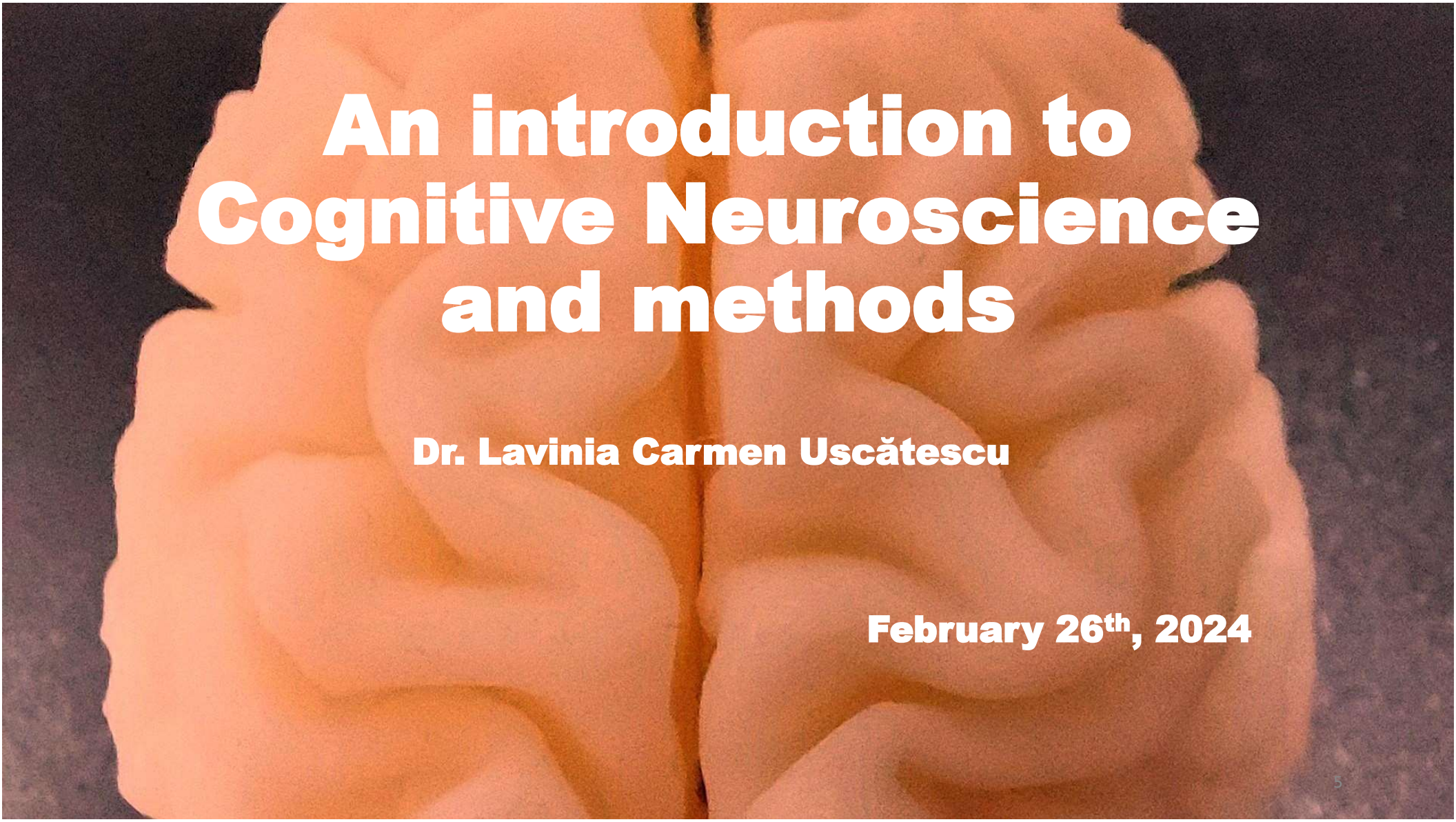


An introduction to Cognitive Neuroscience and methods

Dr. Lavinia Carmen Uscătescu

February 26th, 2024

mind–body problem

How can *a physical substance (****the brain****) can* ***give rise to*** *our sensations, thoughts and emotions (****our mind****)?*

René Descartes
(1596 – 1650)

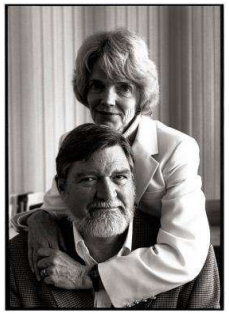
dualism

the **mind** and **brain** are made up of **different kinds of substance**

Baruch Spinoza
(1632 – 1677)

dual-aspect theory

the **mind** and **brain** are **two levels of description** of the same thing



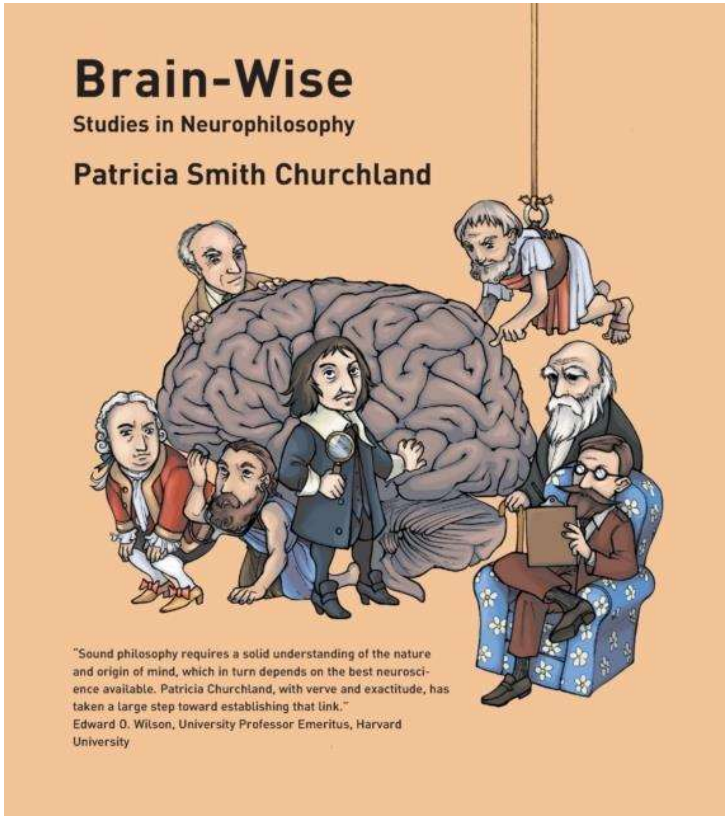
Paul and Patricia Churchland

reductionism

cognitive, **mind-based concepts** will eventually be **replaced** by purely biological, **brain-based constructs**

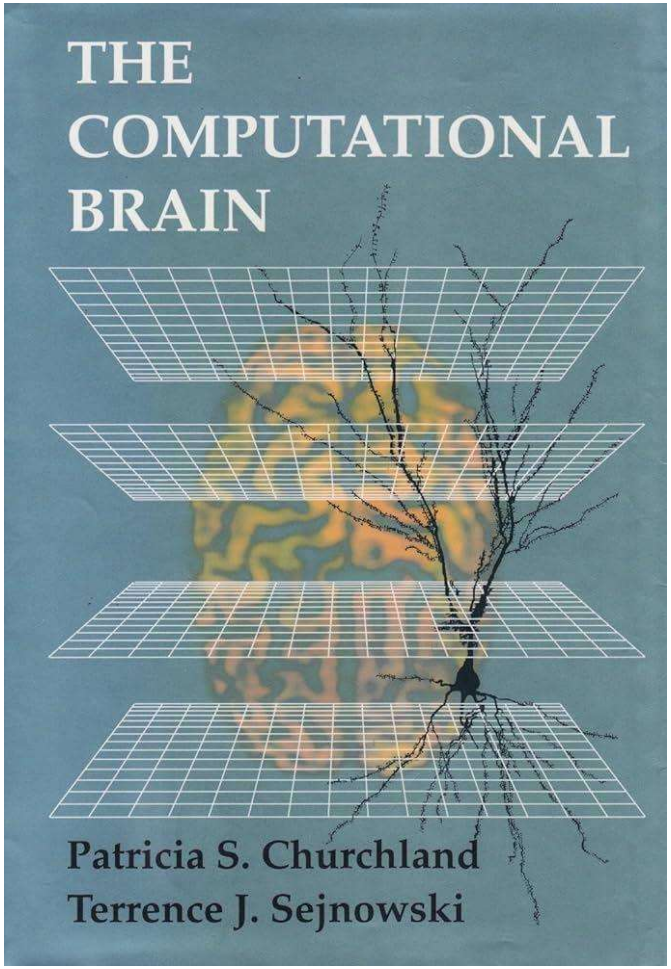
However brains work, much of what they do involves *representing*—representing the brain's body, features of the world, and some events in the brain itself. Performing computational operations on those representations serves to extract relevant information, make decisions, remember, and move appropriately. That brains represent and compute are working assumptions in much of cognitive neuroscience. I emphasize that these are indeed *assumptions*, however, not firmly established truths. As science continues to progress, the assumptions may be amplified, revised, or even falsified in favor of better hypotheses, as yet dimly conceived.

Churchland, (2002), p. 273

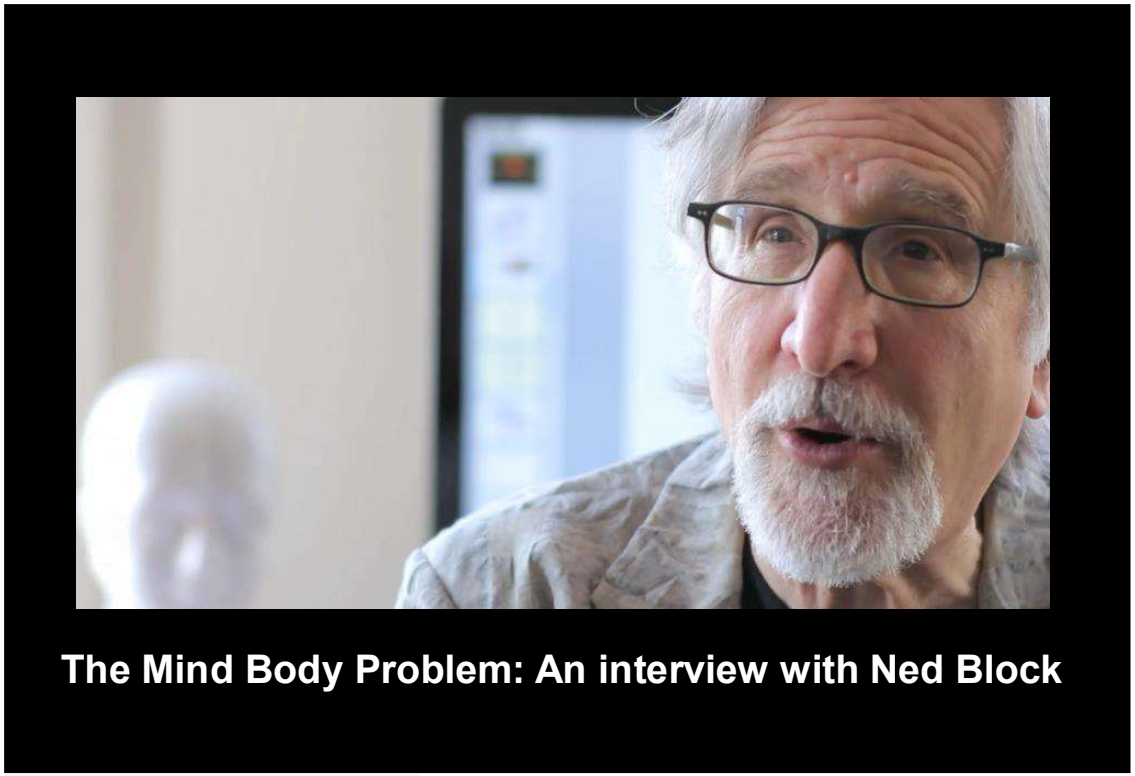


If we are to understand how the brain sees, learns, and is aware, we must understand the architecture of the brain itself. The brain's computational style and the principles governing its function are not manifest to a casual inspection. Nor can they be just inferred from behavior, detailed though the behavioral descriptions may be, for the behavior is compatible with a huge number of very different computational hypotheses, only one of which may be true of the brain. Moreover, trying to guess the governing principles by drawing on existing engineering ideas has resulted in surprisingly little progress in understanding the brain, and the unavoidable conclusion is that there is no substitute for conjuring the ideas in the context of observations about real nervous systems: from the properties of neurons and the way neurons are interconnected.

Churchland & Sejnowski, (1996), p. 14



In a nutshell…



https://vimeo.com/58254376

The early days of scientific Psychology

Hermann von Helmholtz
(1821 – 1894)

Helmholtz's earliest study of **physiology** was with **Johannes Müller** (1801–1858), who was a keen experimenter and naturalist and author of the very influential ***Handbook of Human Physiology***.

From 1838 to 1842, Helmholtz studied **medicine** under Müller.

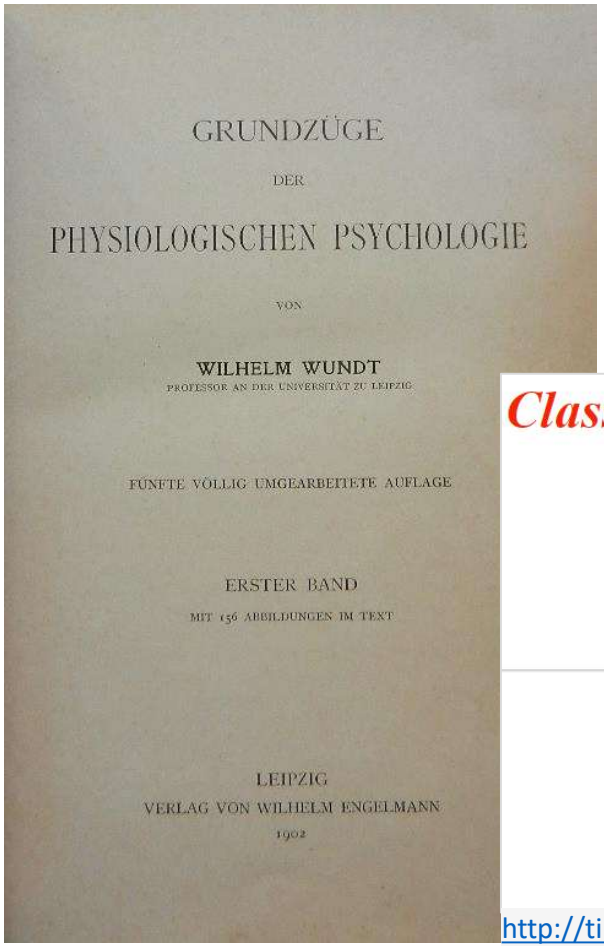
Helmholtz proposes a **"sign" theory** (1848–1868), according to which **sensations symbolize their stimuli but are not direct copies** of those stimuli. While Müller explains the correspondence between sensation and object by means of an innate configuration of sense nerves, Helmholtz argues that **we construct that correspondence by means of a series of learned, "unconscious inferences."**

https://plato.stanford.edu/ENTRIES/hermann-helmholtz/

Wilhelm Wundt
(1832 – 1920)

Laid the **foundations** of **experimental Psychology** in his 1902 book,

"Grundzüge der physiologischen Psychologie"



Classics in the History of Psychology

An internet resource developed by
Christopher D. Green
York University, Toronto, Ontario
ISSN 1492-3173

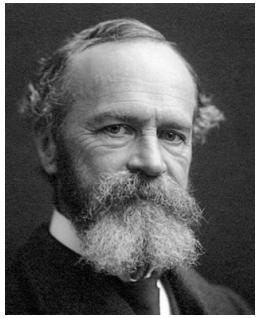
Introduction to

Grundzüge der physiologischen Psychologie
Wilhelm Wundt (1874)

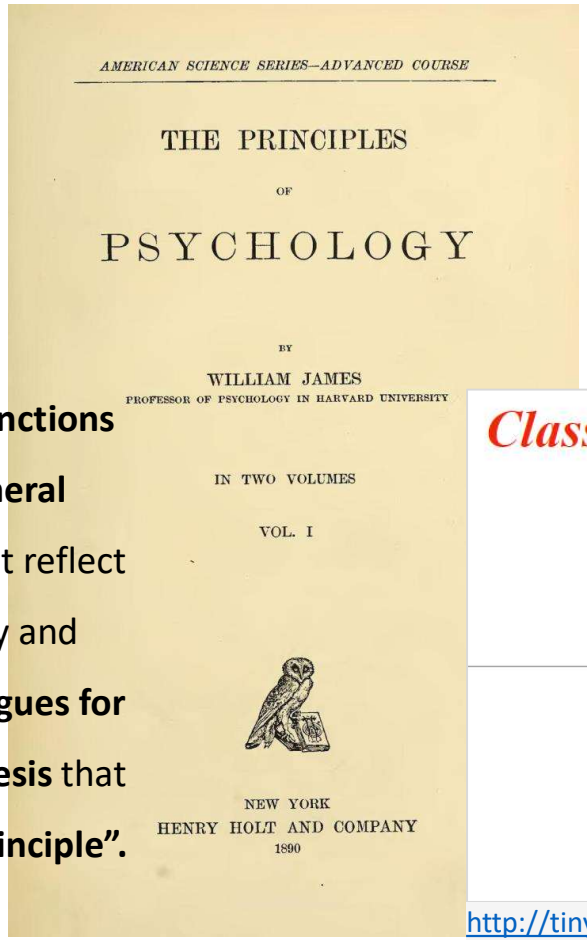
Robert H. Wozniak

http://tinyurl.com/ydzmwyhu

The wrote the *Principles of Psychology* following the "psychological method of introspection": "**the looking into our own minds** and reporting what we there discover".

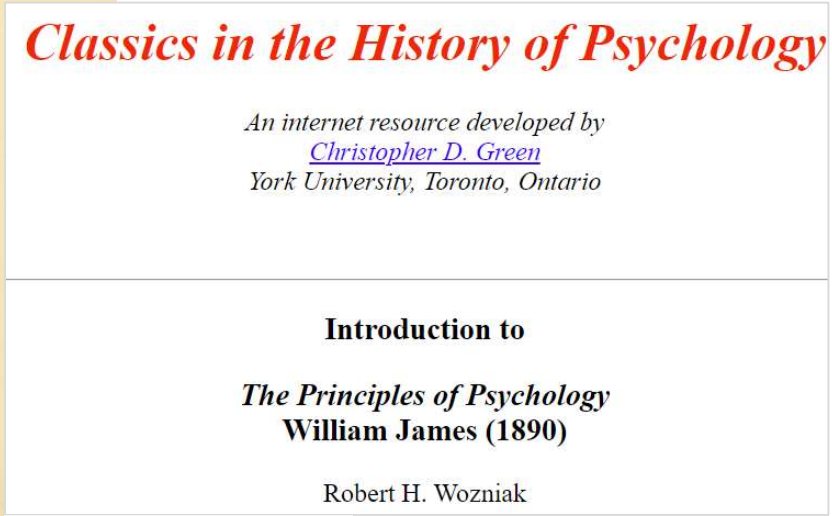


William James
(1842 – 1910)



He includes chapters on **"The Functions of the Brain"** and **"On Some General Conditions of Brain Activity"** that reflect his years as a lecturer in anatomy and physiology at Harvard, and he **argues for the reductive and materialist thesis** that **habit is "at bottom a physical principle".**

https://plato.stanford.edu/entries/james/



http://tinyurl.com/3b577tsr

Behaviorism

"By the beginning of the twentieth century there was a growing **dissatisfaction** with the **lack of systematic** progress in the study of mental processes.

Experimental methods like **introspection** and **subjective judgments** seemed inherently **imprecise**. As a result, psychology in that era, especially in North America, came to be dominated by a new **emphasis on highly controlled experiments** that matched objective external stimuli to **measurable behavior**. This approach, called **behaviorism**, **rejected subjective work** on mental functions as being outside the domain of proper scientific inquiry."

(Purves et al., (2012), p. 2)

John Watson
(1878 – 1958)

Father of Behaviorism

"little Albert" experiment

https://www.youtube.com/watch?v=-wtL5Io3sS8

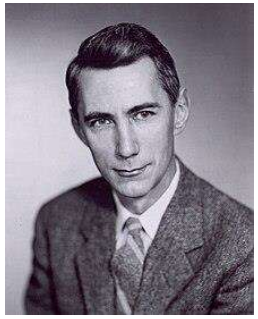
https://www.youtube.com/watch?v=LSv992Ts6as

Burrhus Frederic Skinner
(1904 – 1990)

Cognitive science

In the mid-twentieth century, the avenue of **computational science** and **information theory** => the *"mind as computer"*

Father of information theory



Claude Shannon
(1916 – 2001)

information theory

the mathematical study of the **quantification**, **storage**, and **communication** of information

entropy

scientific concept that is most commonly associated with a state of **disorder**, **randomness**, or **uncertainty**

"**Brain entropy** is based on **Shannon Entropy**, *a measure from information theory that quantifies the uncertainty of a system* from the probability distribution of its states (Shannon, 1948). **A system with a larger repertoire of potential states has greater entropy** than a system with fewer possible states. As **information is the reduction of uncertainty**, **Shannon Entropy is also a measure of the information capacity of a system**. It therefore follows that **a brain with a larger repertoire of neural states has greater entropy**, and thus has a greater information capacity, than a brain with a smaller repertoire of states."

Hull & Morton, (2023), Journal of Neuroscience Methods
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8881863/

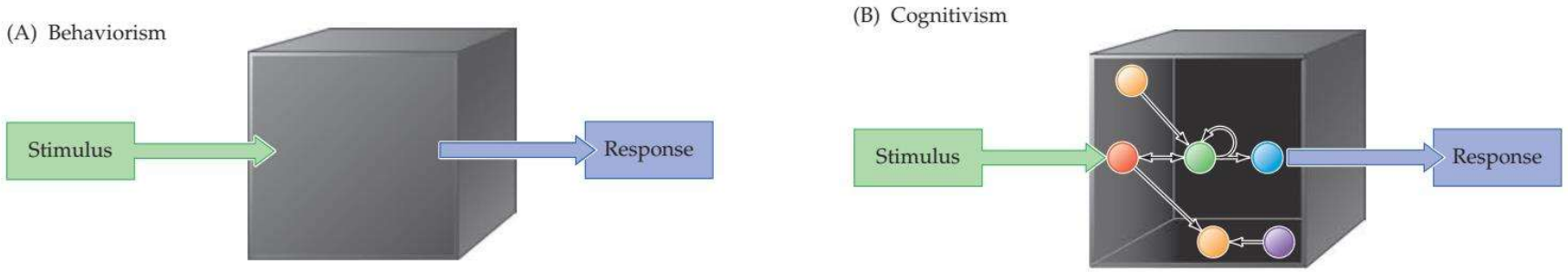


Figure 1.2 Contrasting behaviorist and cognitive approaches to research
(A) Behaviorists tried to explain behavior using only stimuli and responses, avoiding any reference to the underlying mental processes. They did not necessarily deny the existence of internal mental states, but instead argued that mental states could not be defined independently of experimental operations (e.g., stimulus-response relationships). (B) In contrast, cognitive scientists have sought to explain the information processing that intervenes between stimuli and behavior. Those models assume that cognitive functions (the black arrows in this schematic diagram) act upon stored information (colored circles), transforming that information in the service of adaptive behavior.

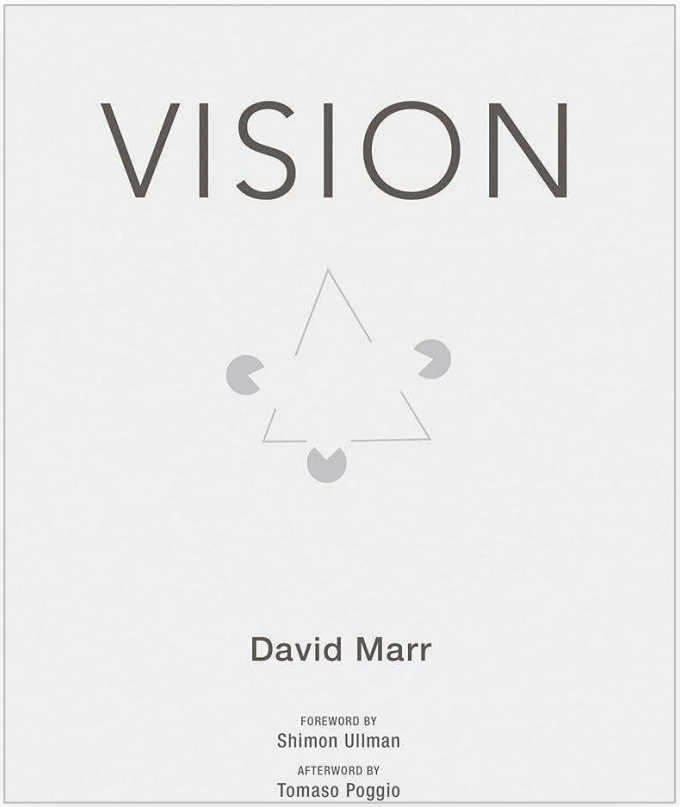
(Purves et al., (2012), p. 4)

cognition

A variety of higher mental processes such as thinking, perceiving, imagining, speaking, acting and planning

The cognitive revolution: an intellectual movement that began in the 1950s as an **interdisciplinary study of the mind** and its processes, from which emerged a new field known as **cognitive science**.

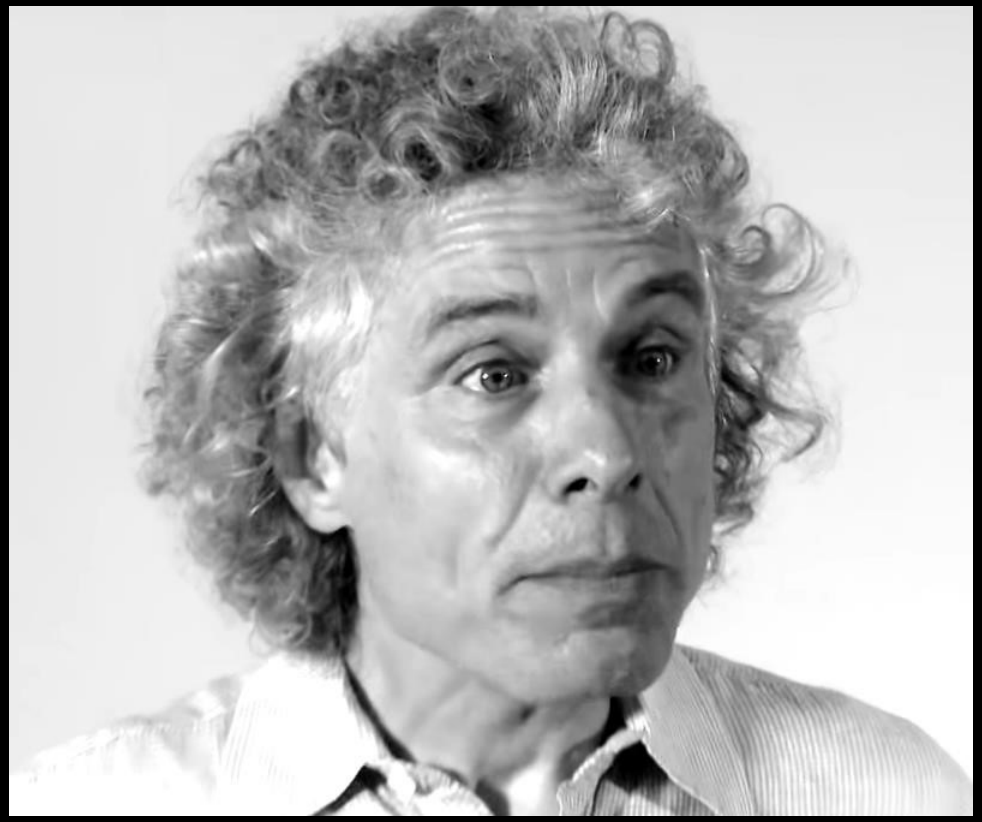
David Marr
(1945 – 1980)



David Marr's Three Levels of Inquiry

- **Computational**: **What computations** does the central nervous system perform and **why**?
- **Algorithmic**: **What representations** and procedures are used in the neural computation?
- **Implementation**: **What** are the **physiological mechanisms** that bring about these representations and carry out these algorithms?

In a nutshell…



Steven Pinker on the Cognitive Revolutions

http://tinyurl.com/2w252n5v

http://tinyurl.com/4vkewsf4

Neuroscience

The first knowledge of **brain function** arose from observing the effects of **brain injury**.

Eur Spine J. 2010 Nov; 19(11): 1815–1823.
Published online 2010 Aug 10. doi: 10.1007/s00586-010-1523-6
PMCID: PMC2989268
PMID: 20697750

The Edwin Smith papyrus: a clinical reappraisal of the oldest known document on spinal injuries

Joost J. van Middendorp,[✉1] Gonzalo M. Sanchez,[2,3] and Alwyn L. Burridge[4]

Table 1 The diagnostic descriptions and therapeutic verdicts of the six spinal injury cases as reported in the Edwin Smith papyrus, based on the Sanchez and Burridge translation [9]

Case	Region	Injury type	Diagnosis of the spinal column	Significant symptoms	Injury of the spinal cord	Significant symptoms	Other documented signs and symptoms	Treatment verdict: "A medical condition…"
29	Cervical	Open	Fracture as a result of a penetrating injury	Stiffness of neck. Inability to rotate and bend the neck	No	–		"…I intend to fight with."
30	Cervical	Closed	Wrenching/sprain with disc injury[a]	Ability to rotate and bend the neck. Painful rotation and flexion of the neck	No	–		"…I can heal."
31	Cervical	Closed	Dislocation[a]	None reported	Yes	Motor and sensory loss of the upper and lower extremities, priapism, urinary incontinence, abdominal distention, priapism[b] and spermatorrhea[b]	Bloodshot eyes[c]	"…that cannot be healed."
32	Cervical	Closed	Compression fracture[a]	Inability to rotate and bend the neck ("face fixed")	No	–		"…I can heal."
33	Cervical	Closed	Burst fracture[a]	None reported	Yes	Motor and sensory loss of the upper and lower extremities	Stupor[c] and aphasia[c]	"…that cannot be healed."
48	Lumbar	Closed	Wrenching /sprain with disc injury	Immediate contraction of the leg after extending it because of vertebral pain	No	–		"…I can heal."

[a] This term is clarified in the case's additional subheading "Explanation", see Appendix

[b] This symptom was documented to be present in an injury located at "the middle vertebra of the back of neck"

[c] This symptoms is considered to be most likely the result of an inaccurately described closed head injury

Edwin Smith Surgical Papyrus
~ 1000 BC (based on an older treatise ~ 3000 BC)

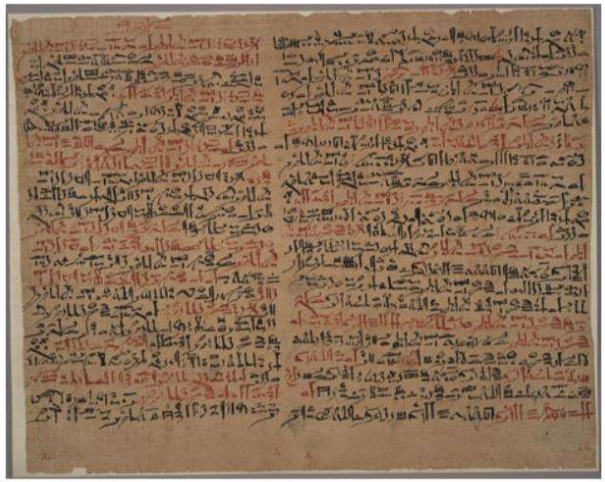


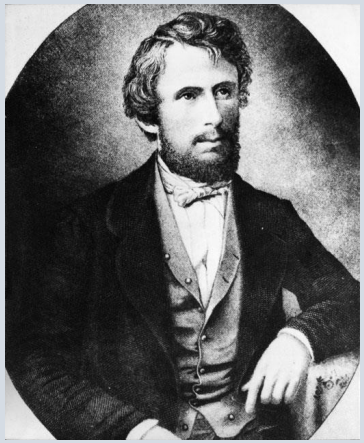
Fig. 1 Plate X and XI of the Edwin Smith papyrus including the five cervical spinal injury cases in hieratic script [7]

http://tinyurl.com/v98k9nh5

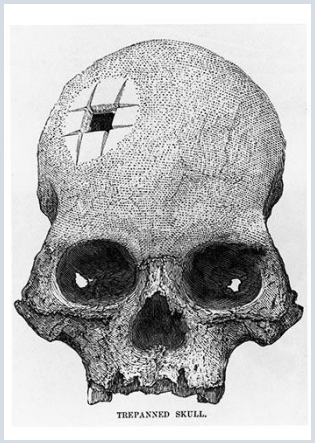
Oldest known neurosurgery (trepanation/trephination) on a living person ~ 1400–1530

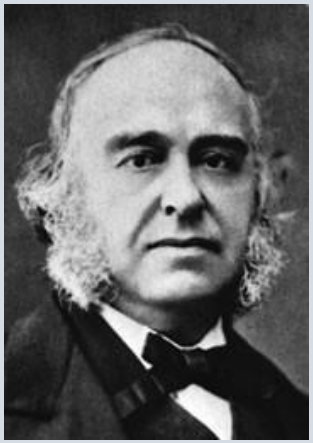
In 1865, this Inca skull was gifted to **Ephraim George Squier**, an American archaeologist in Cuzco, Peru, who then also showed it to **Paul Broca**. In 1876, Broca relayed this finding to the Anthropological Society of Paris, but his conclusion, that **the owner of the trephined skull healed and survived the surgery** was met with scepticism.

The skull is now at the American Museum of Natural History, in NY.



Ephraim George Squier





Paul Broca

https://thereader.mitpress.mit.edu/hole-in-the-head-trepanation/

cognitive neuropsychology

the study of brain damaged patients

to inform theories of normal cognition

The heart v. brain dispute

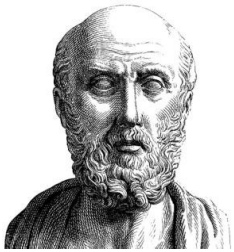
It ought to be generally known that the source of our pleasure, merriment, laughter and amusement, as of our grief, pain, anxiety, and tears, is none other than the brain.

Hippocrates

And of course, the brain is not responsible for any of the sensations at all. The correct view is that the seat and source of sensation is the region of the heart.

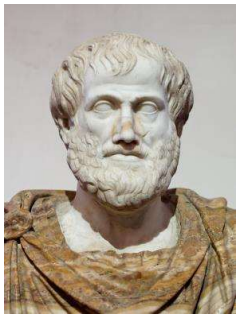
Aristotle

(Andrew Wickens, 2015, pg. 1)



Hippocrates
(460 BC – 370 BC)

Aristotle, by observing **chicken embryos** inside the egg, noticed that their **heart** was the first to show noticeable activity. He surmised that the **heavy vasculature around the brain had the purpose of cooling down the body**, a hypothesis which he extended to the human brain, given its size. He further noted that touching the brain of a living animal did not trigger a noticeable sensation, and that some animals capable of feeling sensations did not have a brain (e.g., worms).



Aristotle
(384 BC – 322 BC)

The first experiments

Galen of Pergamon
(129 – ~ 213)

Galen and the Squealing Pig

Charles G. Gross View all authors and affiliations

Volume 4, Issue 3 | https://doi.org/10.1177/107385849800400317

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Abstract

Galen, who lived in the Roman Empire in the 2nd century, was the greatest experimental physiologist and anatomist of classical antiquity. His ideas about biology and medicine were dominant in Europe for more than 1500 years. In one of his most famous experi ments, he demonstrated loss of vocalization after section of the recurrent laryngeal nerves in the pig. This may have been the first experimental evidence that the brain controls behavior and thought. NEUROSCIENTIST 4:216-221, 1998

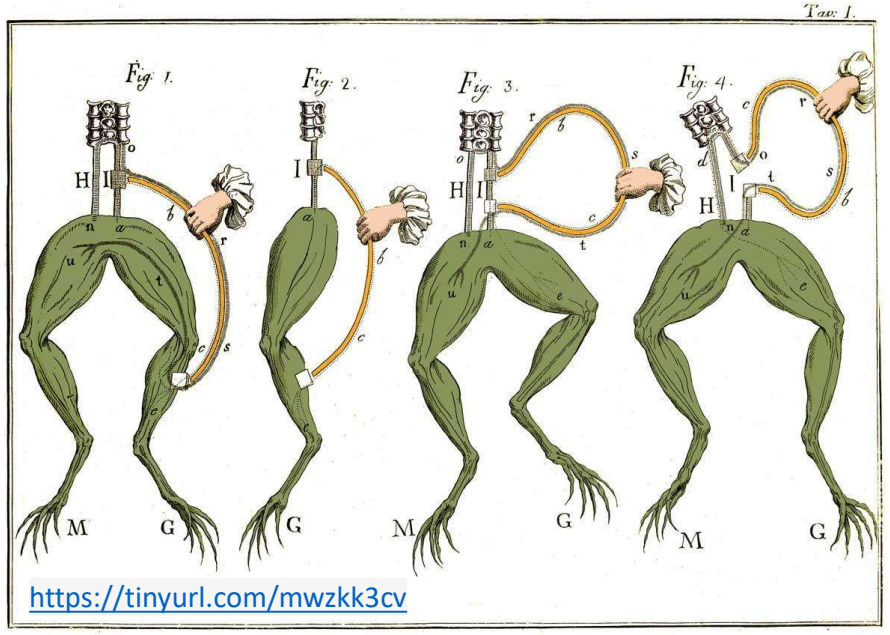
https://tinyurl.com/28x9jxpt

- described many of the **cranial nerves** and their function;
- inferred that the **spinal cord is an extension of the brain** and performed **systematic lesion studies** => sensory and motor function is compromised below the region of the injury;
- records two instances of infants losing the ability to vocalize after accidental injury to their **recurrent laryngeal nerves.**

The discovery of ***"animal electricity"***

Carlo Matteucci
(1811 – 1868)

Luigi Galvani
(1737 – 1798)

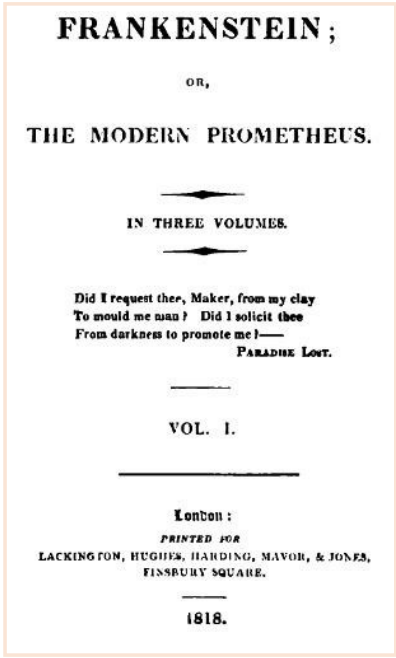


https://tinyurl.com/mwzkk3cv

Luigi Galvani discovered, on September 20th, 1786, that **the sciatic nerve** of a dead frog could conduct an **electrical signal** and contract the frog's leg.

The invention of the ***galvanometer***, in the 1820s, allowed **Carlo Matteucci** to show that nerves and muscles do indeed contain some electrical signals, as Galvani had surmised.

Mary Shelley
(1797 – 1851)



FRANKENSTEIN;

OR,

THE MODERN PROMETHEUS.

IN THREE VOLUMES.

Did I request thee, Maker, from my clay
To mould me man? Did I solicit thee
From darkness to promote me?—
PARADISE LOST.

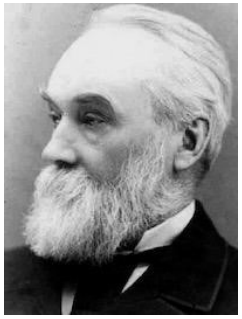
VOL. I.

London:
PRINTED FOR
LACKINGTON, HUGHES, HARDING, MAVOR, & JONES,
FINSBURY SQUARE.

1818.

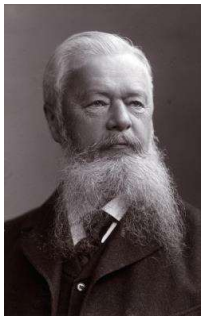
https://tinyurl.com/yckrkzyw

The discovery of the **motor cortex**



John Hughlings Jackson
(1835 – 1911)

- was studying **epilepsy**, when he noted that epileptic seizures gradually propagated from the hands towards the face (*"Jacksonian march"*);
- hypothesized that different parts of the body were controlled by different parts of the cortex;
- surmised that **aberrant electrical activity** in the brain gave rise to epileptic seizures.

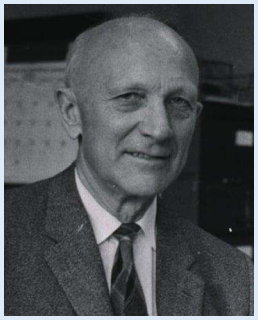


Gustav Fritsch
(1838 – 1927)

Eduard Hitzig
(1838 – 1907)

- in 1870, they identified the motor cortex **experimentally**, by electrically stimulating the motor cortex of a dog;
- they showed the **contralateral** correspondence between stimulation site and the elicited movement;
- further supported their conclusion with **targeted lesion** studies of the motor cortex, in dogs.

The cortical **homunculus**



Wilder Penfield
(1891 – 1976)

Throughout my career, I was driven by the central question that has obsessed both scientists and philosophers for hundreds of years. ***Are mind and body one? Can the mind - thinking, reasoning, imagination — be explained by the functions of the brain?*** *As a doctor, my first concern was always for my patients — to relieve the terrible suffering caused by diseases such as epilepsy.*

http://tinyurl.com/yemjdetn

- together with **Herbert Jasper**, he invented the *"Montréal Procedure"*, which identifies and destroys the neurons where an epileptic seizure originates;
- in preparation for the procedure, he would map out cortical function **by electrically stimulating** the patient's brain;
- he thus mapped out motor and sensory function on the cortex => the **cortical homunculus** was born.

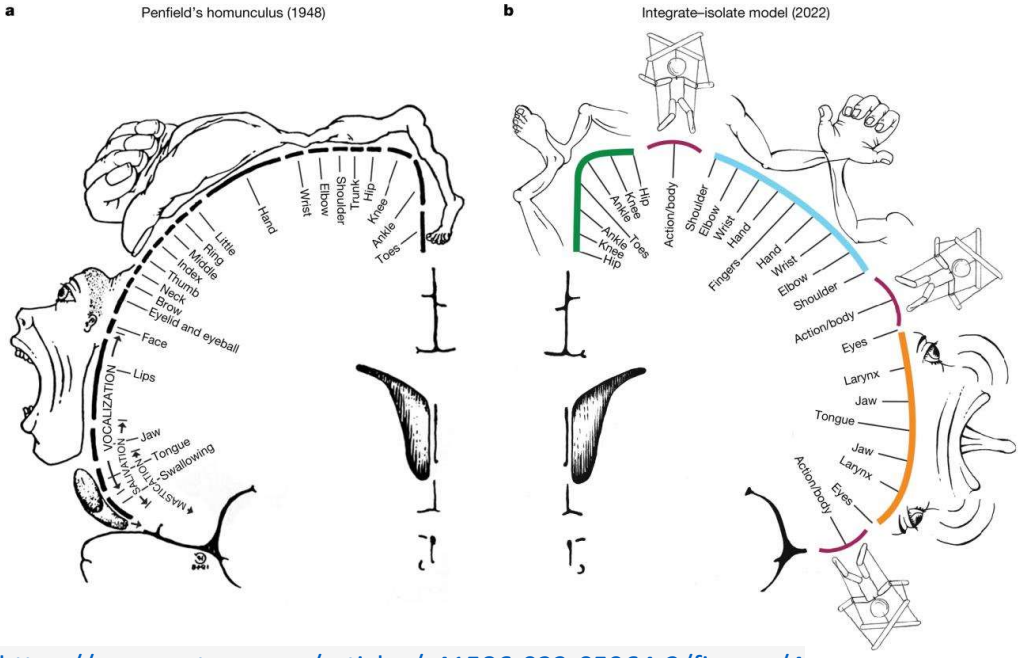
Article | Open access | Published: 19 April 2023

A somato-cognitive action network alternates with effector regions in motor cortex

Evan M. Gordon, Roselyne J. Chauvin, Andrew N. Van, Aishwarya Rajesh, Ashley Nielsen, Dillan J. Newbold, Charles J. Lynch, Nicole A. Seider, Samuel R. Krimmel, Kristen M. Scheidter, Julia Monk, Ryland L. Miller, Athanasia Metoki, David F. Montez, Annie Zheng, Immanuel Elbau, Thomas Madison, Tomoyuki Nishino, Michael J. Myers, Sydney Kaplan, Carolina Badke D'Andrea, Damion V. Demeter, Matthew Feigelis, Julian S. B. Ramirez, ... Nico U. F. Dosenbach + Show authors

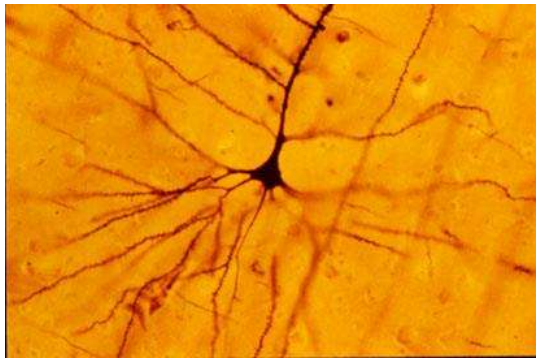
Nature **617**, 351–359 (2023) | Cite this article

141k Accesses | **16** Citations | **1738** Altmetric | Metrics



https://www.nature.com/articles/s41586-023-05964-2/figures/4

The **neuron doctrine**



A human neocortical pyramidal neuron stained via Golgi technique
https://tinyurl.com/258ece5e

neuron = a single, **independent**

unit of the nervous system

The Nobel Prize in Physiology or Medicine 1906

"in recognition of their work on the structure of the nervous system"

Camillo Golgi

1/2 of the prize

Italy

Pavia University
Pavia, Italy

b. 1843
d. 1926

Santiago Ramón y Cajal

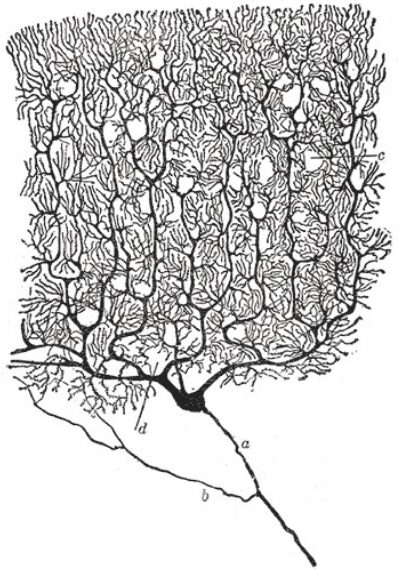
1/2 of the prize

Spain

Madrid University
Madrid, Spain

b. 1852
d. 1934

www.nobelprize.org



Drawing of a Purkinje cell in the cerebellum cortex done by Cajal, using the Golgi stain
https://tinyurl.com/258ece5e

Camillo Golgi
Biographical
https://www.nobelprize.org/prizes/medicine/1906/golgi/biographical/

> Brain Res Rev. 2007 Oct;55(2):490-8. doi: 10.1016/j.brainresrev.2006.11.004. Epub 2007 Jan 9.

How the 1906 Nobel Prize in Physiology or Medicine was shared between Golgi and Cajal

Gunnar Grant [1]

Affiliations + expand

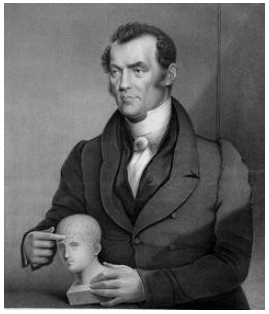
PMID: 17306375 DOI: 10.1016/j.brainresrev.2006.11.004

https://tinyurl.com/2xwunam6

Santiago Ramón y Cajal
Biographical
https://www.nobelprize.org/prizes/medicine/1906/cajal/biographical/

Phrenology

Franz Joseph Gall
(1758 – 1828)



Johann Spurzheim
(1776 – 1832)

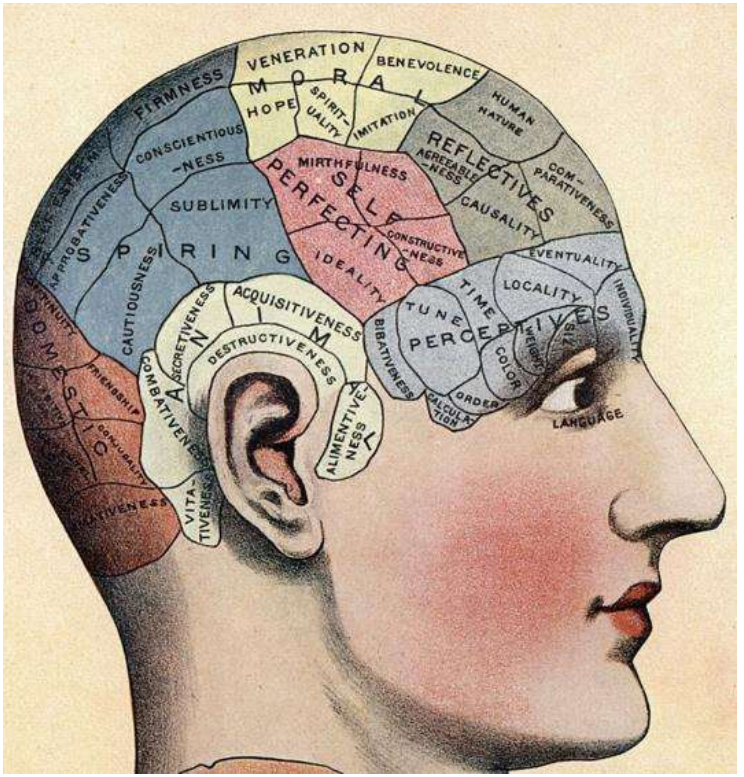
As the skull takes its shape from the brain, the surface of the skull can be read as an accurate index of psychological aptitudes and tendencies.
(Franz Joseph Gall)

Even in Gall's day, phrenology was ridiculed by many investigators. Yet, phrenology was to prove an important step forward in the history of neuroscience, especially the biological study of the mind. For one thing, phrenology's rise in popularity, despite the protestations of the Church, quickly led to a change in the academic climate where the soul was exorcised from brain functioning, thereby making it more amenable to objective and scientific investigation. Phrenology also helped establish psychology as a biological science, encouraging a more naturalistic approach to the study of behaviour, and paving the way for evolutionist theories that saw man as part of the animal kingdom. However, perhaps most important of all, was phrenology's insistence that mental faculties could be localised to discrete areas of the brain. While this idea was rejected for much of the nineteenth century by brain researchers, including Pierre Flourens who was widely regarded as the greatest authority of them all, Gall was eventually proven correct – at least in some respects. Despite its many failings, phrenology represents a point in the historical development of neuroscience where a significant break with the dogma and assumptions of the past was made. Consequently, it was crucially important in formulating a more modern way of understanding the brain.

Andrew Wickens, (2015), p. 135

functional specialization

different regions of the brain are specialized for different functions



Ward, (2020), p. 5

Cognitive neuroscience: the intersection of cognitive science and neuroscience

neural correlates of cognition ≠ causal mechanisms of cognition

Methods of cognitive neuroscience are **complementary**, and results can be viewed from a **convergence** point of view.

Different methods have different **limitations** and offer different **advantages**.

temporal resolution
the accuracy with which one can measure **WHEN** an event is occurring

spatial resolution
the accuracy with which one can determine **WHERE** an event is occurring

invasive v. **non-invasive** methods

portability

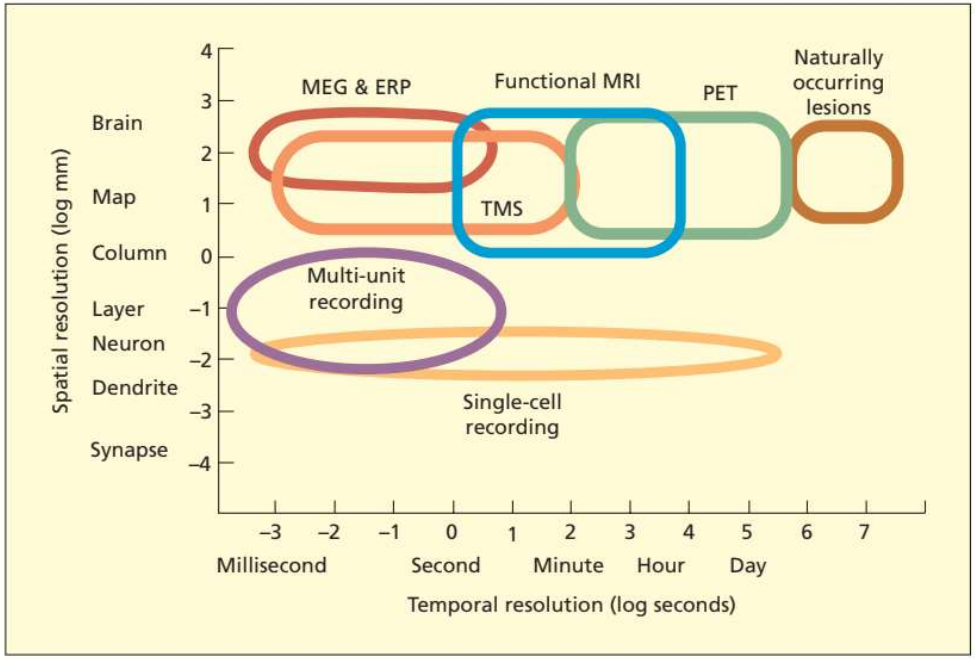


FIGURE 1.5: The methods of cognitive neuroscience can be categorized according to their spatial and temporal resolution.

Adapted from Churchland and Sejnowski, 1988.

Ward, (2020), p. 9

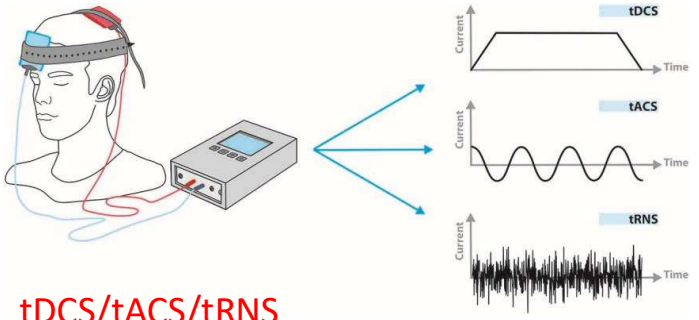
A variety of neuroscientific methods

Optogenetics
(Karl Deisseroth, but see also Zhuo-Hua Pan)

"Optogenetics makes living neurons sensitive to light by introducing special genes, carried by a virus, which produce photoreceptive proteins. By shining light on those cells — generally with a fiber-optic wire — scientists can either activate or suppress particular groups of neurons, exploring how different parts of the brain work and how they communicate with the rest of the brain."
(https://tinyurl.com/4u5426nt)

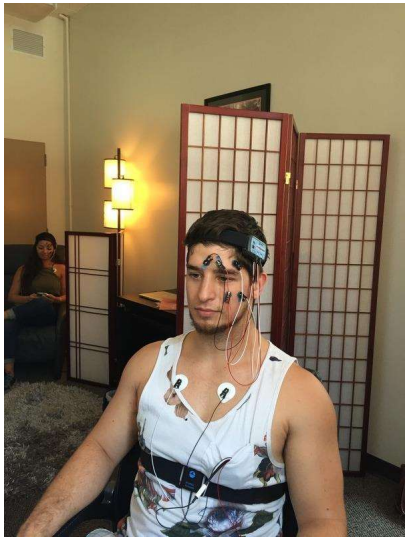
MRI/fMRI

MEG



tDCS/tACS/tRNS

TMS



Psychophysiology

EEG

and more…

A variety of neuroscientific **branches**

Systems neuroscience

how neurons connect to form networks that support different brain functions

Cellular and **molecular** neuroscience

neurons, glia, neurotransmitters, receptors

Cognitive and **behavioral** neuroscience

how brain function relates to observable/measurable cognition and behavior

Translational and **clinical** neuroscience

tries to expand/translate basic or experimental research findings into clinical tools to improve patient outcome

Computational neuroscience

tries to explain, using mathematical models, the laws that relate brain function, at different levels of detail, to observable behavior and cognition