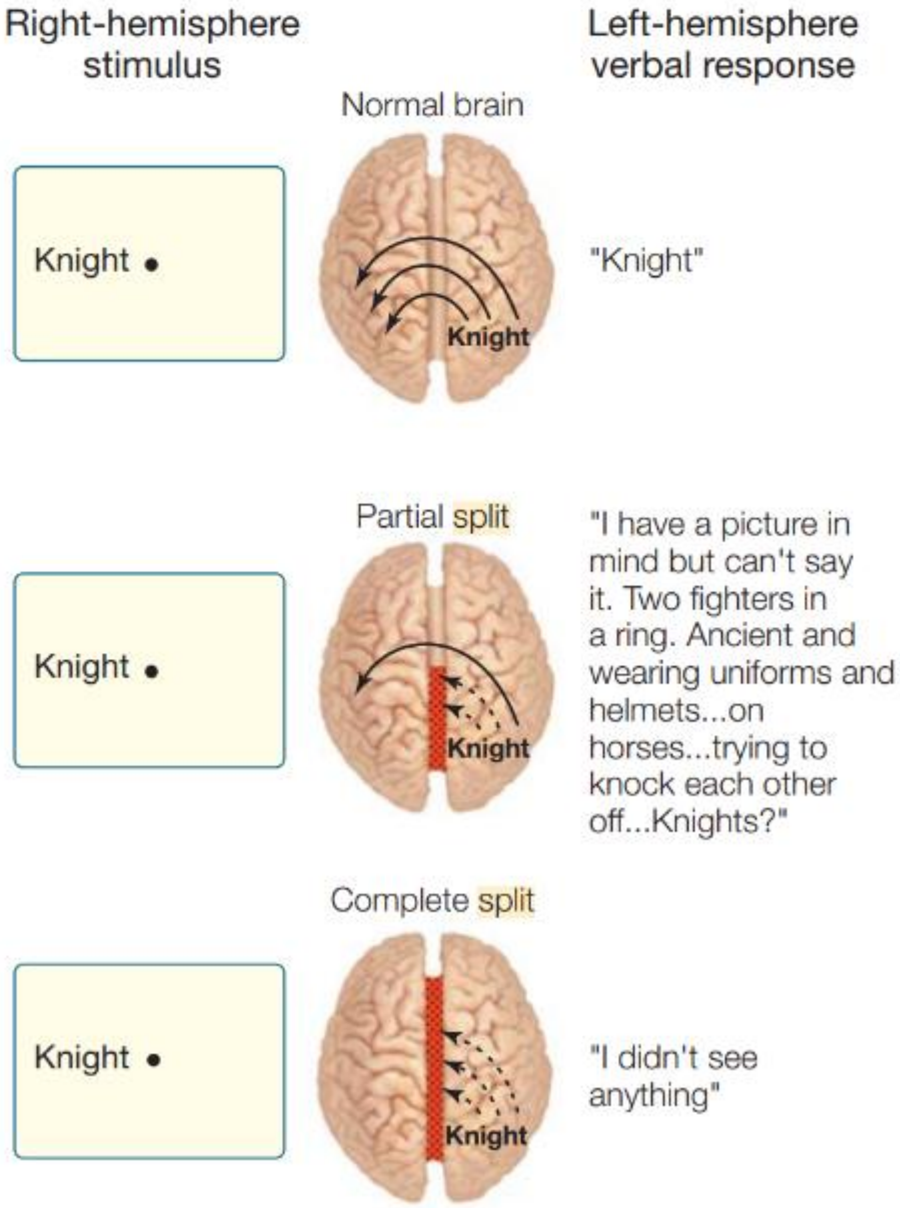
Structure and function
are intimately related.

https://youtu.be/lfGwsAdS9Dc

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

The study of split brains: hemispheric specialization





ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Patient Phineas Gage: The ventromedial prefrontal cortex (vmPFC)

- Part of prefrontal cortex
- Crucial for cognitive/affective control

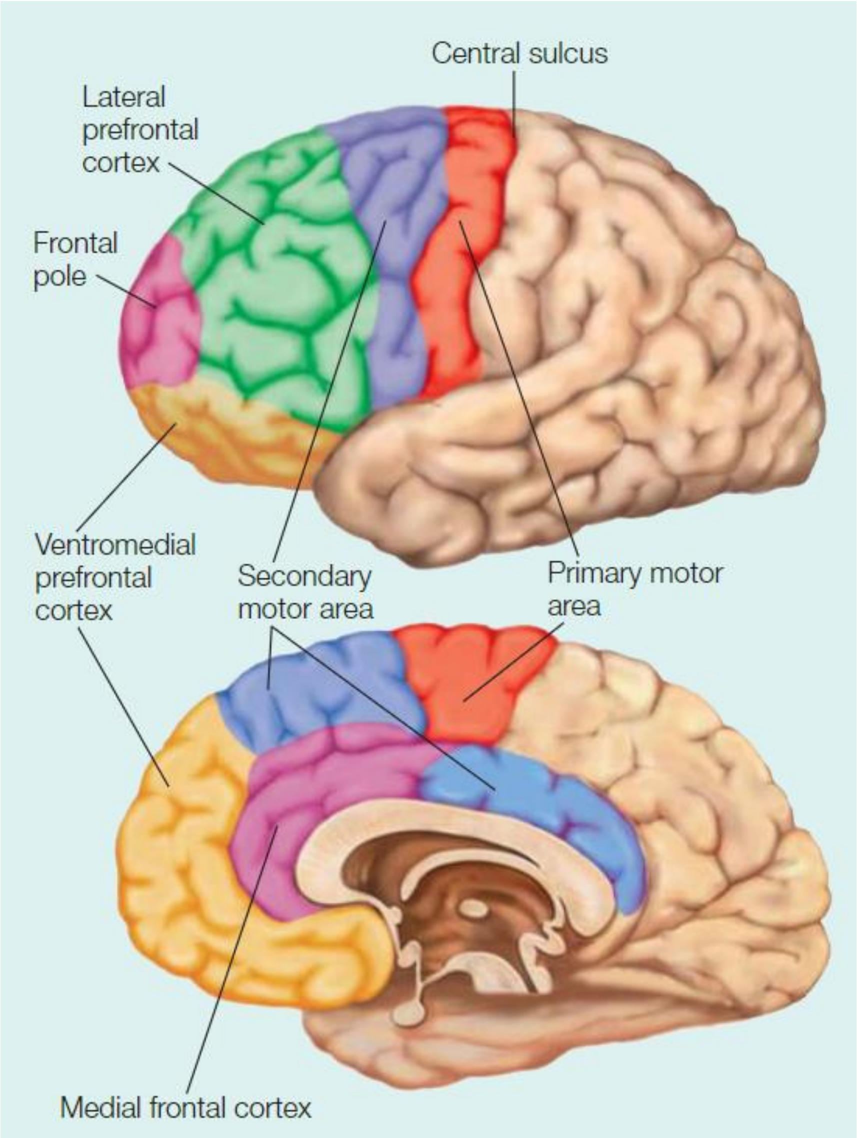
- The most ventral part of the ventromedial prefrontal cortex is frequently referred to as the orbitofrontal cortex, referring to the cortex which lies above the bony orbits of the eyes.

https://youtu.be/yXbAMHzYGJ0

The ventromedial prefrontal cortex (vmPFC)

- Part of prefrontal cortex
- Crucial for cognitive/affective control

- The most ventral part of the ventromedial prefrontal cortex is frequently referred to as the orbitofrontal cortex, referring to the cortex which lies above the bony orbits of the eyes.

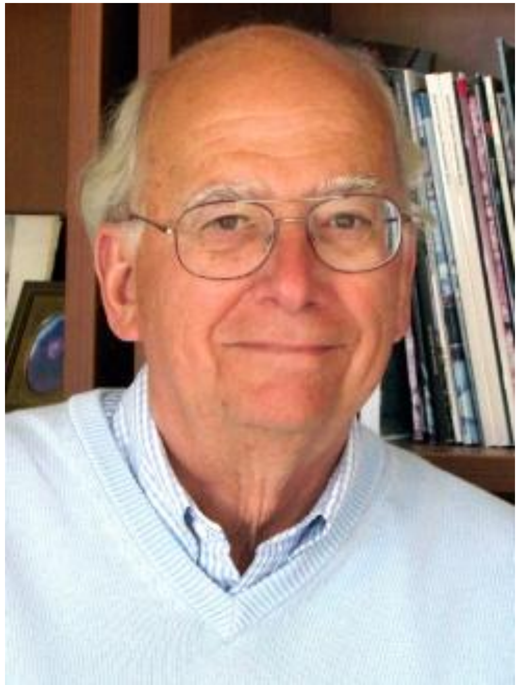


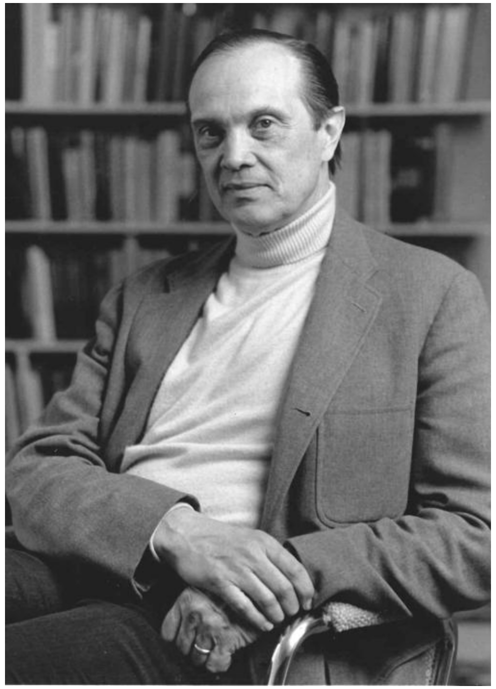
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Brain lesions provide causal evidence on the relation between structure and function

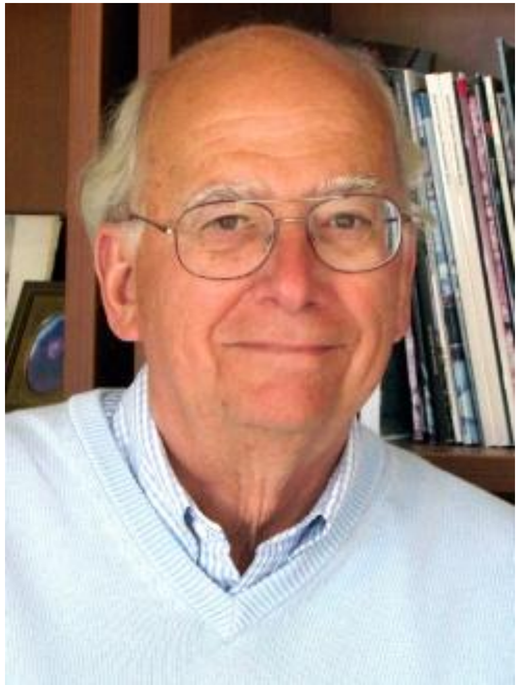
https://www.brainfacts.org/3d-brain#intro=false

Guess who, where, when

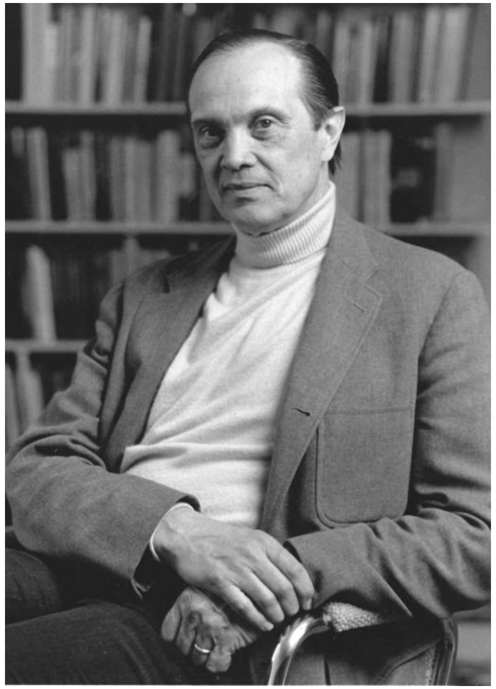




The birth of the term cognitive neuroscience



Michael S. Gazzaniga
(born 1939)



George A. Miller
(1920-2012)

Algonquin Hotel

Cognitive neuroscience

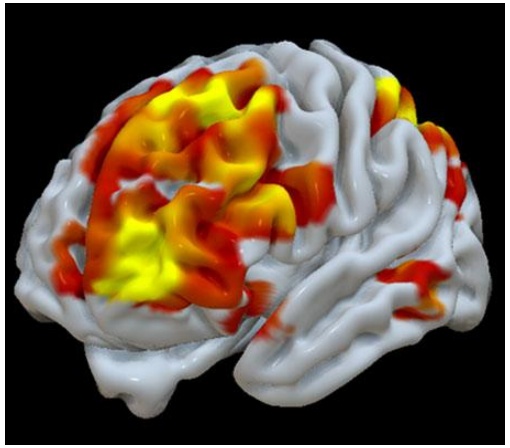
Brain lesions:

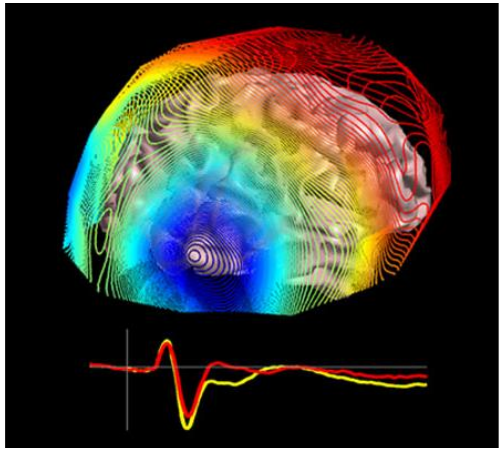
- provide causal evidence on the relation between structure and function
- enabled neuroscientists and psychologists to argue that the brain must enable the mind

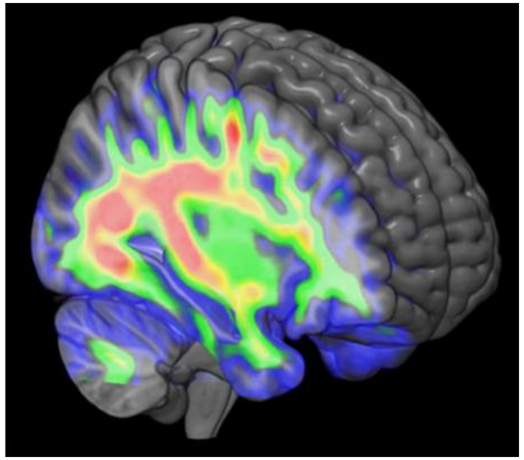
BUT HOW DOES THE BRAIN ENABLE THE MIND?

Understanding brain function depends on an understanding of both structure and function, and crucially, of the relation between the two.

The major goal of cognitive neural science is to understand neural representations of mental processes.







ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Revision questions

- Analyze the relationship between neuroscience and artificial intelligence. To what extent is the brain a good model for machine intelligence, and what are the potential benefits and limitations of using neuroscience to inspire AI development?

- Discuss the historical development of the concept of localization of function in the brain. How has this concept evolved over time, and what evidence supports or challenges it?
- Structure and function are intimately related in the nervous system. Choose an example from cognitive neuroscience to illustrate that function or cognition directly emerges from the nervous system or brain structure.
- What is cytoarchitectonics and how did it contribute to the understanding of brain functioning?

Glossary of Key Terms

Aggregate Field Theory: The theory that the whole brain participates in behavior, rather than specific regions being responsible for particular functions.

Cardiocentrism: The ancient belief that the heart is the center of intelligence and consciousness.

Cognitivism: A theoretical framework in psychology that emphasizes the study of internal mental processes, including perception, attention, memory, language, and problem-solving.

Cognitive Neuroscience: The interdisciplinary field that studies the neural basis of cognition, seeking to understand how brain structure and function give rise to mental processes.

Cytoarchitectonics: The study of the cellular composition and organization of different brain regions.

Encephalocentrism: The belief that the brain is the center of intelligence and consciousness.

Localizationism: The theory that specific mental functions are localized to particular regions of the brain.

Glossary of Key Terms

Neuron Doctrine: The fundamental principle that the nervous system is composed of discrete, individual cells called neurons.

Neuroscience: The scientific study of the nervous system, encompassing its structure, function, development, and pathology.

Phrenology: A pseudoscientific theory that claimed to assess personality and mental abilities by analyzing bumps on the skull.

Synapse: The specialized junction between two neurons, where communication occurs through the transmission of chemical or electrical signals.

Recommended readings

- Brooks R, Hassabis D, Bray D, Shashua A. Turing centenary: Is the brain a good model for machine intelligence? Nature. 2012 Feb 22;482(7386):462-3. doi: 10.1038/482462a. PMID: 22358812.

- Gazzaniga, Ivry, Magnum. Cognitive Neuroscience, the biology of the mind, Chapter 1

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA