


# Brain studies and aspects of consciousness

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Hannover, 5 Dec 2019

# Outline

- The brain, neurons, the functions, the measurement instruments
  - What is consciousness
  - Who is studying consciousness?
    - The philosophers
    - The physicists
    - The neuroscientists
  - The experiments of Benjamin Libet
  - The experiments of Giulio Tononi
  - Some perspectives
- 
- A decorative graphic consisting of several parallel white lines of varying lengths, slanted upwards from left to right, located in the bottom right corner of the slide.

# Why brain, why now ?

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*Observations*

## Why We Need to Study Consciousness

Science has made outstandingly accurate descriptions of the world but has told us little about our subjective experience of it

By Kenneth Shinozuka on September 12, 2019

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## Decoding the neuroscience of consciousness

A growing understanding of consciousness could lead to fresh treatments for brain injuries and phobias.

Emily Sohn

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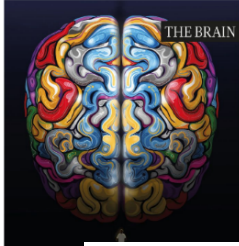
## The brain

This supremely complex organ is slowly giving up its valuable secrets.

Richard Hodson

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natureOUTLOOK




In the hand, the human brain is a jelly-like mass, easily deformed by touch. However, its unassuming appearance belies the complexity within. The brain's inner workings are mysterious. But our understanding of them is improving, as is our ability to apply that knowledge elsewhere.

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By Todd E. Feinberg, Jon Mallatt on October 17, 2018



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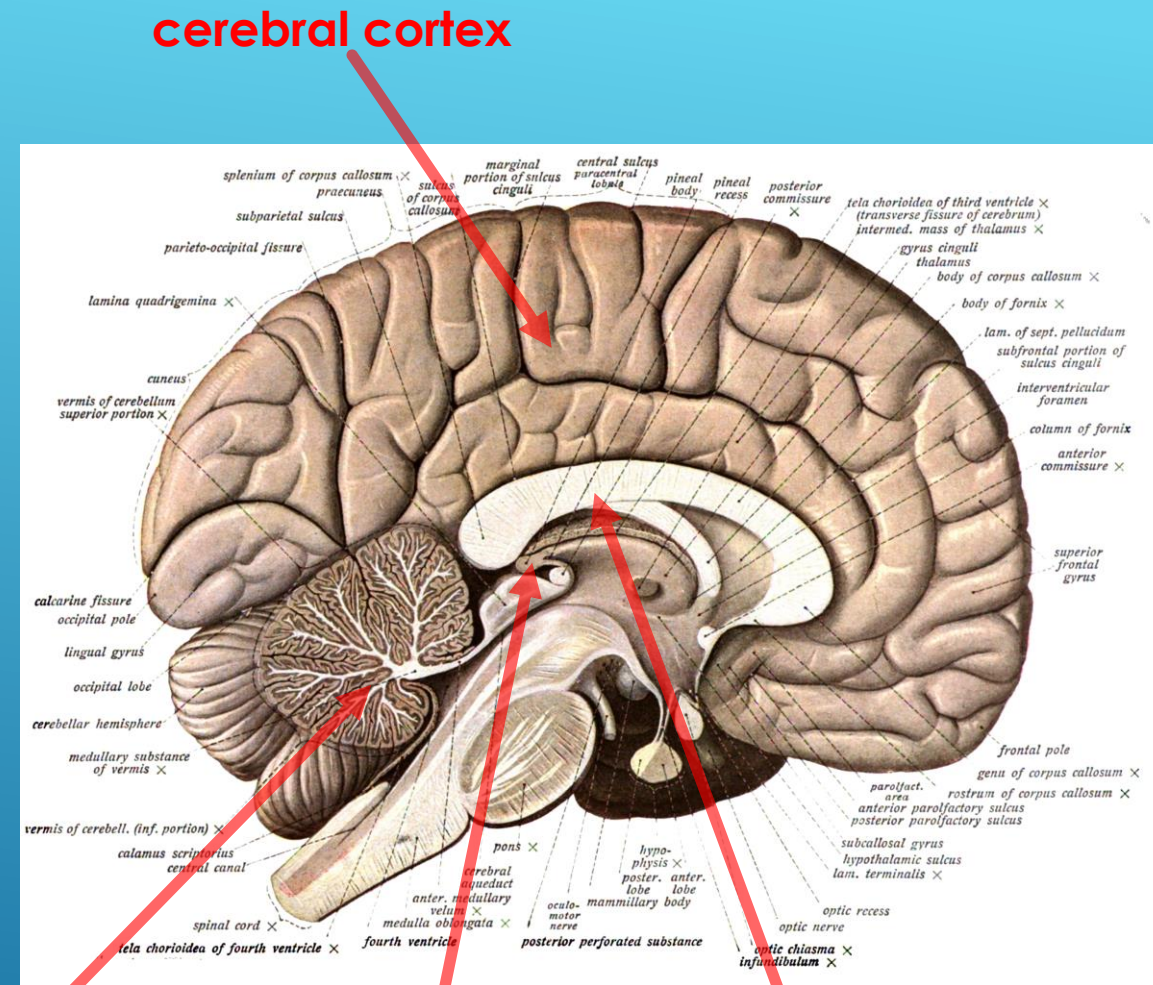
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# The brain

Aristotle believed that the heart is the superior organ; the brain is a radiator to stop the body from overheating, also if Hippocrates (years before) asserted that the brain was the site of our emotions.

Only after the Renaissance anatomy studies (Andreas Vesalius), the importance of the brain was recognized.

René Descartes describes the brain as a hydraulic system that controls behavior. “Higher” mental functions are generated by a spiritual entity, however, which interacts with the body via the pineal gland (the epiphysis).

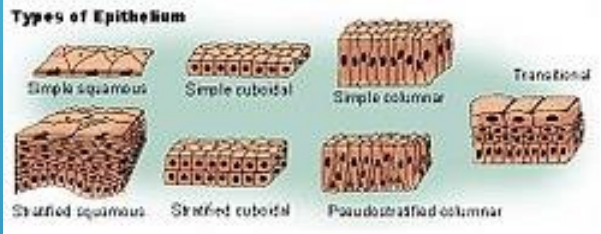


cerebellum

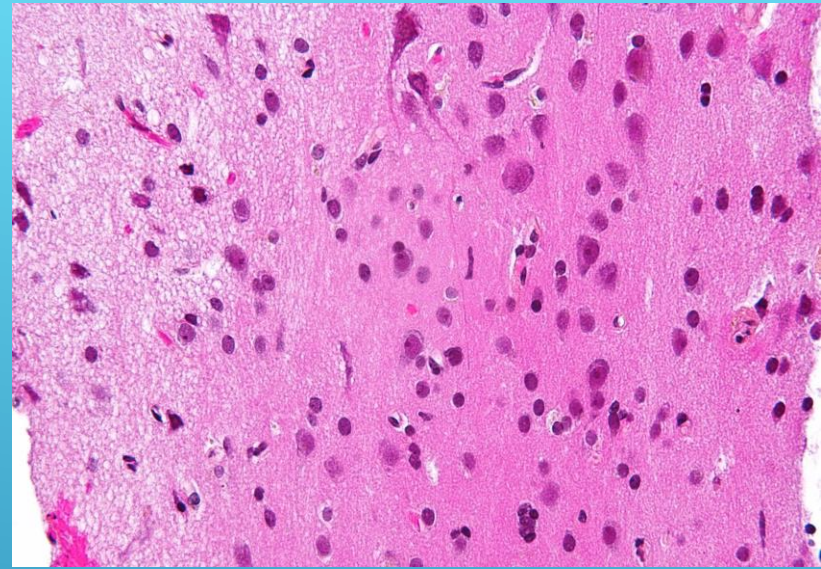
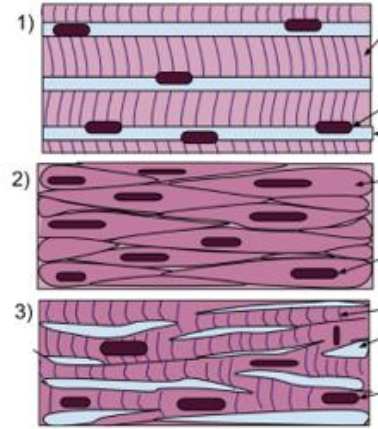
epiphysis

corpus callosum

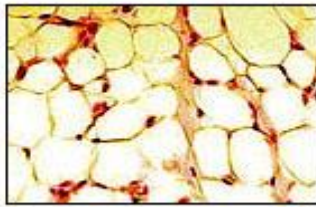
# Neural tissues are unique



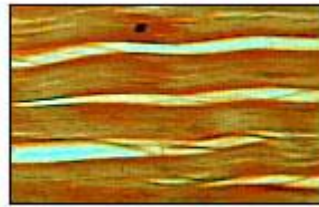
## Muscular tissue



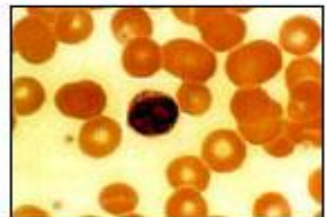
Areolar connective tissue



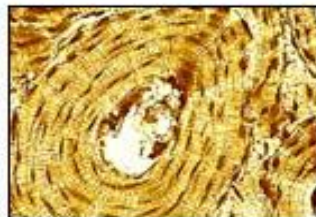
Adipose tissue



Fibrous connective tissue



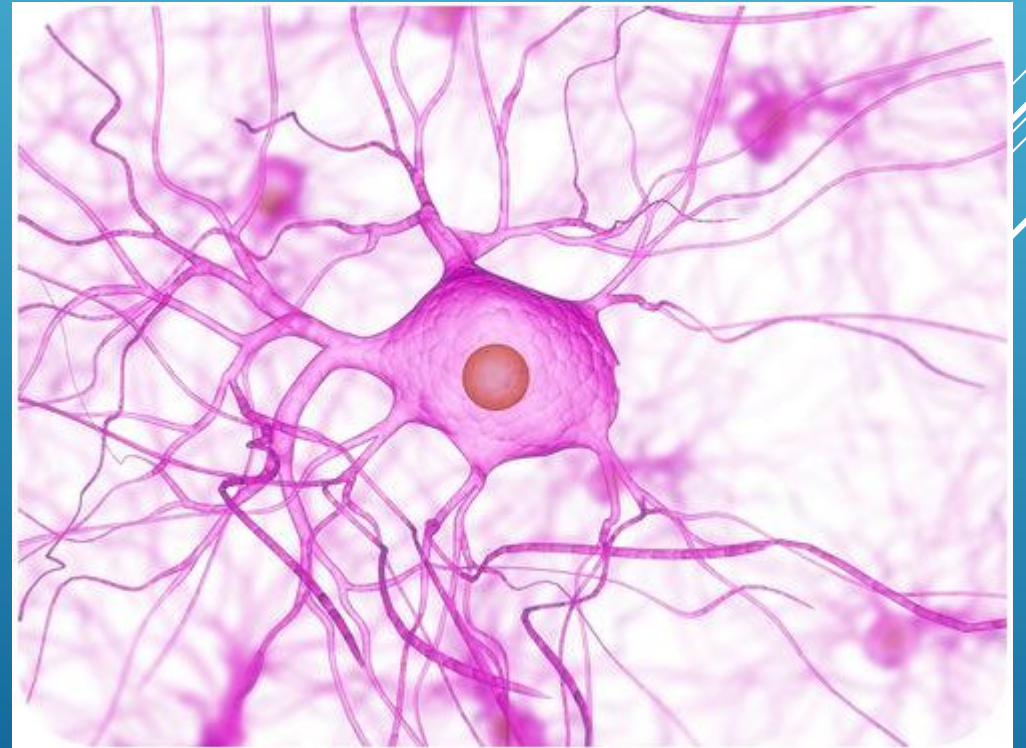
Blood



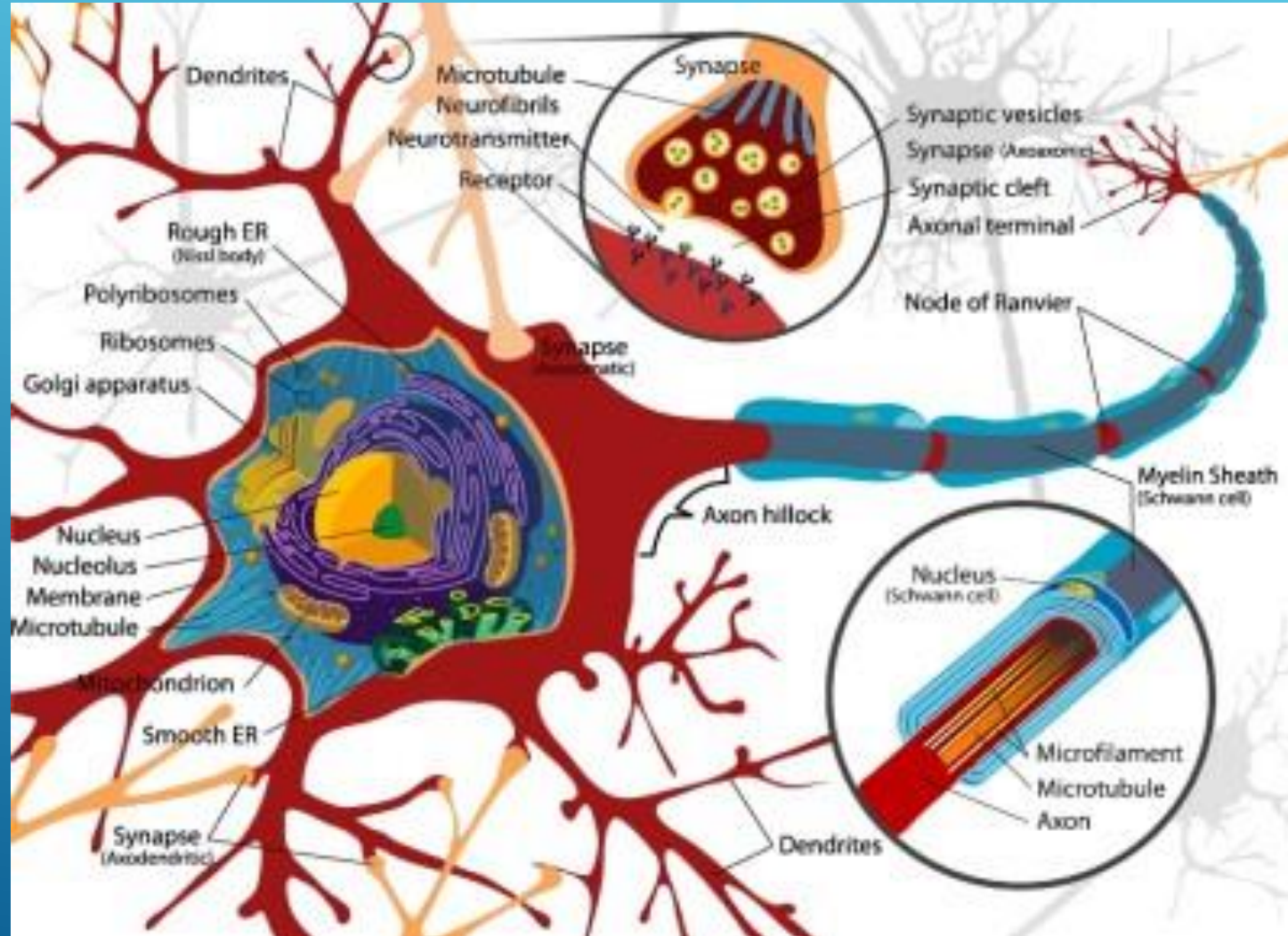
Osseous tissue



Hyaline cartilage

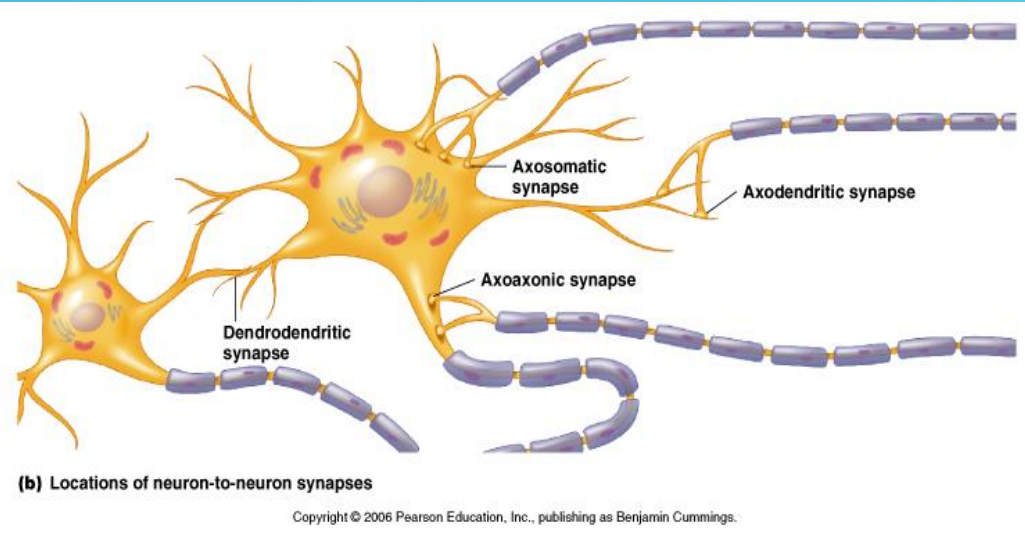


# Neurons

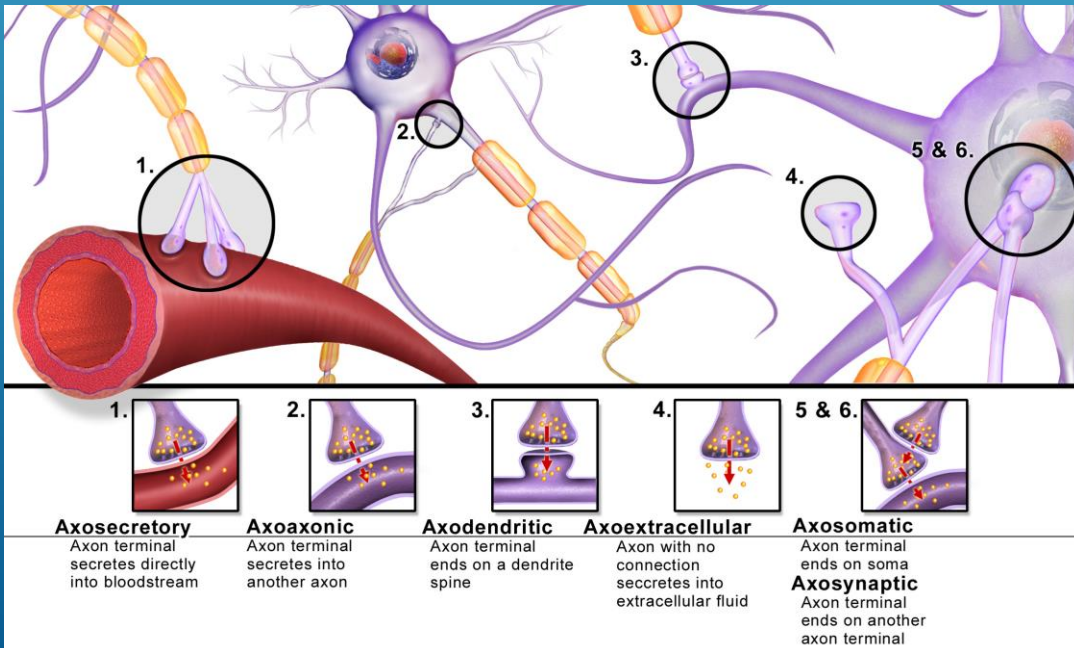


There are  $1 \sim 2 \times 10^{10}$  neurons in the cerebral cortex and 55~70 billions in the cerebellum.

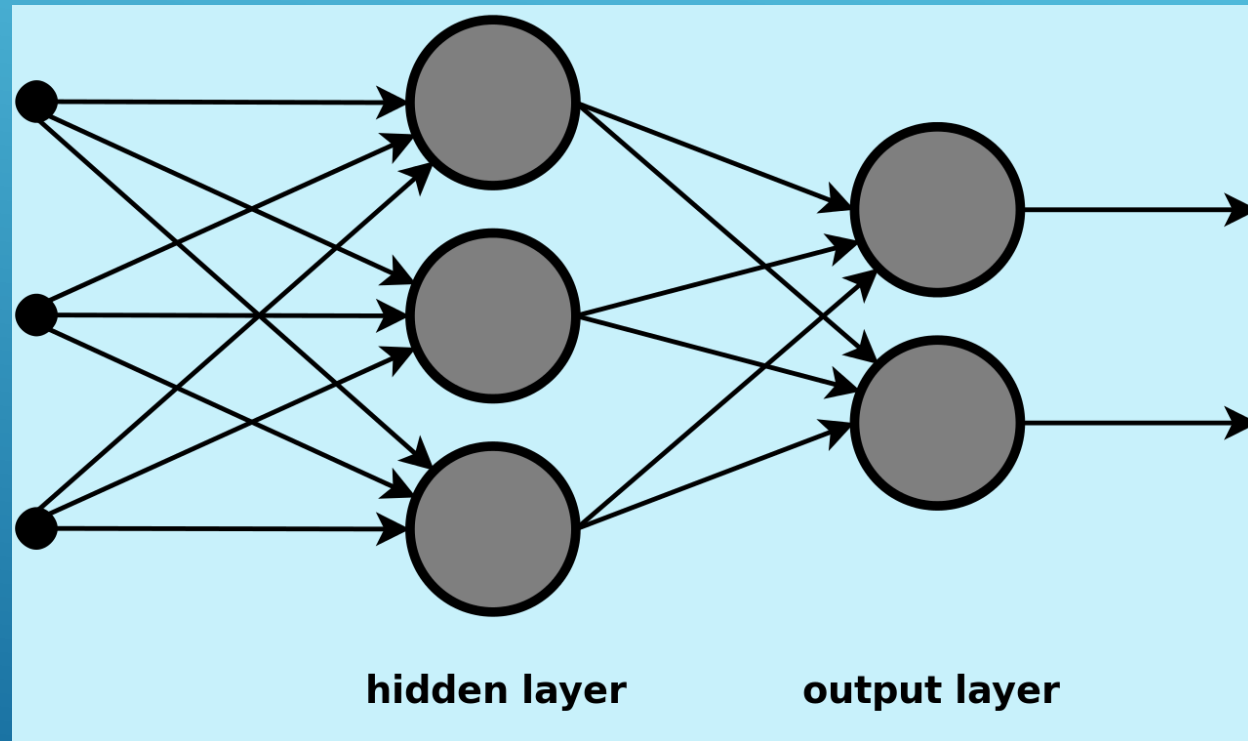
# Synapses



- Electrical
- Chemical



# Artificial neurons



$$y_k = \varphi \left( \sum_{j=0}^m w_{kj} x_j \right)$$



# Brain functions

Regulation

Sensory

Movements

Language

Cognition

Emotion

Consciousness

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses".

Cognitive processes use existing knowledge and generate new knowledge.

# Neuroimaging

Computed axial tomography (x-ray and inverse Radon transform)

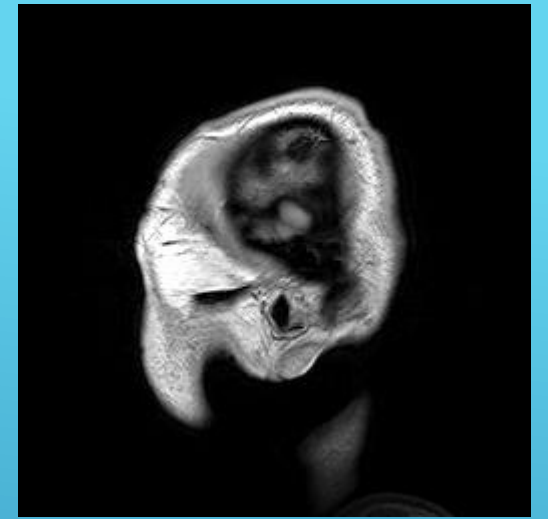
Magnetic resonance imaging

Functional magnetic resonance imaging (based on the properties of the emoglobin)

Electroencephalography (EEG)

Magnetoencephalography

Positron emission tomography



Magnetic resonance



Computer tomography

# Consciousness

- A definition of consciousness is “the awareness of ourselves and of the external world”.
- Obviously this is not satisfactory: we simply have deferred the definition of consciousness to that of awareness.
- But, probably, we can use the words used by Louis Armstrong to whom who asked what is Jazz: *“If you gotta ask, you’ll never know.”*
- The problem to delve with consciousness is that, although it is immediate to verify in ourselves, it seems impossible to prove the existence in other persons or animals.
- Moreover, we cannot know how to “measure” it.
- Note that in Romance languages the same word is used for **consciousness** and **conscience** (deriving both from the latin *conscientia*)

# “Hard science” and consciousness

- Physical laws describe many systems very well.
  - Perhaps all chemistry and biology (and, why not ? also psychology and sociology). Perhaps the behavior and evolution of any organism.
  - But would these organisms be conscious or would they be ‘zombies’ that could do anything - love or the Thirty Years’ War – with no awareness ?
- Which is the origin of consciousness ?
  - is it an emergent property of the **complex systems** ? (but how ?)
  - is it a property already present in **elementary particles** ?
  - are there other explanations, as **«the ghost in the machine»** (the cartesian dualism or, in a religious form, the «soul») ?
- **Perhaps we need new physics (or more physics).**

# Conscious and unconscious cognition or actions

Not all stimuli come to consciousness, only a little part indeed.

To bring something to consciousness we need time.

Many activities, as walking, driving, playing music and sometimes also speaking are activities that are only partially conscious. Perhaps almost all activities are unconscious, also problem solving and artistic creation.

The placebo effect seems possible also without consciousness.

A decorative graphic consisting of several parallel white lines of varying lengths and orientations, located in the bottom right corner of the slide.

# Behaviorism and “Renaissance of consciousness”

Because of the problems to tackle consciousness, at the beginning of XX century “**Behaviorism**”, an approach to psychology studies emerged and became hegemonic. The main scientists were John B. Watson and Burrhus F. Skinner.

**Behaviorism claims that consciousness is neither a definite nor a usable concept.** The only thing that psychology can investigate, in men and animals, is the behavior. So psychology eluded all ambits where consciousness had a role.

Anyway it is obvious that the presence of consciousness defines the psychology of man and his behavior.

The situation changed at the end of the seventies, and slowly studies on consciousness flourished.

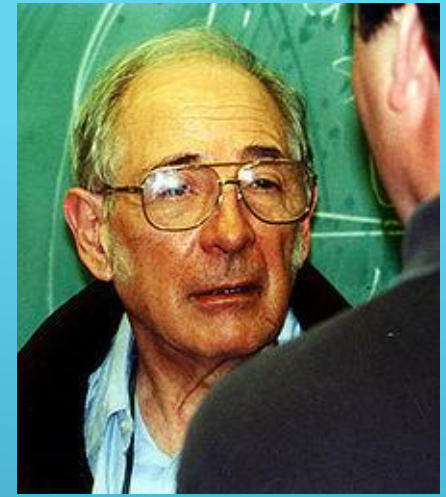
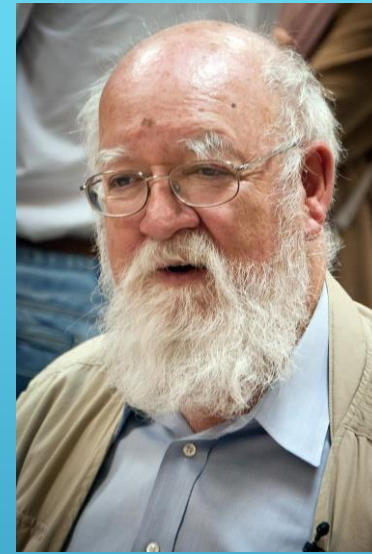
Three type of scholars have been the actors of this period: **philosophers, physicists** and **neuroscientists**.

**The results are not big, the studies are non mature, the situation is involved, but something is moving.**

And today consciousness has been recognized as one of the main scientific topics.

# “Philosophers”

- Daniel Dennet
- John Searle (see the chinese room)
- Paul Churchland
- Patricia Smith Churchland
- David Chalmers (the «hard problem of consciousness»)
- Susan Blackmore



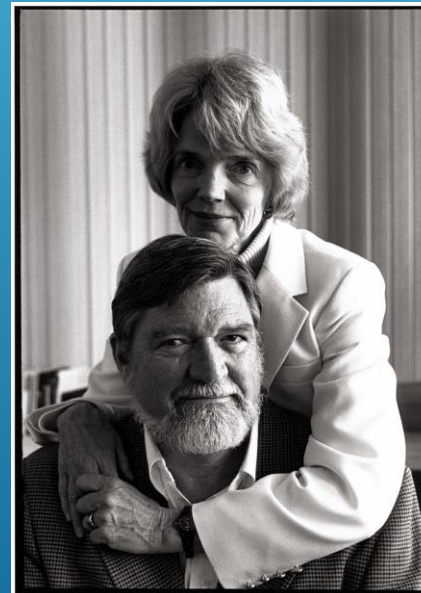
The work of philosophers at beginning was very important, but then became sterile.

A scientist searches for solutions to a problem.

A philosopher searches for problems in a solution.

Scientists “simplifies” the problem and solve the simplified problem.

Philosophers seek complexities in a problem.



# What have philosophers done ?

They analyzed the problem, defined all the possible positions about the problem, divided themselves, creating schools and fighting with high assurance.

Among the different positions,

- the AI to generate consciousness (??)
- the inexistence of consciousness: consciousness is an illusion (but who can be deluded, if there are no conscious being ?)



The screenshot shows the top portion of a Scientific American article. At the top, there are navigation links for 'Subscribe' and 'Latest Issues' on the left, the 'SCIENTIFIC AMERICAN' logo in the center, and 'Cart 0', 'Sign In', and 'Stay Informed' on the right. Below this is a horizontal menu with categories: 'THE SCIENCES', 'MIND', 'HEALTH', 'TECH', 'SUSTAINABILITY', 'EDUCATION', 'VIDEO', 'PODCASTS', 'BLOGS', and 'PUBLICATIONS'. The main heading of the article is 'COGNITION' followed by the title 'There Is No Such Thing as Conscious Thought' in a large, bold, serif font. Below the title is a sub-headline: 'Philosopher Peter Carruthers insists that conscious thought, judgment and volition are illusions. They arise from processes of which we are forever unaware'. At the bottom, it says 'By Steve Ayan on December 20, 2018' and 'أعرض هذا باللغة العربية'.



# The Turing test (the algorithmic zombies)

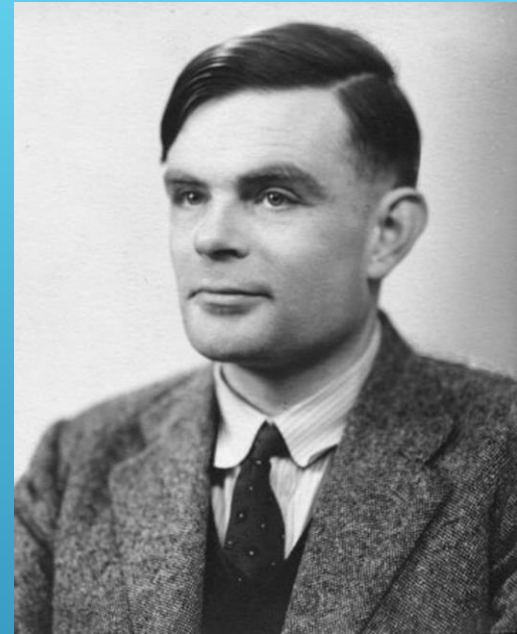
A. M. Turing (1950) *Computing Machinery and Intelligence*. *Mind* 49: 433-460.

## COMPUTING MACHINERY AND INTELLIGENCE

By A. M. Turing

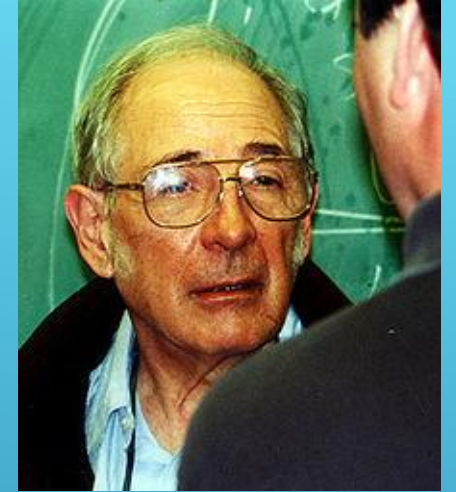
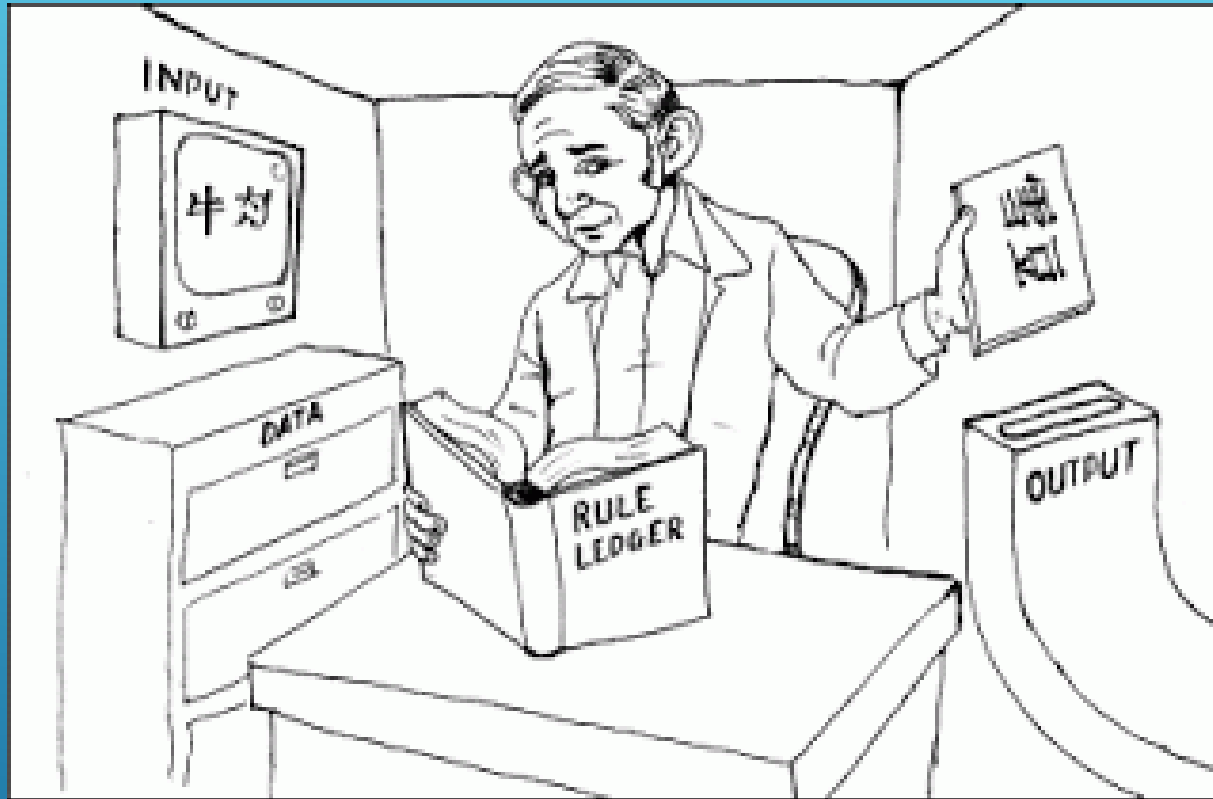
### 1. The Imitation Game

I propose to consider the question, "Can machines think?" This should begin with definitions of the meaning of the terms "machine" and "think." The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words "machine" and "think" are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, "Can machines think?" is to be sought in a statistical survey such as a Gallup poll. But this is absurd. Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words.



- ▶ In a famous paper, on the dawn of informatics, Alan Turing asks «Can the machine think?», where «think» means **«to show an intelligent behaviour»**.
- ▶ To do the test, Turing proposes to have a chat between a human and a machine; if the human cannot recognize non-human behaviour in the machine, the machine has overcome the test.
- ▶ Today computers overcome the test.
- ▶ The test is obvious not the proof of a consciousness of the machine, but this point has been cause of many ambiguities (**behaviour cannot be used to investigate consciousness**).

# The chinese room (John Searle)



This simply demonstrates that «intelligent» behaviour is not related to consciousness.

**Would a non-conscious being interrogate herself on it ? The existence of the problem is a demonstration that consciousness does exist.**

# The question has long been clear to (some) physicists

**Werner Heisenberg:** "The discontinuous change in the wave function takes place with the act of registration of the result by the mind of the observer. It is this discontinuous change of our knowledge in the instant of registration that has its image in the discontinuous change of the probability function."

**Von Neumann:** "consciousness, whatever it is, appears to be the only thing in physics that can ultimately cause this collapse or observation."

**Max Planck:** "I regard consciousness as fundamental. I regard matter as derivative from consciousness." *J. W. N. Sullivan, Observer, 25 January 1931, p. 17*

**Erwin Schrodinger:** "The only possible inference ... is, I think, that I –I in the widest meaning of the word, that is to say, every conscious mind that has ever said or felt 'I' -am the person, if any, controls the 'motion of the atoms'. ...The personal self equals the omnipresent, all-comprehending eternal self... There is only one thing, and even in that what seems to be a plurality is merely a series of different personality aspects of this one thing, produced by a deception."

**Freeman Dyson:** "At the level of single atoms and electrons, the mind of an observer is involved in the description of events. Our consciousness forces the molecular complexes to make choices between one quantum state and another."

(cont.)

**Eugene Wigner:** "It is not possible to formulate the laws of quantum mechanics in a consistent way without reference to the consciousness."

**Niels Bohr:** "Everything we call real is made of things that cannot be regarded as real. A physicist is just an atom's way of looking at itself."

**Wolfgang Pauli:** "We do not assume any longer the *detached observer*, but one who by his indeterminable effects creates a new situation, a new state of the observed system"

**John Stewart Bell:** "As regards mind, I am fully convinced that it has a central place in the ultimate nature of reality."

**Martin Rees:** "The universe could only come into existence if someone observed it. It does not matter that the observers turned up several billion years later. The universe exists because we are aware of it."

# Quantum Mechanics, brain and consciousness.

Many attempts to solve problems of cognition and consciousness have been based on quantum mechanics, but invariably fail because the size and the temperature of the brain and neurons seem to exclude quantum coherence.

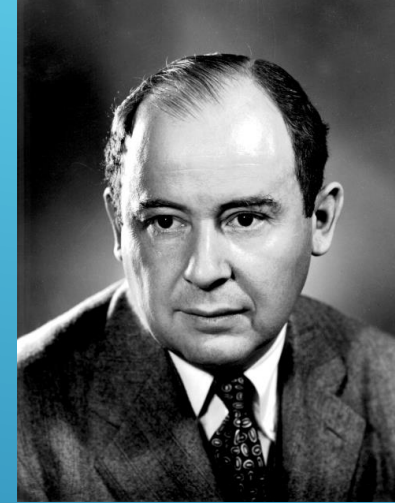
The unicity of the self, and a non-hierarchical structure of the brain, suggest that quantum coherence could have a role.

A decorative graphic consisting of several parallel white lines of varying lengths, slanted diagonally from the bottom right towards the top right, set against a blue gradient background.

# Von Neumann–Wigner interpretation of quantum mechanics

The von Neumann–Wigner interpretation, also described as "consciousness causes collapse [of the wave function]", is an interpretation of quantum mechanics in which consciousness is postulated to be necessary for the completion of the process of quantum measurement.

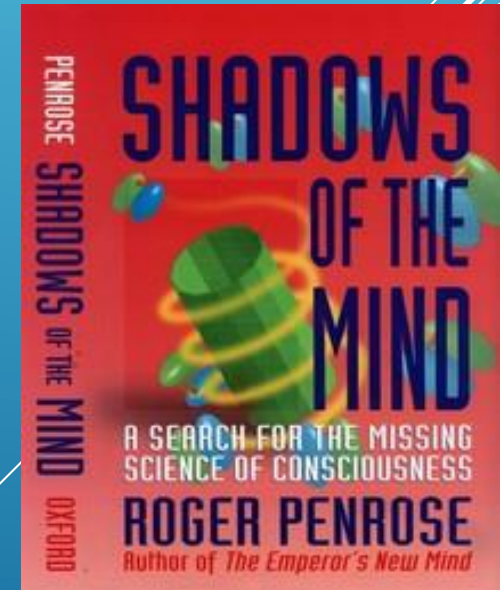
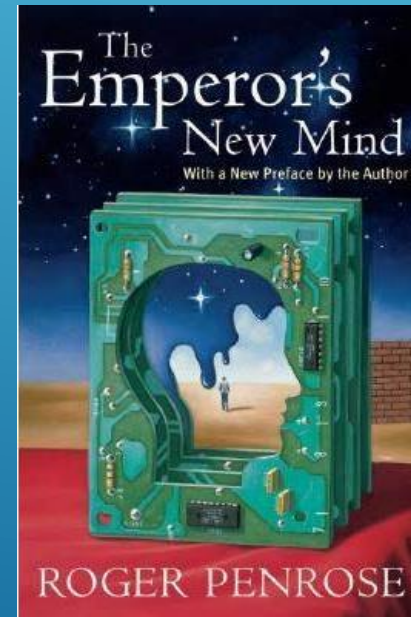
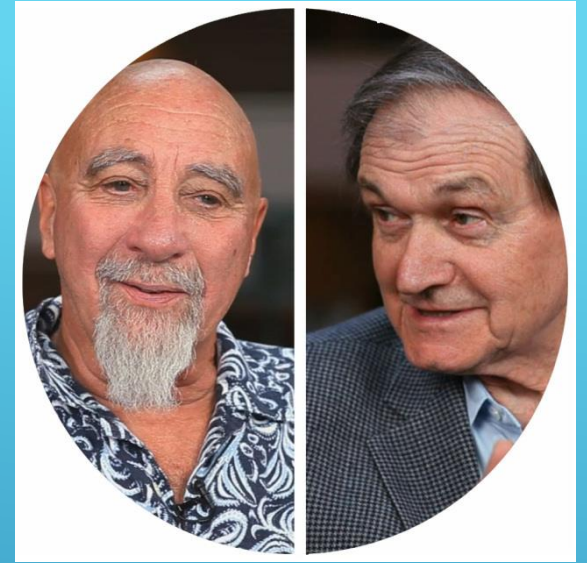
This idea was developed, among others, by Henry Stapp (*Mind, Matter and Quantum Mechanics* (2009) *Mindful Universe: Quantum Mechanics and the Participating Observer*. (2011) *Quantum Theory and Free Will: How Mental Intentions Translate into Bodily Actions*. (2017)).

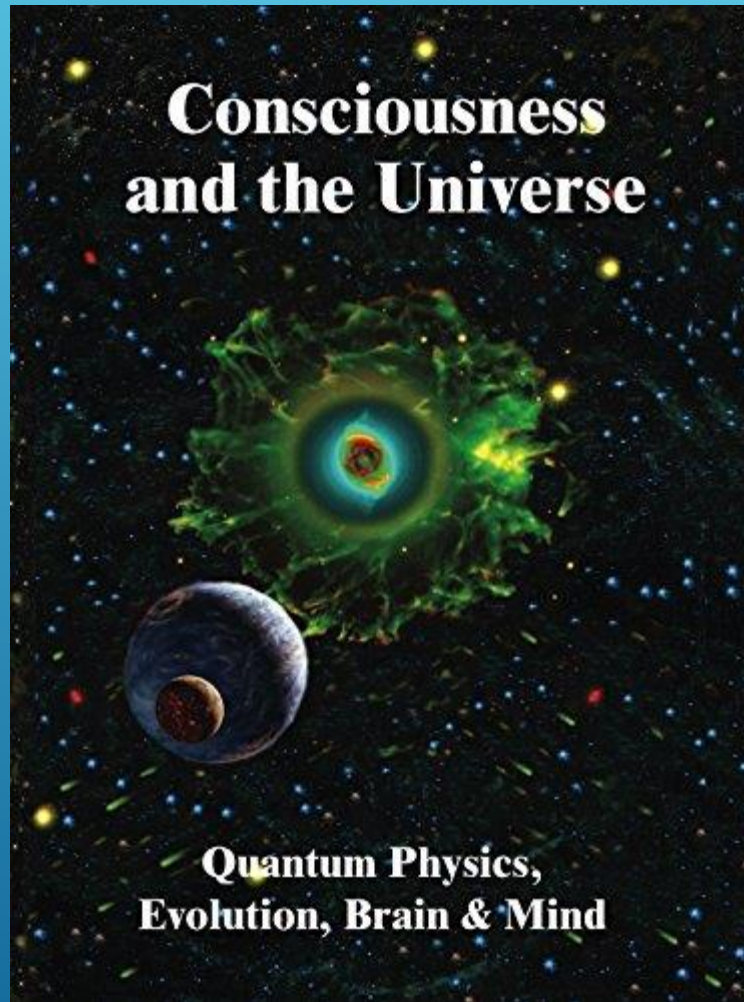


# Roger Penrose theory (with Stuart Hameroff)

Orchestrated objective reduction (Orch OR) is a theory that postulates that consciousness originates at the quantum level inside neurons, rather than the conventional view that it is a product of connections between neurons. The mechanism is held to be a quantum process called objective reduction that is orchestrated by cellular structures called microtubules. It is proposed that the theory may answer the hard problem of consciousness and provide a mechanism for free will.

Max Tegmark (MIT) and others criticize the theory, quantitatively.





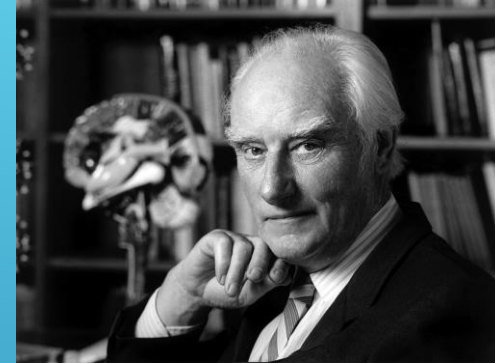
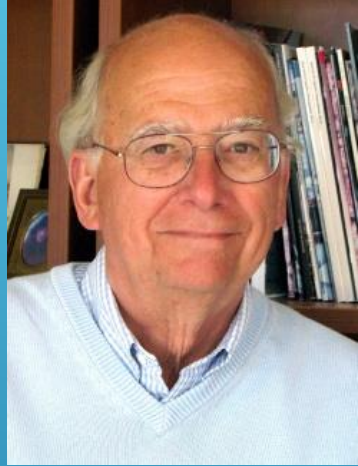
A collection of theories primarily by physicists, edited by Roger Penrose, 2017 (last edition)

1. Consciousness in the Universe: Neuroscience, Quantum Space-Time Geometry and Orch OR Theory
16. The Macro-Objectification Problem and Conscious Perceptions, Gian Carlo Ghirardi
49. Quantum Reality and Mind, Henry P. Stapp

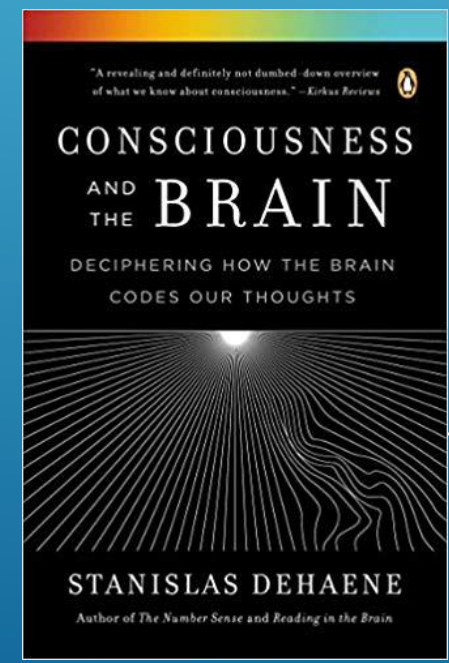
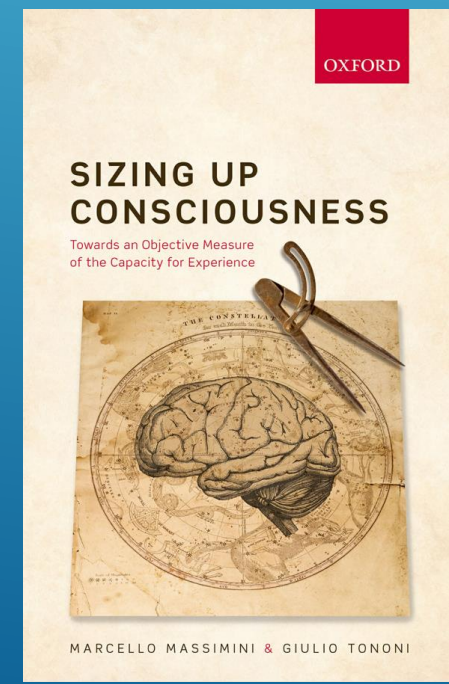
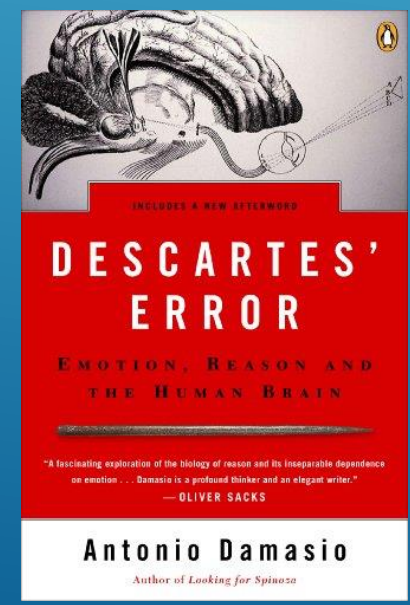
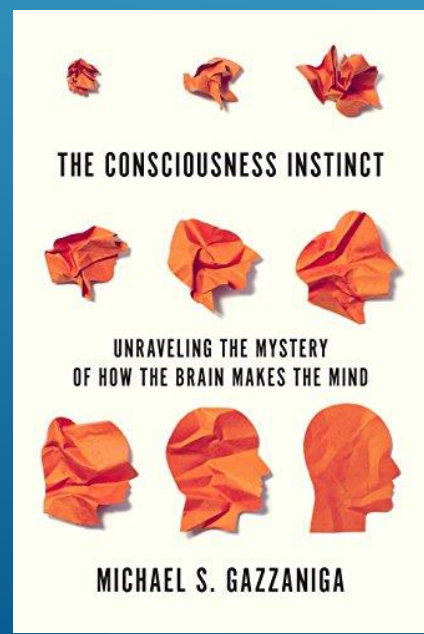
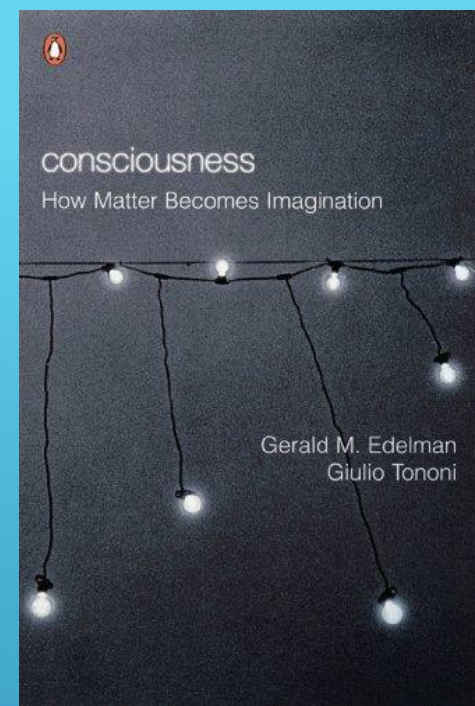
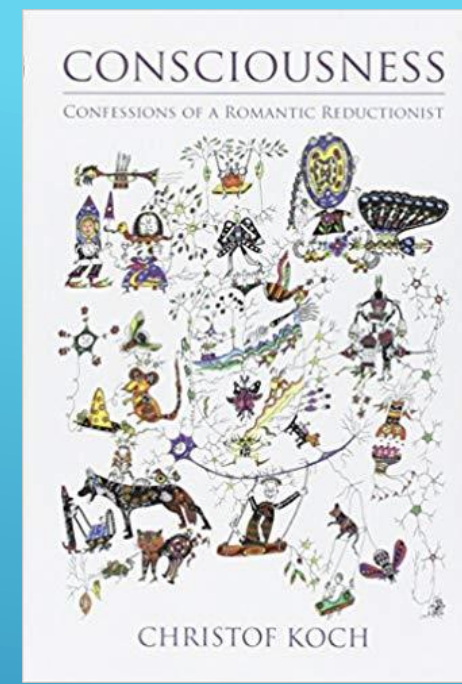
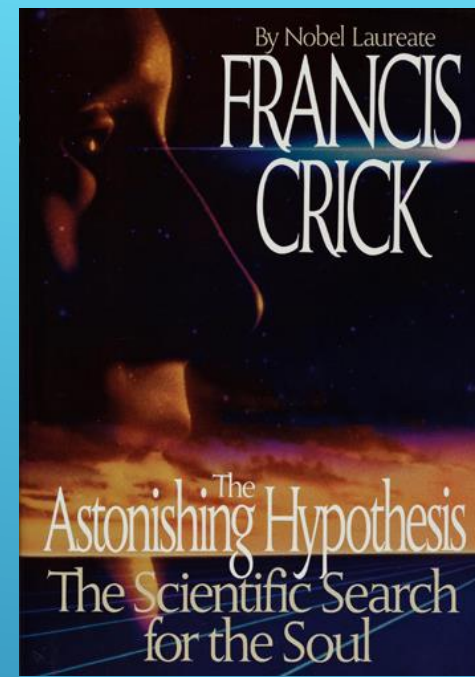
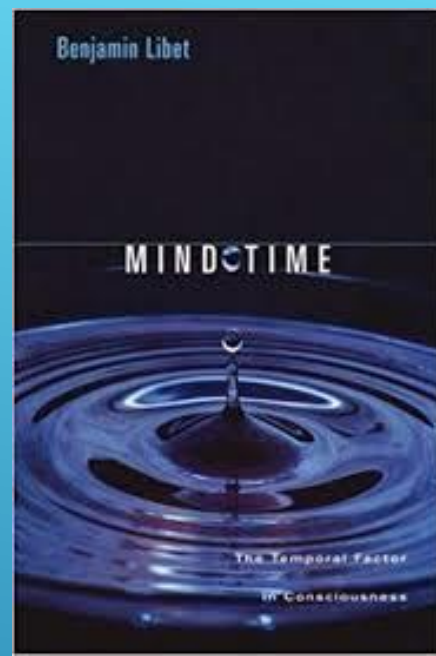


# Neuroscientists and biologists

John Eccles  
Benjamin Libet  
Francis Crick  
Christof Koch  
Michael Gazzaniga  
Antonio Damasio  
Gerald Edelman  
Giulio Tononi  
Marcello Massimini  
Stanislas Dehaene



# Some books



# Neural correlate of consciousness (NCC)

The Neuronal Correlates of Consciousness (NCC) constitute the smallest set of neural events and structures sufficient for a given conscious percept or explicit memory.

Neuroscientists use empirical approaches to discover neural correlates of subjective phenomena; that is, neural changes which necessarily and regularly correlate with a specific experience.

Note that we speak of “correlation”, not “causation”.

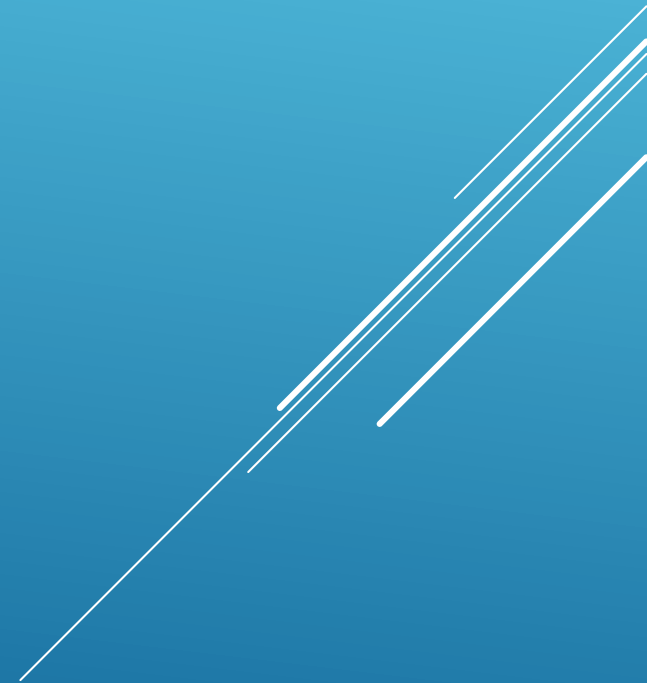


# Free will

Free will is the ability to choose between different possible courses of an unimpeded action, and the choice comes from the person and not from external forces.

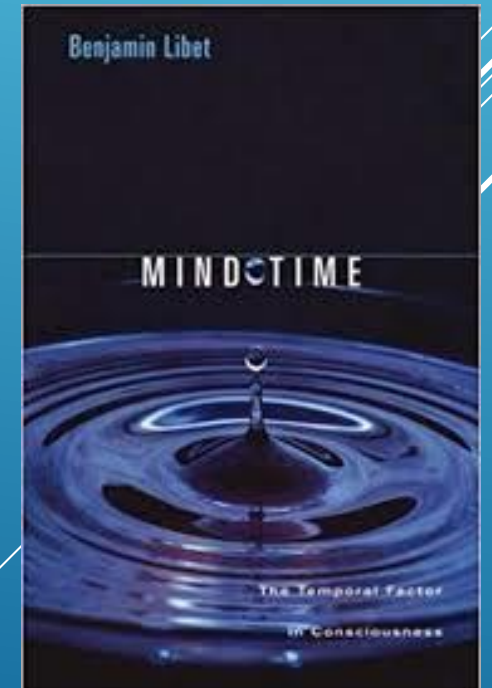
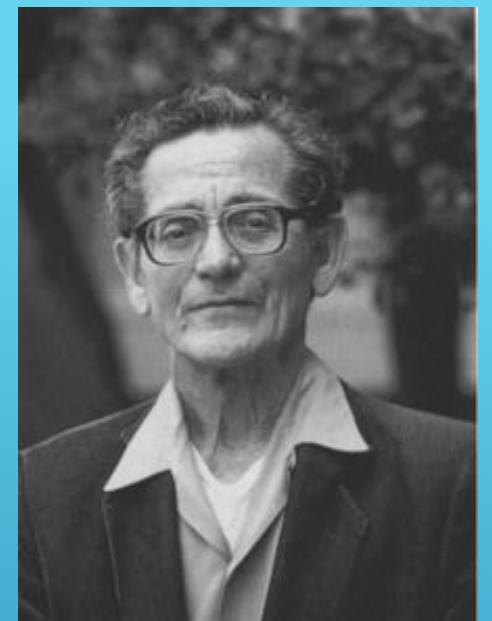
The existence of free will is fundamental to define the bases of the responsibility and then the right and ethics.

It is connected to consciousness, but it is different: you should be conscious to have free will, but you can be conscious without having free will.

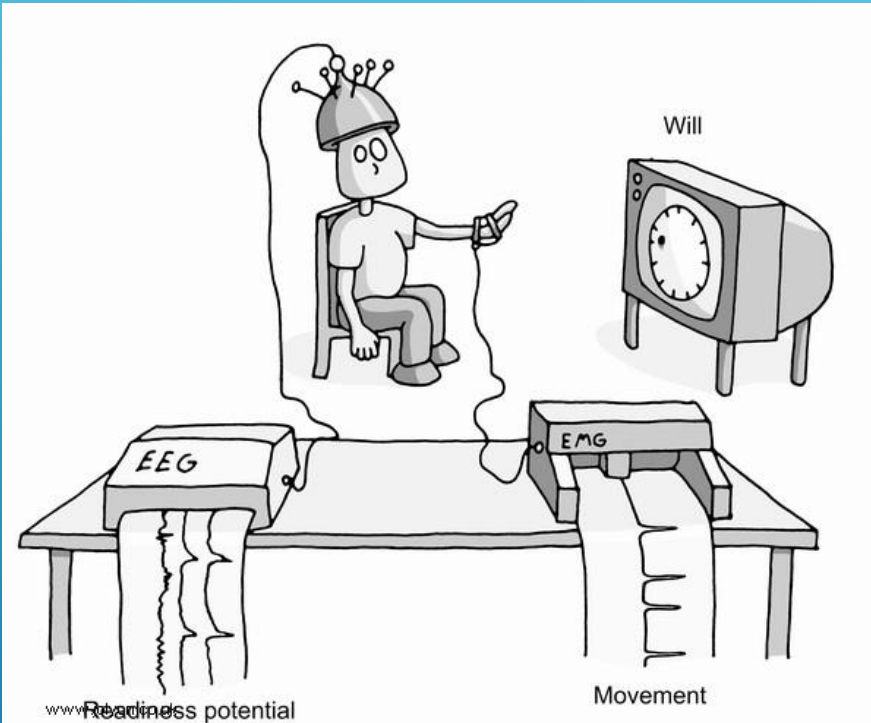


# Benjamin Libet (1916-2007)

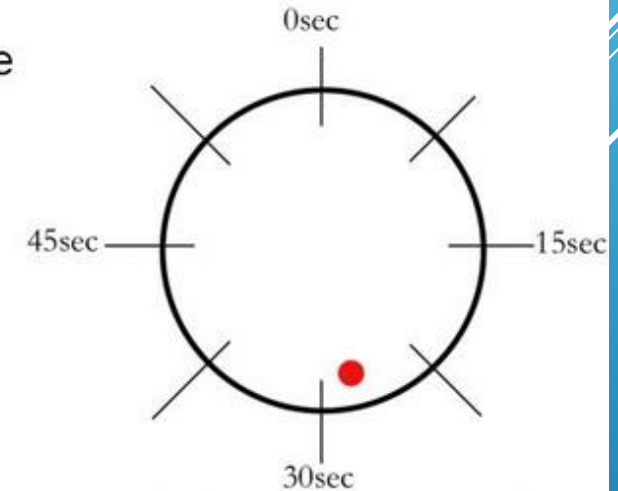
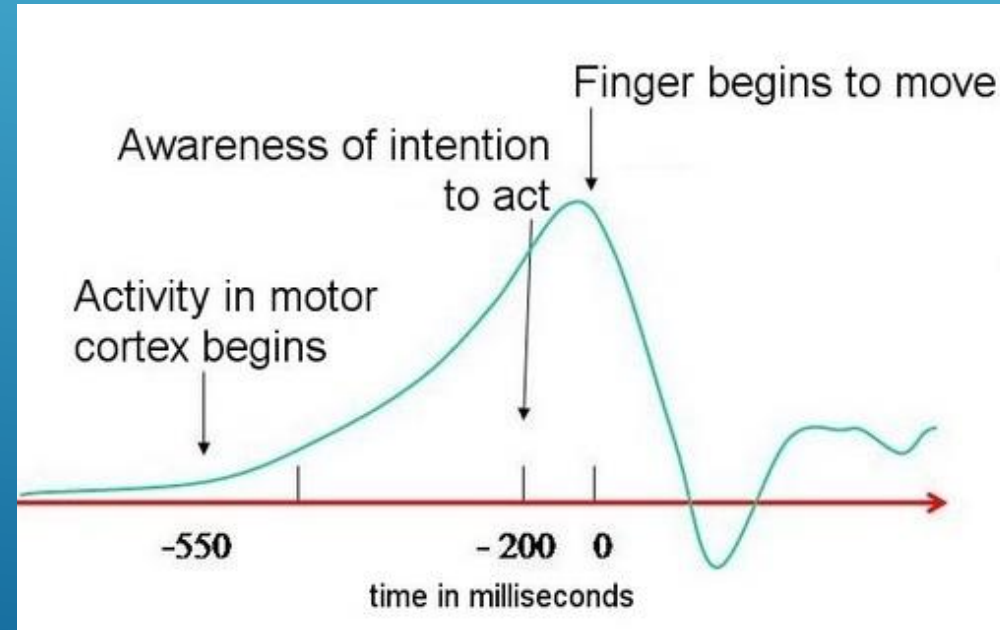
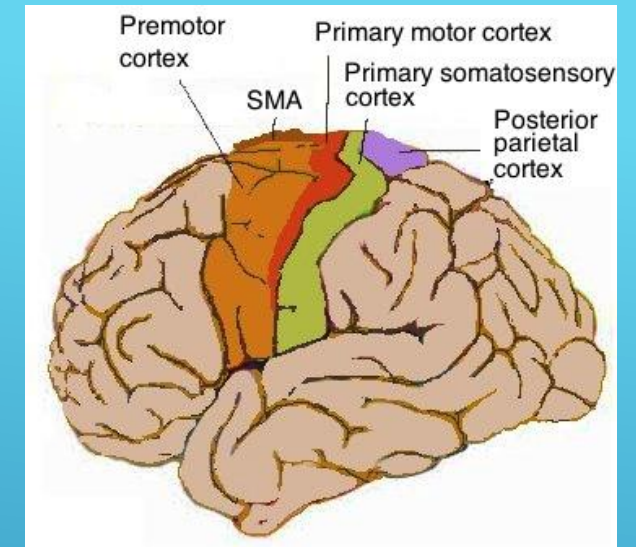
- ▶ He was an American neurophysiologist
- ▶ He worked at the University of California in San Francisco
- ▶ In 2003 he was awarded the «Virtual Nobel Prize in Psychology»
- ▶ Using the **readiness potential** discovered by Hans Helmut Kornhuber, he studied how the evolution of the execution of an action and the awareness of this.



# Libet experiment



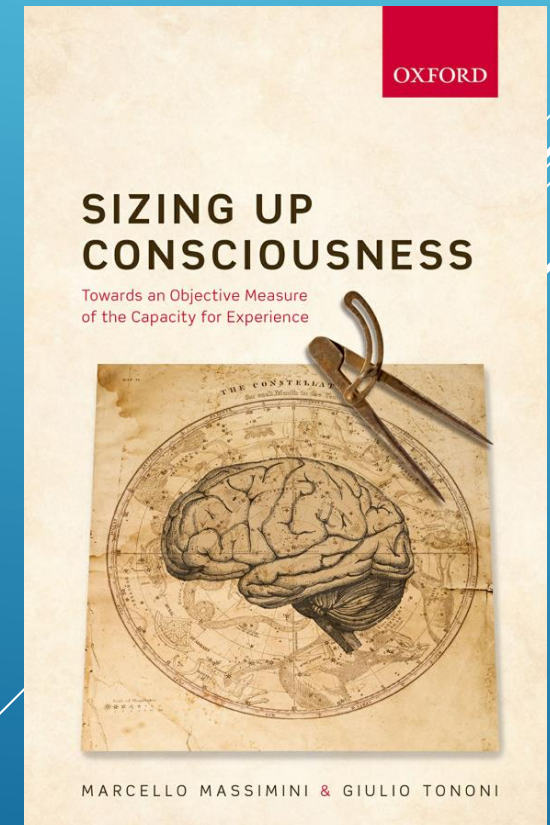
Motor cortex  
(excited during  
voluntary  
movements)



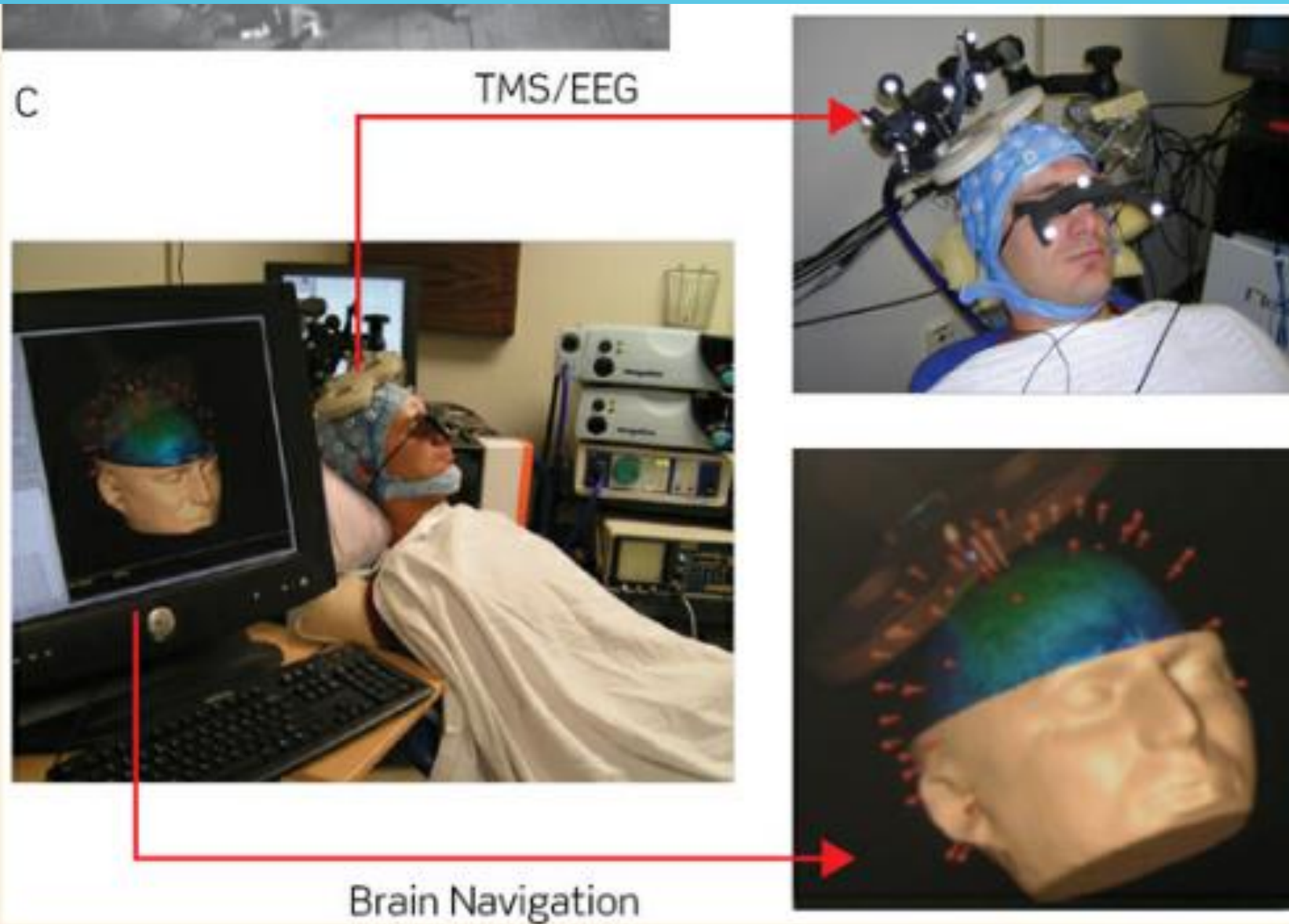
Libet's electronic clock. The subject notes where the red dot is when his/her intention to act arises.

# Giulio Tononi

- ▶ is an Italian neuroscientist and psychiatrist who holds the David P. White Chair in Sleep Medicine, as well as a Distinguished Chair in Consciousness Science, at the University of Wisconsin (Madison)
- ▶ He worked with Gerald Edelman (*A Universe of Consciousness: How Matter Becomes Imagination* (2000))
- ▶ He developed a technique that found an interesting neural correlate of consciousness, based TMS (transcranial magnetic stimulation) brain excitation and the EEG (electroencephalogram).
- ▶ **Observing the excitation of the brain neurons, we can establish the conscious state of a man or animal.**
- ▶ This test gives also an idea on how consciousness works, as a non-local property of the brain.



# TMS-EEG system: typical experimental setup

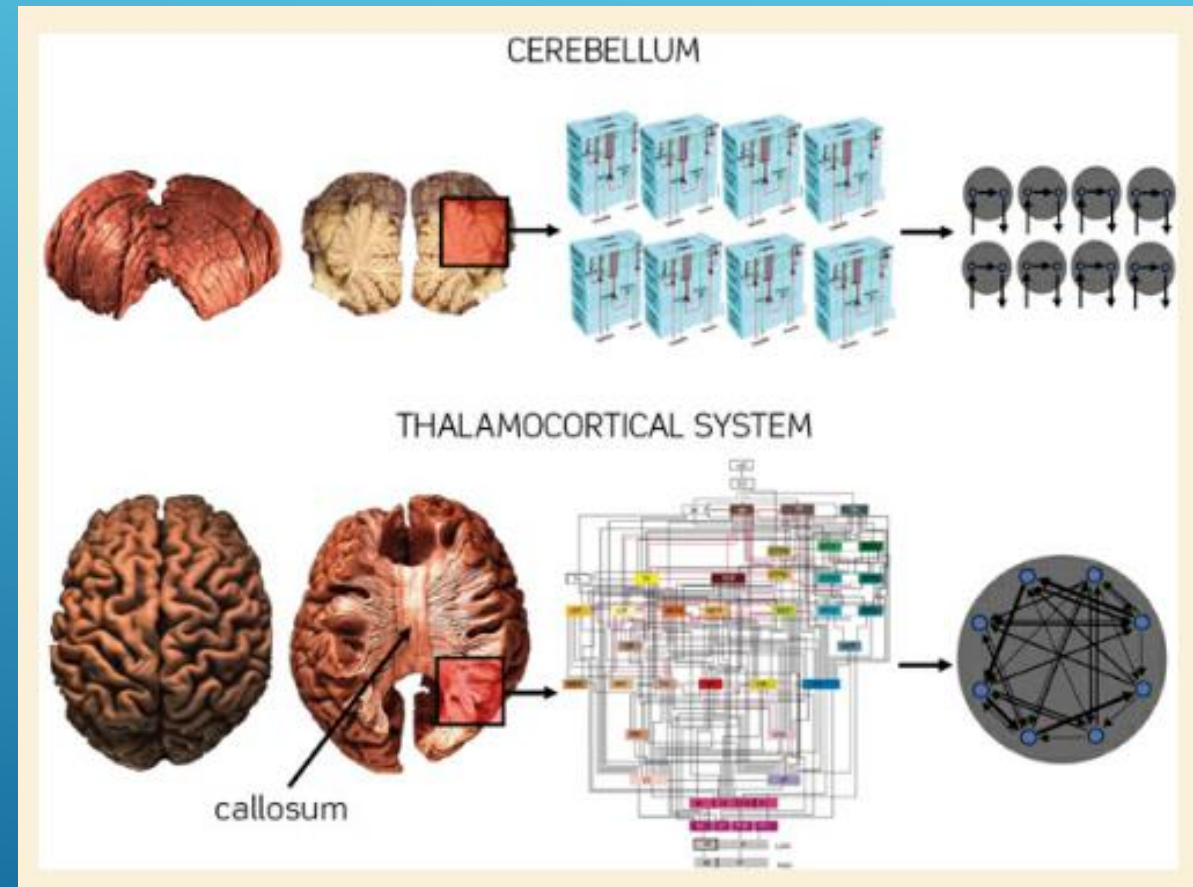




# A comparison between the architecture of the cerebellum (top) and the one of the thalamocortical system (bottom)

Opening between the two hemispheres of the cerebellum, reveals the complete absence of connections between the right and the left side of the structure. Instead, the two hemispheres of the cerebral cortex are connected by the 200 million fibers of the corpus callosum.

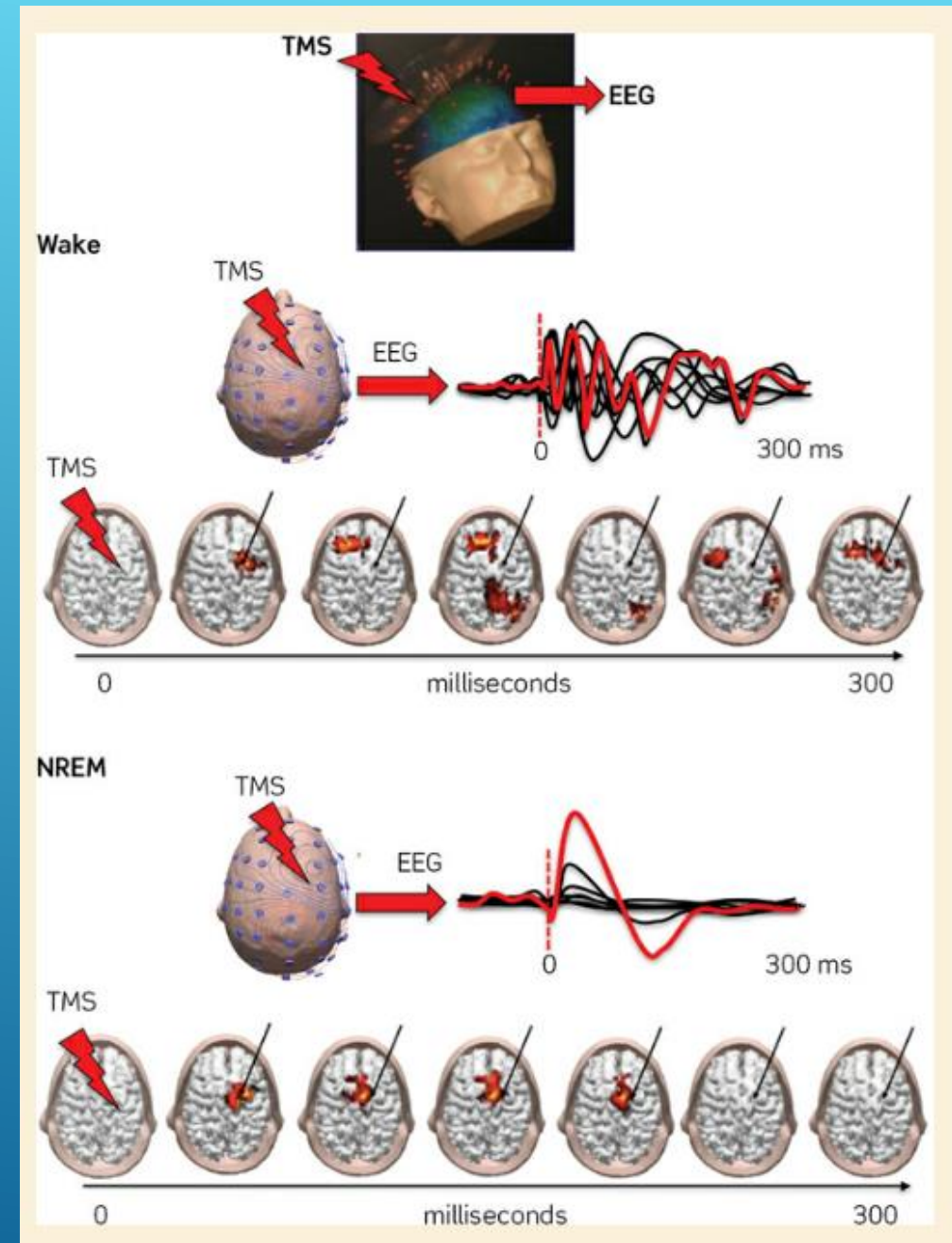
A microscopic examination shows that the cerebellar cortex is composed of myriads of segregated feed-forward circuits that do not form an integrated entity. Conversely, the cerebral cortex is characterized by a balanced architecture that is, at once, highly integrated and highly differentiated. This is exemplified here by the Van Essen Matrix, which summarizes the connectivity patterns of the visual system.



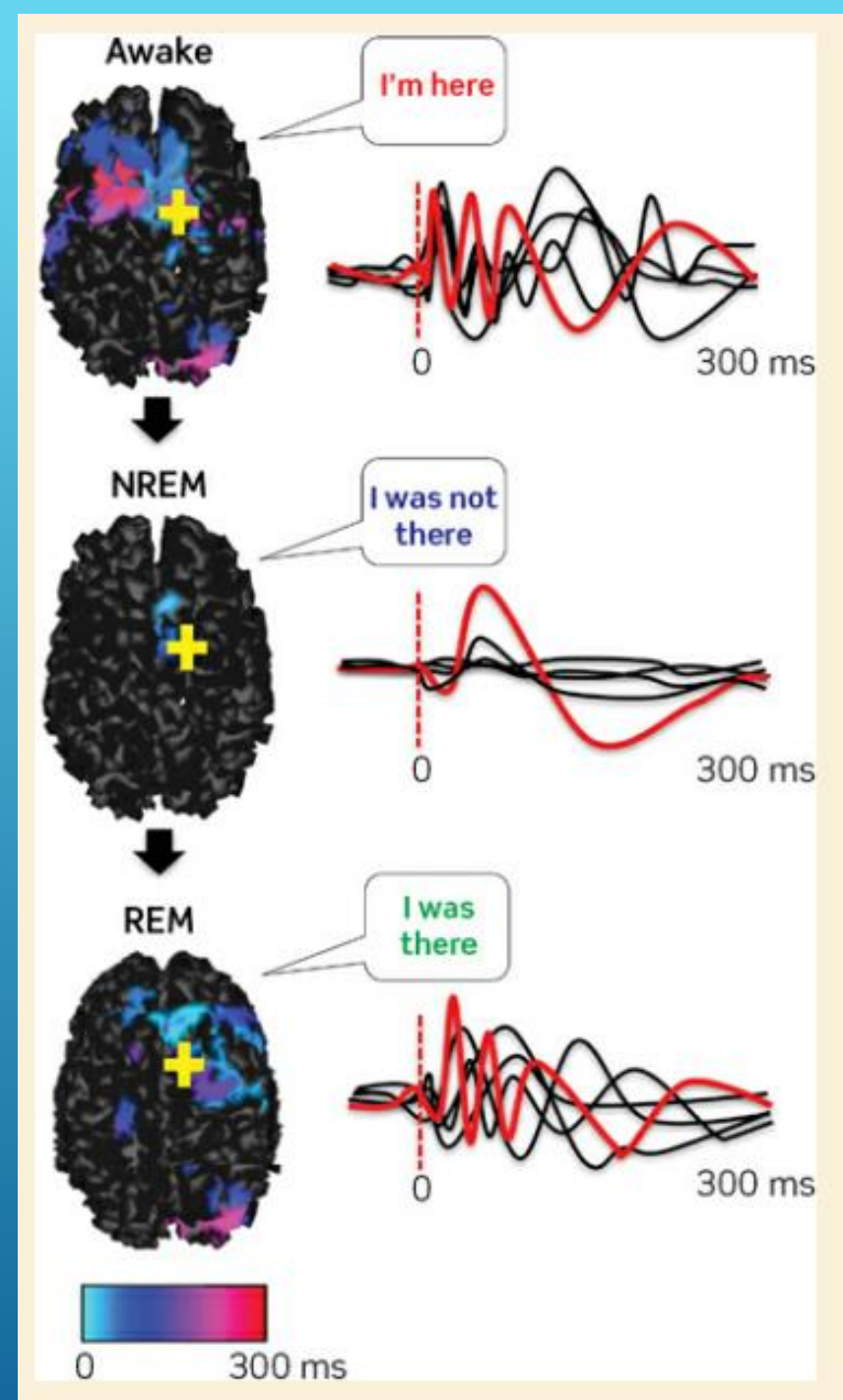
# TMS/EEG measurements in wakefulness and in NREM sleep

The red arrow indicates the site of stimulation

The traces represent the averaged (150 trials) electrical response of the brain recorded by different electrodes (the red trace highlights the activity picked up by the electrode located directly under the stimulator). The seven images depicted below show the spatial-temporal dynamics of cortical activation (after source reconstruction) triggered by TMS



# Awake, non-REM sleep, REM sleep



# Integrated information theory



Integrated information theory (IIT) attempts to explain what consciousness is and why it might be associated with certain physical systems. Given any such system, the theory predicts whether that system is conscious, to what degree it is conscious, and what particular experience it is having. According to IIT, a system's consciousness is determined by its causal properties and is therefore an intrinsic, fundamental property of any physical system.



Phi, the symbol for integrated information.



## PyPhi: A toolbox for integrated information theory

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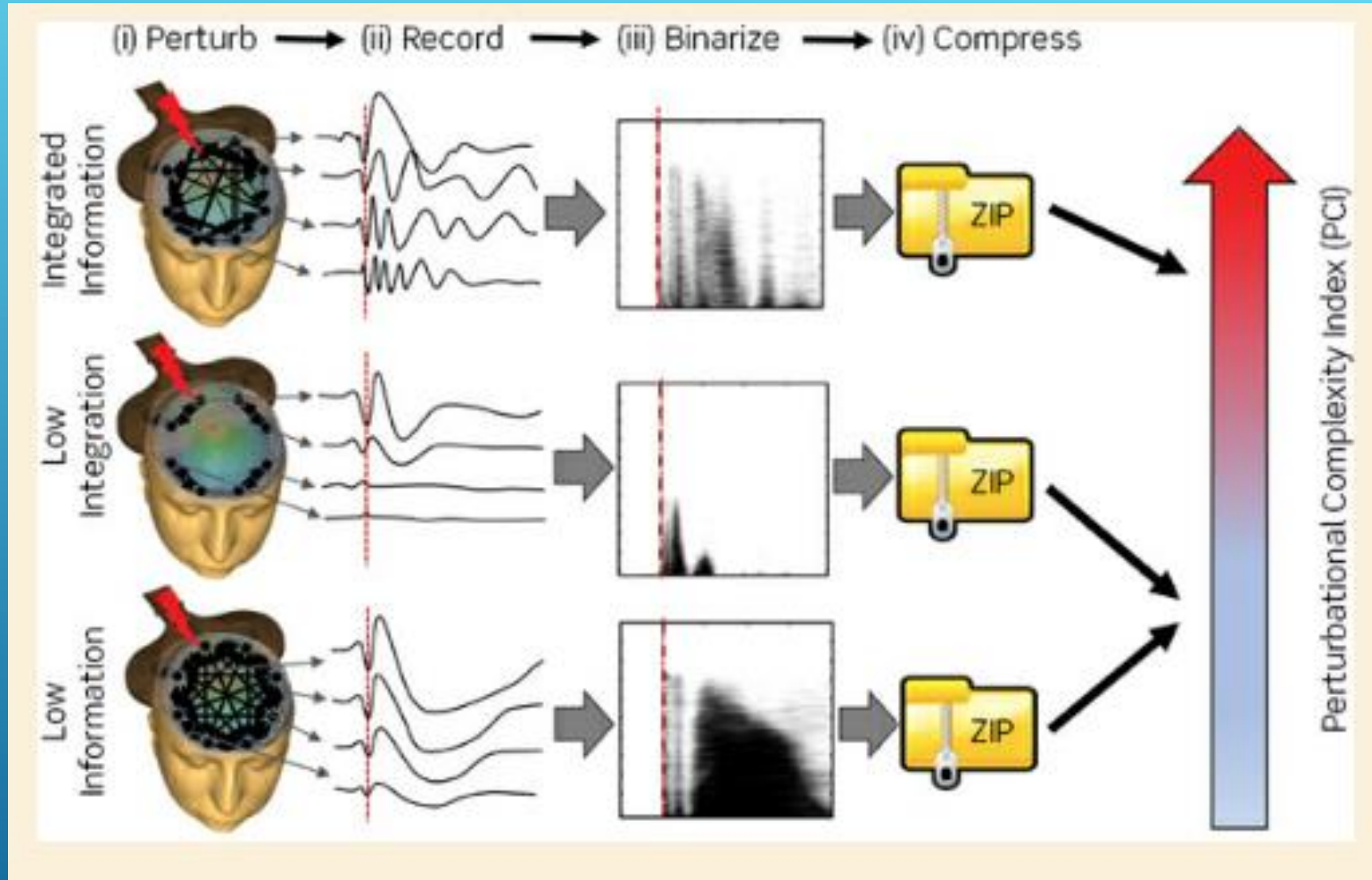
Version 2 

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### Abstract

Integrated information theory provides a mathematical framework to fully characterize the cause-effect structure of a physical system. Here, we introduce *PyPhi*, a Python software package that implements this framework for causal analysis and unfolds the full cause-effect structure of discrete dynamical systems of binary elements. The software allows users to easily study these structures, serves as an up-to-date reference implementation of the formalisms of integrated information theory, and has been applied in research on complexity, emergence, and certain biological questions. We first provide an overview of the main algorithm and demonstrate *PyPhi*'s functionality in the course of analyzing an example system, and then describe details of the algorithm's design and implementation. *PyPhi* can be installed with Python's package manager via the command `pip install pyphi` on Linux and macOS systems equipped with Python 3.4 or higher. *PyPhi* is open-source and licensed under the GPLv3; the source code is hosted on GitHub at <https://github.com/wmayner/pyphi>. Comprehensive and continually-updated documentation is available at <https://pyphi.readthedocs.io>. The `pyphi-users` mailing list can be joined at <https://groups.google.com/forum/#!forum/pyphi-users>. A web-based graphical interface to the software is available at <http://integratedinformationtheory.org/calculate.html>.

# Measure by zipping



# TMS-EEG technique

- ▶ «When we knock on the skull with the magnetic stimulator, the conscious brain vibrates and resonates with a complex echo, while the unconscious brain responds with a simple thud»
- ▶ Results are consistent in very diverse states
  - ▶ Wakefulness
  - ▶ Non-REM sleep
  - ▶ REM sleep
  - ▶ Various cerebral injuries
  - ▶ In anesthesia
  - ▶ Various coma types
  - ▶ In vegetative state
  - ▶ Locked-in state

## Zapping and Zipping

In pursuit of a consciousness test, Silvia Casarotto of the University of Milan and her colleagues recruited 102 healthy subjects and 48 still responsive and awake brain-injured patients. Their brains were “zapped” with magnetic pulses (transcranial magnetic stimulation) in both conscious and unconscious states, and brain activity was detected with an EEG and analyzed with a data-compression algorithm—and so it was said to be “zipped.” A value known as a perturbational complexity index (PCI) was calculated for the EEGs—and participants were also interviewed about their state of mind. It was determined that a conscious person exhibited at least one value above 0.31 (PCI\*), whereas unconscious subjects all had lower scores. Using this value, the zap-and-zip testing was then performed on patients with severe disorders of consciousness (results not shown), finding some individuals who appeared to be conscious.



# Perspectives

Understanding how consciousness comes about is far from clear.

Nowadays the question is considered interesting and worthy of attention by reputable scientists.

We can now see the first steps towards a quantitative framework for understanding how it works and answering many interesting questions...

Can consciousness exist without a brain ?

Is a swarm of bees conscious ?

Can a machine ever become conscious ?



# Some science fiction - The Fermi paradox

A breakthrough in deciphering consciousness may only come with new physics and may bring new technology. In particular communication.

If the “old” physics phase lasts no more than a few centuries, the probability to detect a civilization in the phase of “old” physics is very low....

