Introduction to Cognitive Neuroscience

Lecture 02: The Brain and Behavior

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The Brain and Behavior

The last frontier of the biological sciences--
the ultimate challenge is to understand the **biological basis of consciousness** and the brain processes by which we **feel**, **act**, **learn**, and **remember**

A first step toward understanding the mind, therefore, is to learn how neurons are organized into signaling pathways and how they communicate by means of synaptic transmission

We must also understand both the innate (genetic) and environmental determinants of behavior

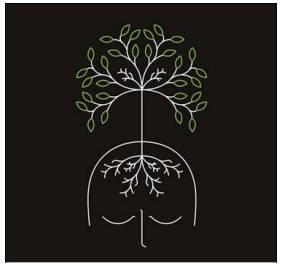
Unified approach in biological studies

- **Genetic studies** provides a common conceptual framework for all of cell biology, including cellular neural science
- This view gives rise a challenge:
  - the **unification** of the study of behavior— the science of the mind—and neural science— the science of the brain.
- In this view, mind and body are not viewed as **separate entities**
- **Behavior** is the result of **brain function**
  - **Mind** is a set of operations carried out by the **brain**

Fundamental questions in neural sciences

- How do the billions of individual nerve cells in the brain produce behavior and cognitive states?
- How are those cells influenced by the environment, which includes social experience ?
- Is a particular mental process carried out in specific regions of the brain, or does it involve the brain as a whole?
- If a mental process can be localized to discrete brain regions, what is the relationship between the functions of those regions
- Correlation between **structure** and **function**

Philosophy of mind



A branch of philosophy that studies the ontology, nature, and relationship of the **mind to the body**

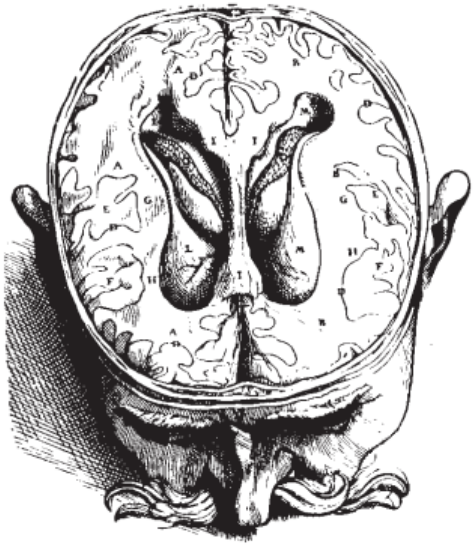
- The **mind–body problem**
- **Hard problem of consciousness**
- **Dualism** and **monism** are the two central schools of thought on the mind–body problem
- **Substance dualists (**like Descartes argue)
- **property dualists**
  - Mind is a group of independent **properties** that **emerge** from and cannot be reduced to the **brain**, but that it **is not a distinct substance**
- **Monism** is the position that mind and body are not ontologically distinct
  - **Physicalists**
  - **Idealists (**George Berkeley, Panpsychism, Phenomenalism)

Advancement of our views about nerve cells

Our views about nerve cells, the brain, and behavior emerged from synthesis of five experimental traditions: **anatomy**, **embryology**, **physiology**, **pharmacology**, and **psychology**

Mechanical view to brain

- Galen's (the 2nd century Greek physician) view of the brain prevailed for almost 1500 years
  - nerves convey **fluid secreted** by the brain and spinal cord
- Whole concept was strengthened in the early **seventeenth century** when French inventors began developing **hydraulically** controlled mechanical devices
- until the late 1800s, when the Italian Camillo **Golgi** and the Spaniard Santiago Ramón y **Cajal** produced detailed about nerve cells

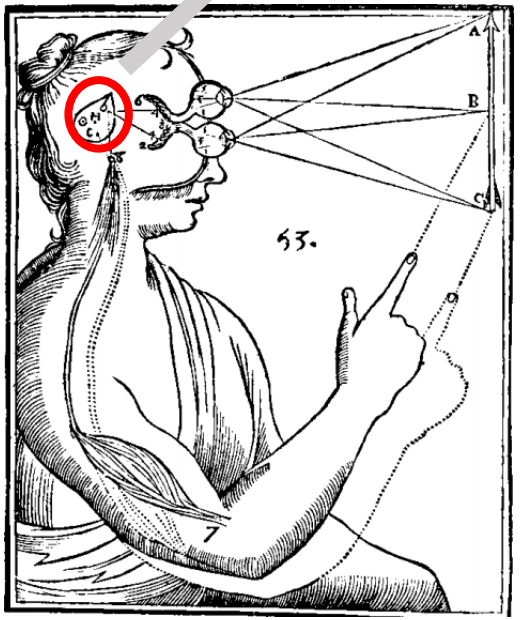


Human brain ventricles depicted during the Renaissance

René Descartes (1596–1650) chief advocate of fluid-mechanical theory of brain function

- The mind influences the motor response by **controlling the pineal gland (H)** . The **soul**, a spiritual entity communicates with the **machinery** of the brain by means of the pineal gland.
- Pineal gland which works like a **valve** to control the movement of **animal spirits** through the nerves that inflate the muscles
- In his view, the mind is a spiritual entity that receives sensations and commands movements by communicating with the **machinery of the brain** via the pineal gland

Hollow nerves from the eyes project to the brain ventricles.



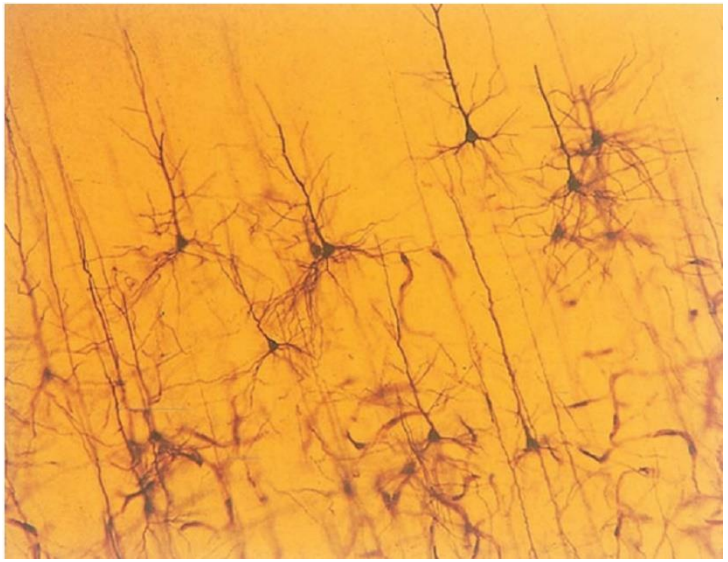
This drawing appeared in a 1662 publication by Descartes

Italian Camillo Golgi and the Spaniard Santiago Ramón y Cajal terminate mechanical view

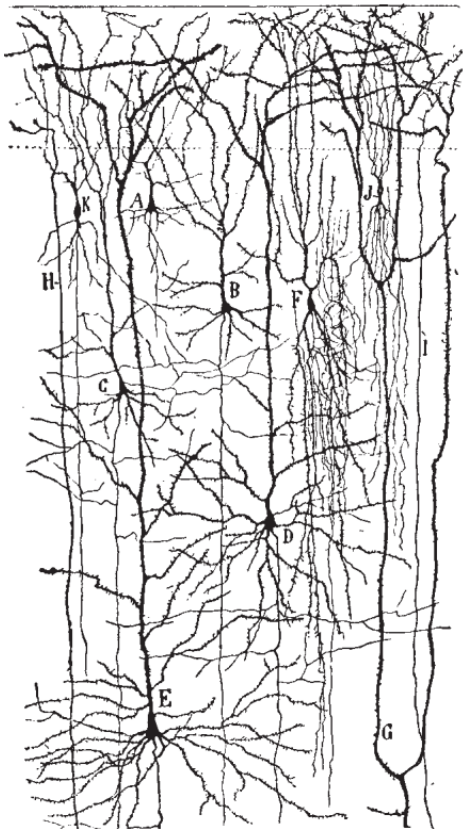
- Golgi developed a method of **staining neurons** with silver salts that revealed their entire cell structure under the microscope

- He found each neuron typically has a cell body and two types of processes:
  - branching dendrites at one end
  - a long cable-like axon at the other

Golgi-stained



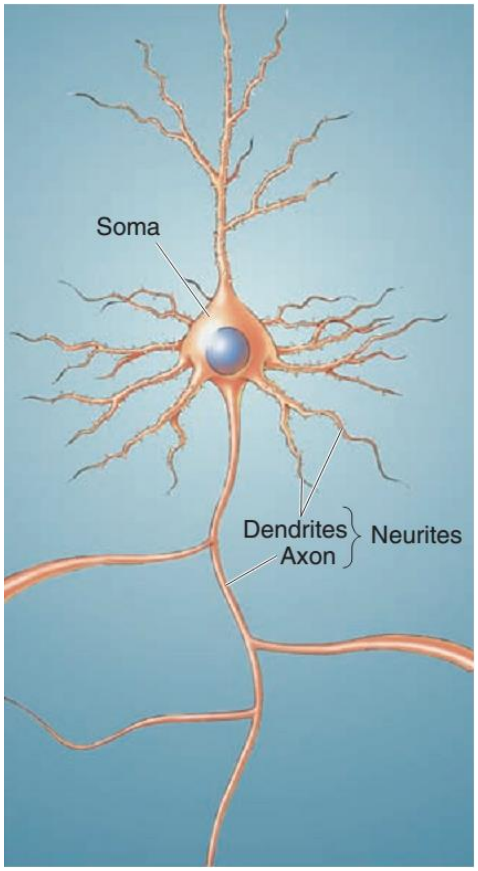
Golgi-stained neurons.(Source: Hubel, 1988, p. 126.)



One of Cajal's many drawings of brain circuitry

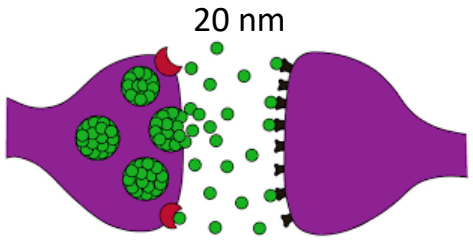
Golgi vs Cajal view on neuronal networks

- **Golgi** argued that similar to the arteries and veins of the circulatory system, neurites of different cells are fused together to form a **continuous reticulum, or network**
- Ramón y Cajal discovered that nervous tissue is not a syncytium, a continuous web of elements, but a network of **discrete cells**
- **Cajal** developed *neuron doctrine*:
  - The principle that individual neurons are the elementary **building blocks** and signaling elements of the nervous system

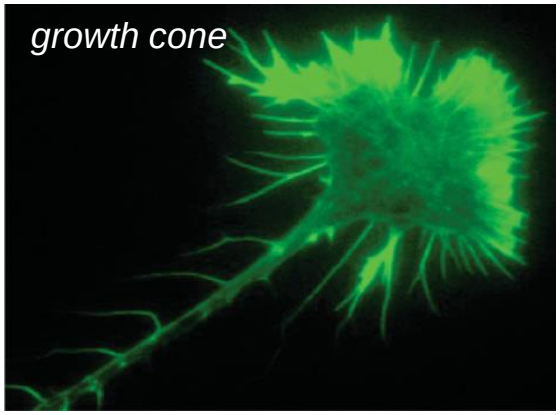


Support for the neuron doctrine

- Embryology (1920):
  - dendrites and the axon **grow from the cell body** and that they do so even when each neuron is isolated from others in tissue culture

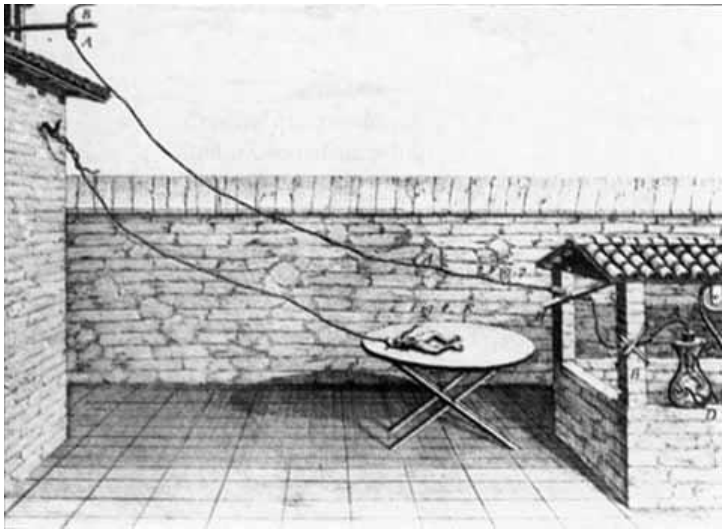


- Electron microscopy; (mid-950s)



Physiological investigation of the nervous system

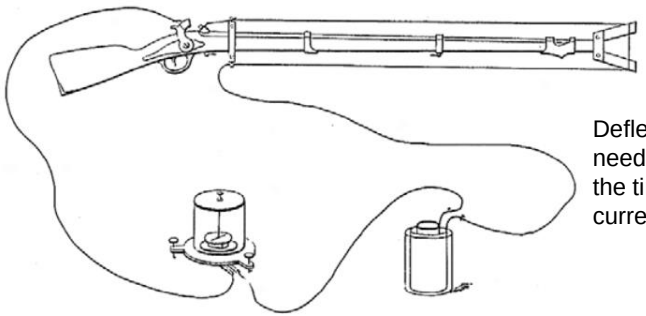
- Began in the late 1700s by Luigi Galvani
- He discovered that muscle and nerve cells produce electricity



Late 1780s diagram of Galvani's experiment on frog legs

Modern electrophysiology

- Grew out of work in the 19th century three **German** physiologists
  - Johannes Müller, Emil du Bois-Reymond, and Hermann von Helmholtz
- Measuring the **speed of conduction** of electrical activity along the axon of the nerve cell



Deflection of a galvanometer needle served to measure the time during which the current was active

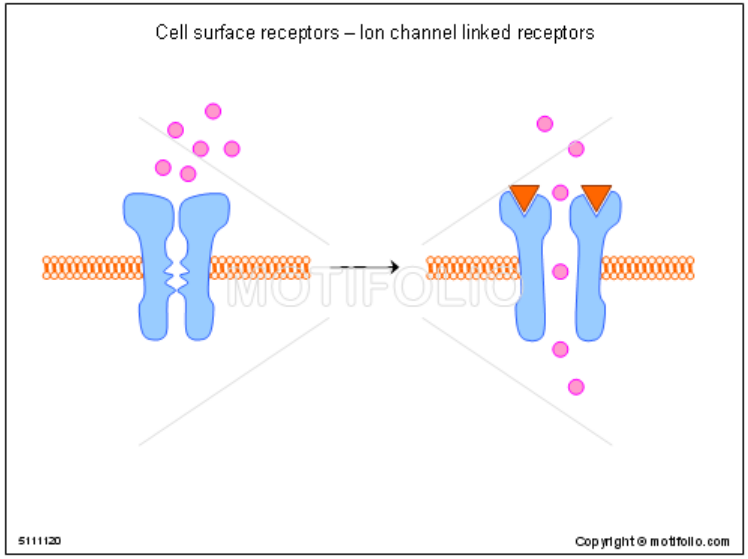
Pouillet's method for measuring short time intervals

Müller Reymond Helmholtz

Schmidgen, Henning. "Of frogs and men: the origins of psychophysiological time experiments, 1850–1865." *Endeavour* 26.4 (2002): 142-148.

Impact of pharmacology

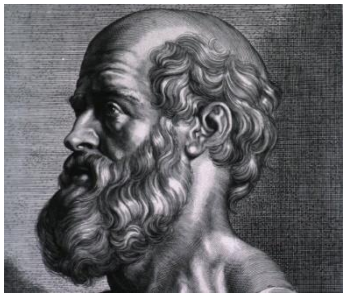
- Drugs do not act just anywhere on a cell, but rather bind discrete receptors typically located in the surface **membrane of the cell**
- So nerve cells can communicate with each other by chemical means



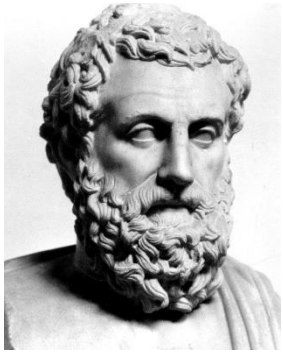
Psychological thinking about behavior

Greek philosophers

- **Hippocrates** (460–379 B.C.) : brain not only was involved in sensation but also was the seat of intelligence



- **Aristotle** (384–322 B.C.) belief that the heart was the center of intellect



17th century

René Descartes distinguished body and mind

His **mechanistic approach** to explain observations was very important for studding *Behavior Physiologically*

1596 - 1650 (aged 53)

Later in the 17th century

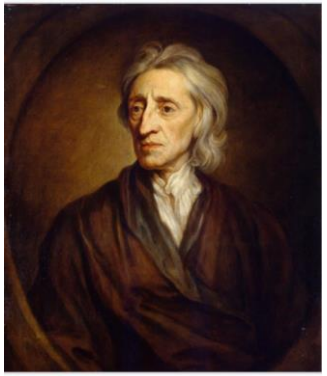
Baruch Spinoza began to develop a unified view of mind and body

Existence of a basic substance that is neither physical nor mental (neural monism)

1632 - 1677 (aged 44)

18th century; Western ideas about the **mind** split along new lines

- **Empiricists**: brain is initially a blank slate (*tabula rasa*)
  - John Locke
  - David Hume
  - George Berkeley



John Locke (1632–1704), a leading philosopher of British empiricism

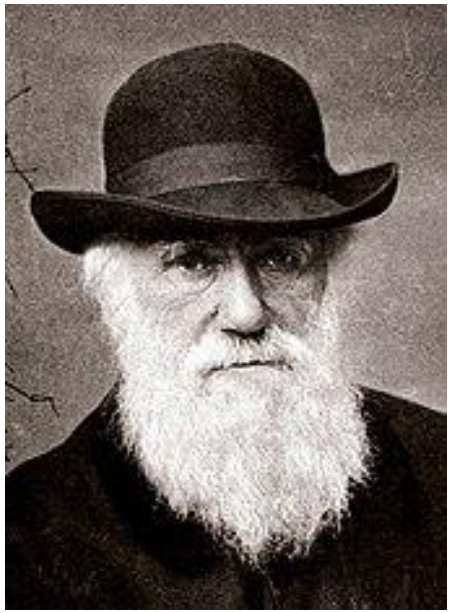
- **Idealists**: notably Immanuel Kant, believed that our perception of the world is determined by inherent features of our mind or brain

1724 - 1804 (aged 79)

Mid-19th century

- **Charles Darwin** set the stage for the modern understanding of the brain as the seat of all behavior

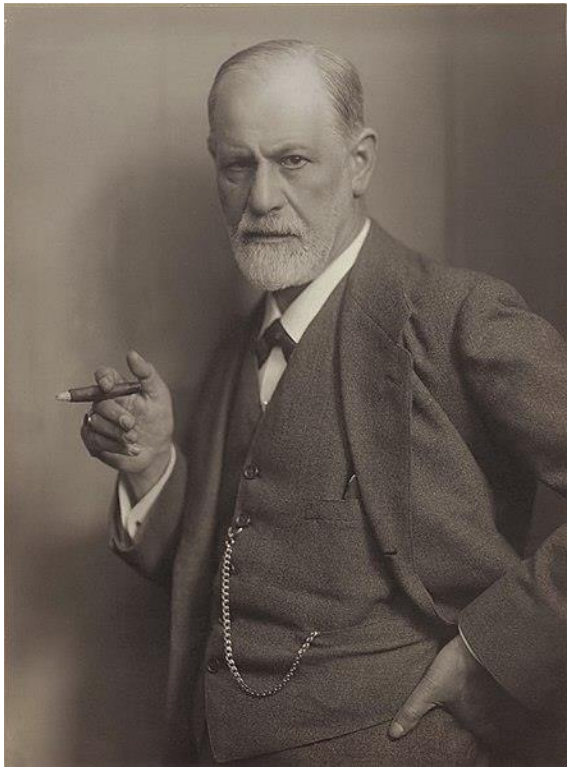
- He said animals could serve as models of human behavior → the study of **evolution** gave rise to ethology and experimental psychology



Charles Darwin (1809–1882)

Beginning of the 20th century

Sigmund Freud



1856 - 1939 (aged 83)

He introduced psychoanalysis,
first systematic cognitive psychology

Early as 1800; Franz Joseph Gall

- Gall proposed two radically new ideas:
  - Brain is the organ of the mind; rejected dualism
  - Cerebral cortex **contain many organs** and **each regions** of the cerebral cortex control **specific functions**

Franz Joseph Gall

1758 - 1828 (aged 70)

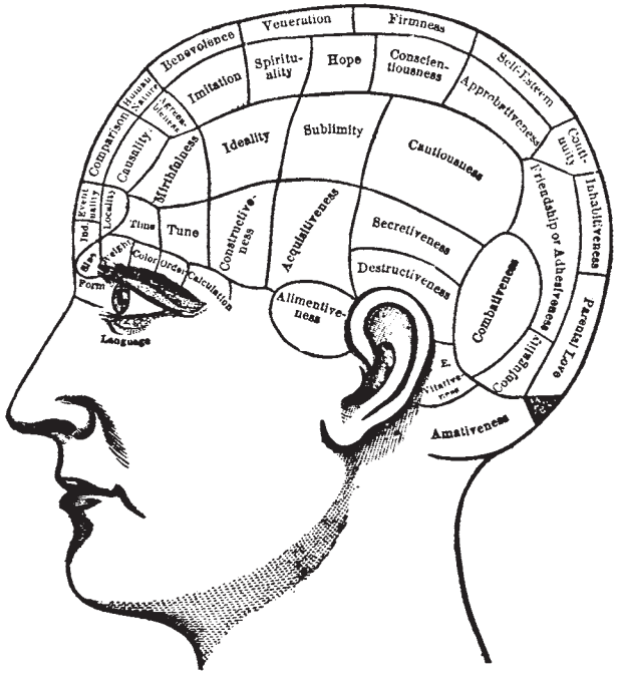
Gall's experimental approach to localization was extremely naïve

- Gall **rejected** all evidences of lesion studies
- Influenced by **physiognomy**, the popular science based on the idea that **facial features reveal character**
- He got this idea when he noticed that classmates who excelled at memorizing school assignments had prominent eyes.
  - He concluded that this was the result of an overdevelopment of regions in the front of the brain involved in **verbal memory**
  - He confirmed this idea when he was in asylum in Vieen: because the patient functioned well in all other behaviors, the brain defect must be **discrete**
- In his principle the deficit could be localized by **examining the skulls** of these patients

Phrenology; functional localization in the brain

- A discipline concerned with determining personality and character based on the **detailed shape of the skull**

- Traits such as combativeness, spirituality, hope, and conscientiousness are controlled by specific areas in the brain, which **expand as the traits develop** → This enlargement of local areas of the brain was thought to produce characteristic bumps and ridges on the overlying skull



An early map of functional localization in the brain. This map show 42 intellectual and emotional faculties in distinct areas of the skull and the cerebral cortex underneath

Empirical testing of Gall map, the *holistic* view of the brain

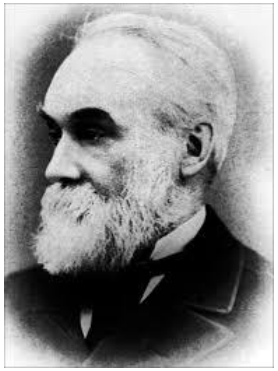
- In the late 1820s by French physiologist **Pierre Flourens**
- Destroying Gall's functional centers in the brains of experimental animals
- He concluded that specific brain regions are not responsible for specific behaviors, but that **all brain regions, participate in every mental operation**
  - Injury to any one area of the cerebral hemisphere should therefore affect all higher functions equally
- Represented a **cultural reaction against the materialistic** view that the human mind is a biological organ

Challenging holistic view

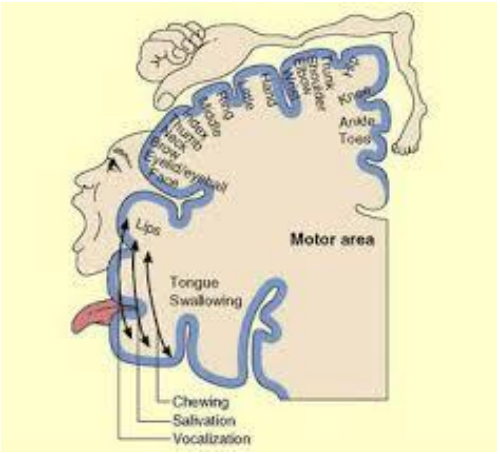
- In the **mid-19th** century by the French neurologist **Paul Pierre Broca**, the German neurologist **Carl Wernicke**, and the British neurologist **Hughlings Jackson**.

Broca

Wernicke



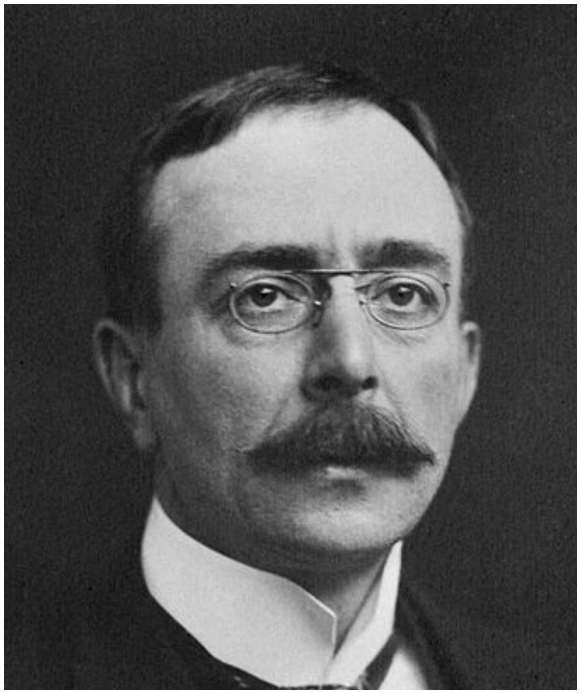
Jackson



Cellular connectionism

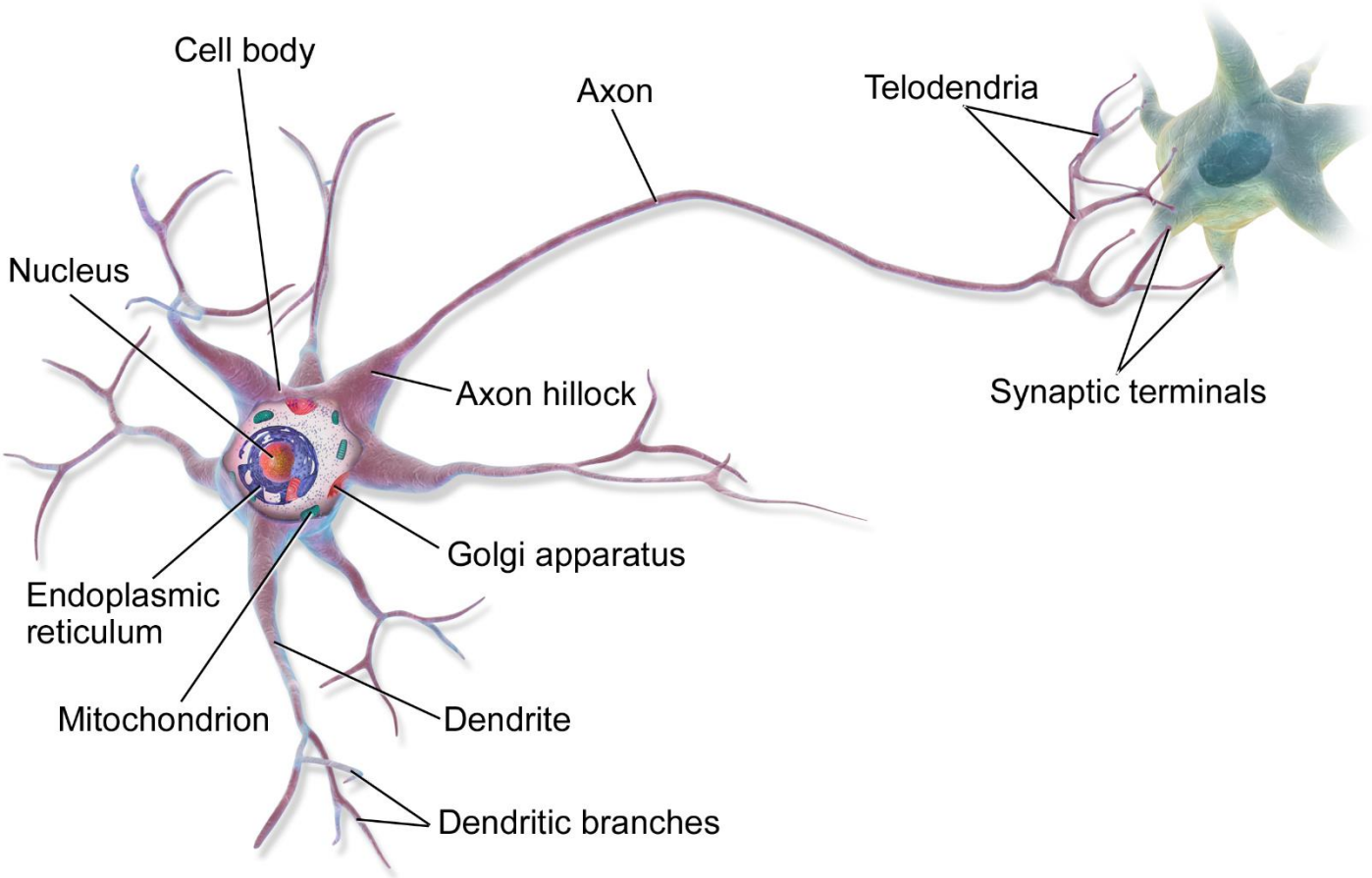
- **Charles Sherrington** and **Ramón y Cajal** extended the **localization view** to the cellular level; ***cellular connectionism***
- According to this view individual neurons are the signaling units of the brain
- Neurons are **arranged** in **functional groups** and connect to one another in a precise fashion.

Charles Sherrington



1857 - 1952 (aged 94)

in 1932 for their work on the functions of neurons

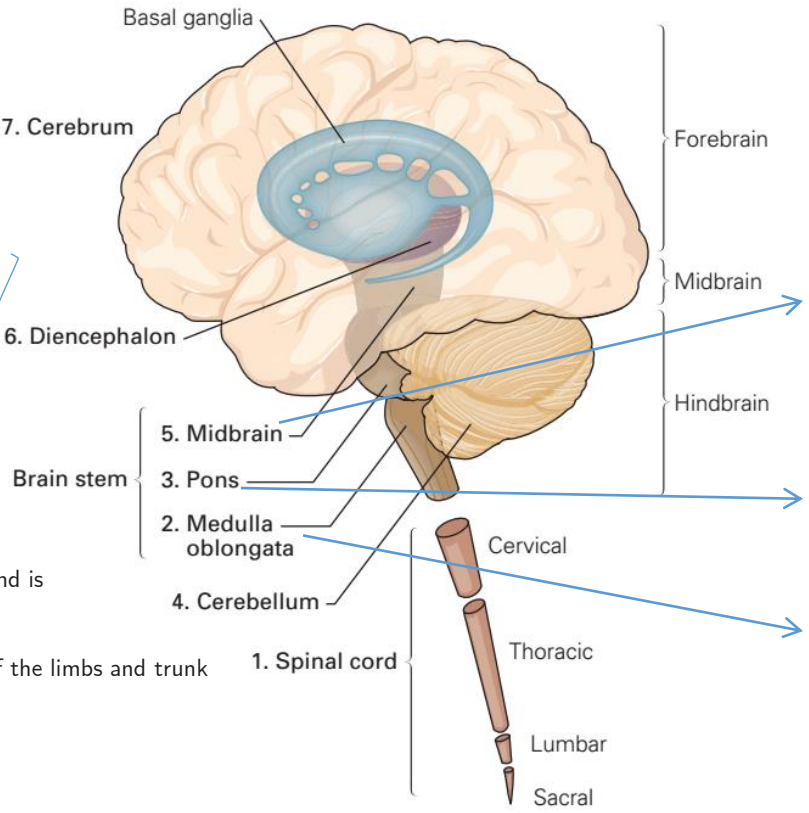

Cell body
Axon
Telodendria
Nucleus
Axon hillock
Synaptic terminals
Golgi apparatus
Endoplasmic reticulum
Mitochondrion
Dendrite
Dendritic branches

The Brain Has Distinct Functional Regions

The central nervous system can be divided into seven main parts

thalamus processes most of the information reaching the cerebral cortex from the rest of the central nervous system

hypothalamus regulates autonomic, endocrine, and visceral functions



- Input/ output for spinal cord
- motor control for the head's musculature
- regulates levels of arousal and awareness through the reticular formation

modulates the force and range of movement and is involved in the learning of motor skills

Input/ output: skin, joints, and muscles of the limbs and trunk

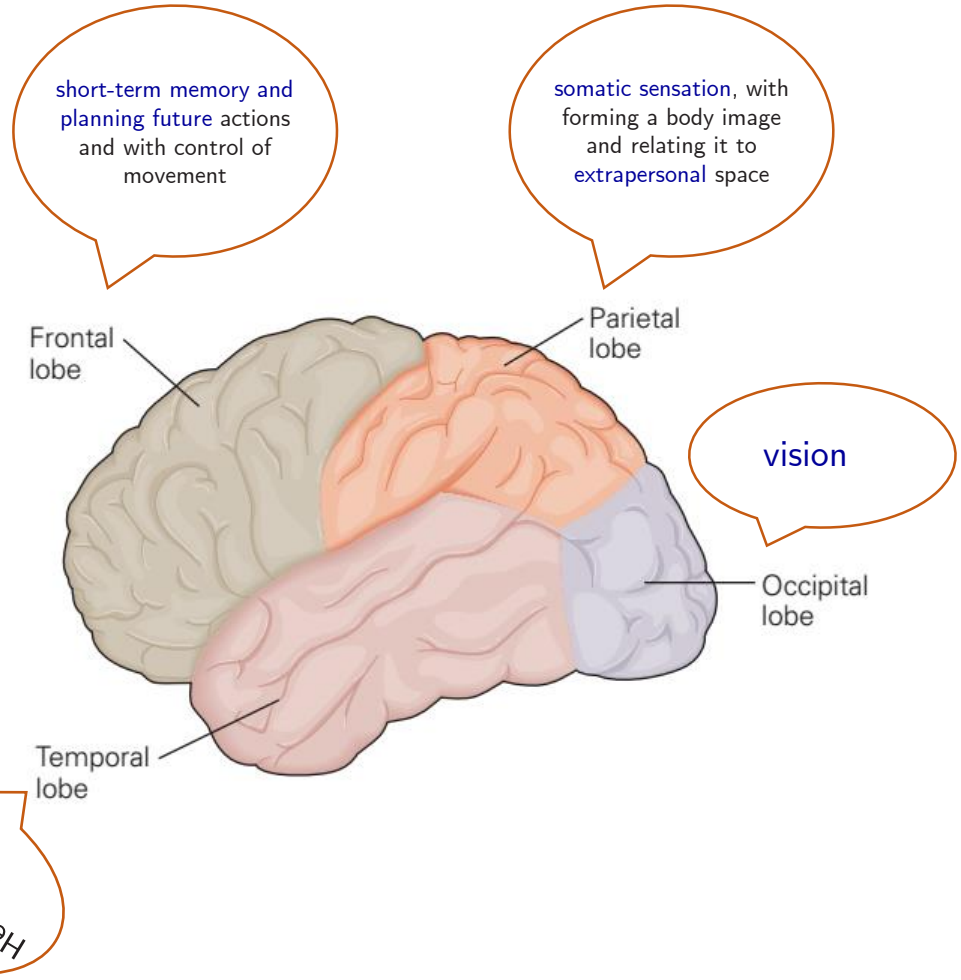
controls many sensory and motor functions, including eye movement and the coordination of visual and auditory reflexes

conveys information about movement from the cerebral hemispheres to the cerebellum

includes several centers responsible for vital autonomic functions, such as digestion, breathing, and the control of heart rate

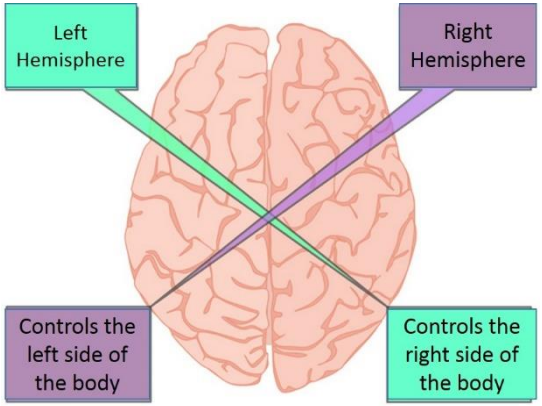
Cerebrum

- Two cerebral hemispheres
- Four component:
  - ***Cerebral Cortex****:* heavily superficial wrinkled outer layer; consist of 4 lobes; named for the skull bones that overlie them.
  - Three deep-lying structures:
    - *Basal ganglia:* regulating motor performance
    - *Hippocampus:* aspects of memory storage
    - *Olfactory bulb*



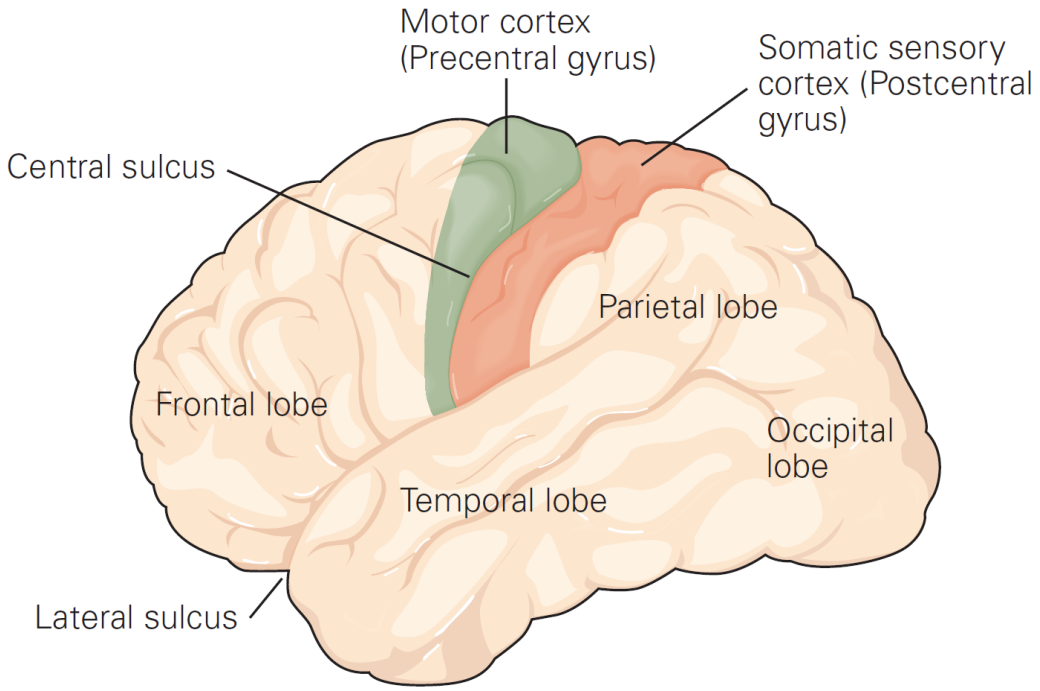
Cerebral cortex organization features

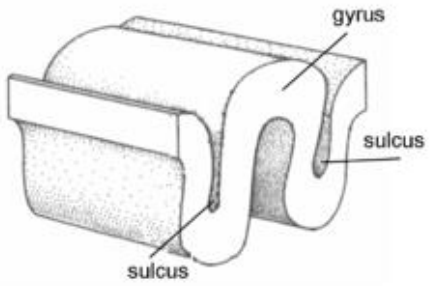
- **First**, each hemisphere is concerned **primarily** with sensory and motor processes on the contralateral (opposite)



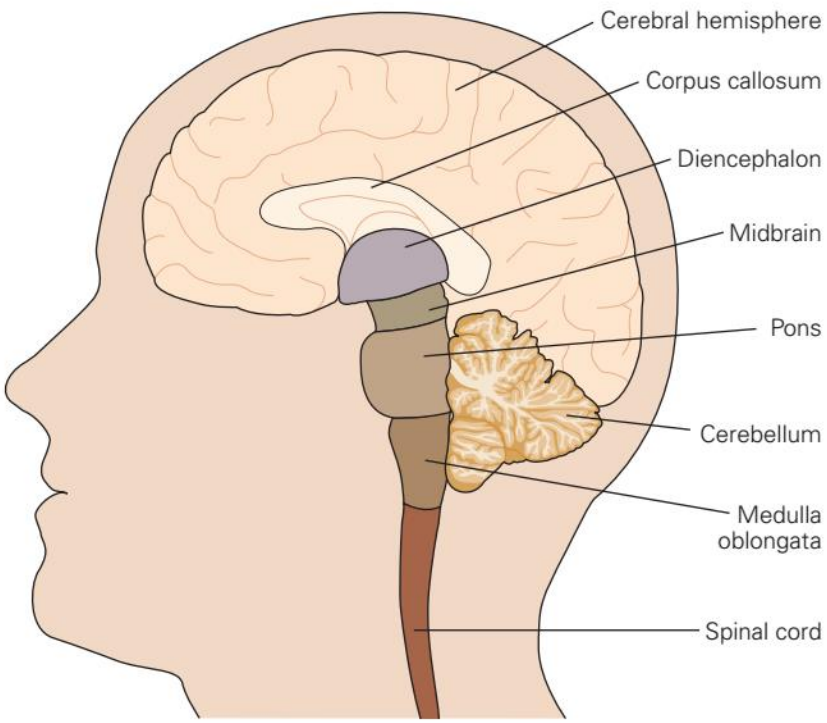
- **Second**, although similar in appearance, are **neither** completely symmetrical in structure nor equivalent in function

The motor and somatic sensory areas of the cortex are separated by the central sulcus





The main divisions are clearly visible when the brain is cut down the midline between the two cerebral hemispheres



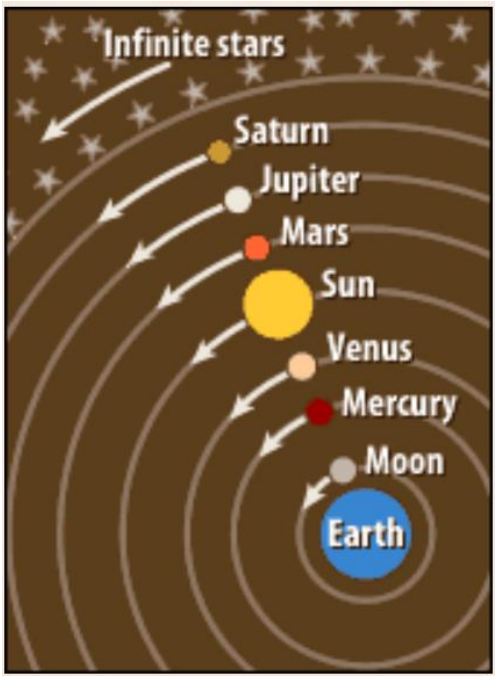
Modern imaging studies support localization

- Imaging techniques enable us:
  - To get structure
  - Evaluate the metabolic activity of discrete regions of the brain (fMRI)

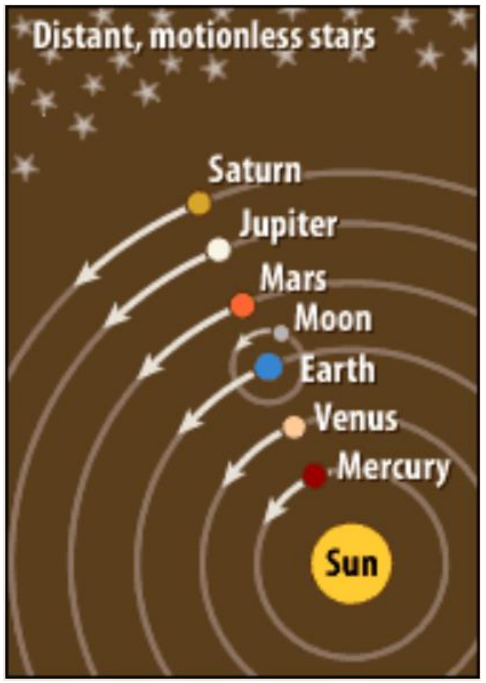
- Such studies provide evidence that **specific** types of behavior involve particular regions of the brain

Gall's idea is one of the cornerstones of modern brain science

Ptolemaic Model vs. Nicolaus Copernicus in astronomy, wrong introduction can lead to true results



Ptolemy's model: "Earth-centered," or "geocentric"



Copernicus' model: "Sun-centered," or "heliocentric"

The first strong evidence for localization of cognitive abilities came from studies of language disorders

- *Aphasia* studies
  - **Language disorder** that most often occurs when certain areas of brain tissue are destroyed by a stroke
- Broca was influenced by Gall's efforts but instead of skull, he correlated clinical evidence of aphasia with brain lesions discovered **post mortem**.
- In 1861 he wrote:

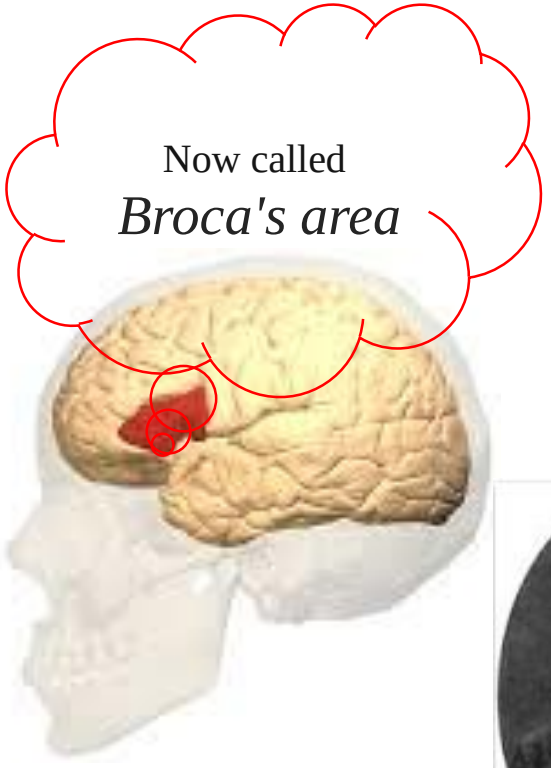
  "I had thought that if there were ever a **phrenological** science, it would be the phrenology of convolutions (*in the cortex*), and not the phrenology of bumps (*on the head*)."
- Based on this insight Broca founded ***neuropsychology***

An important case; Leborgne

As a result of a stroke:

- He **could not speak**, although he **could understand** language perfectly well
- He **had no** motor deficits of the tongue, mouth, or vocal cords
- He **could** utter **isolated words, whistle, and sing a melody** without difficulty.
- He **could not** speak grammatically or create complete sentences, nor could he express ideas in writing.

Postmortem examination of Leborgne



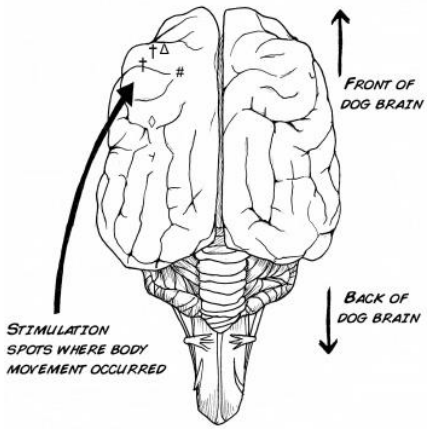
Broca

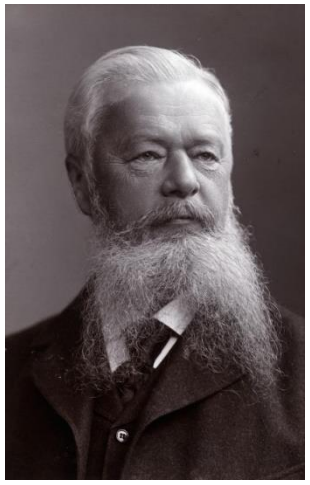
Broca found **8** similar patients, and this discovery led Broca to announce in 1864:

We speak with the left hemisphere!

Dominant hemisphere; same hemisphere controls the right hand

- 1870 Gustav **Fritsch** and Eduard **Hitzig**:
  - Stimulating discrete regions of the precentral gyrus of dog.
  - Watching limb movements in contralateral
- **Right hand people** use same hemisphere for writing and speaking → left hemisphere is dominant



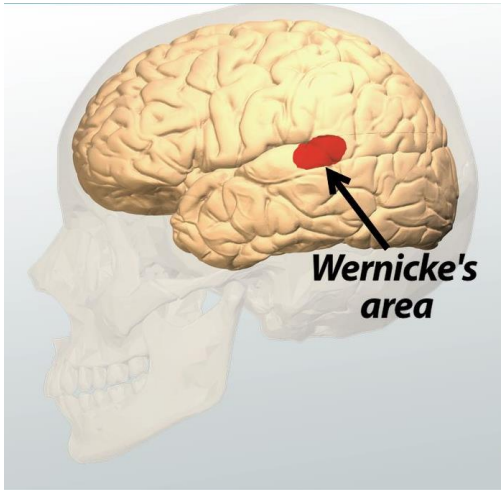

Fritsch


Hitzig

Karl Wernicke

Wernicke

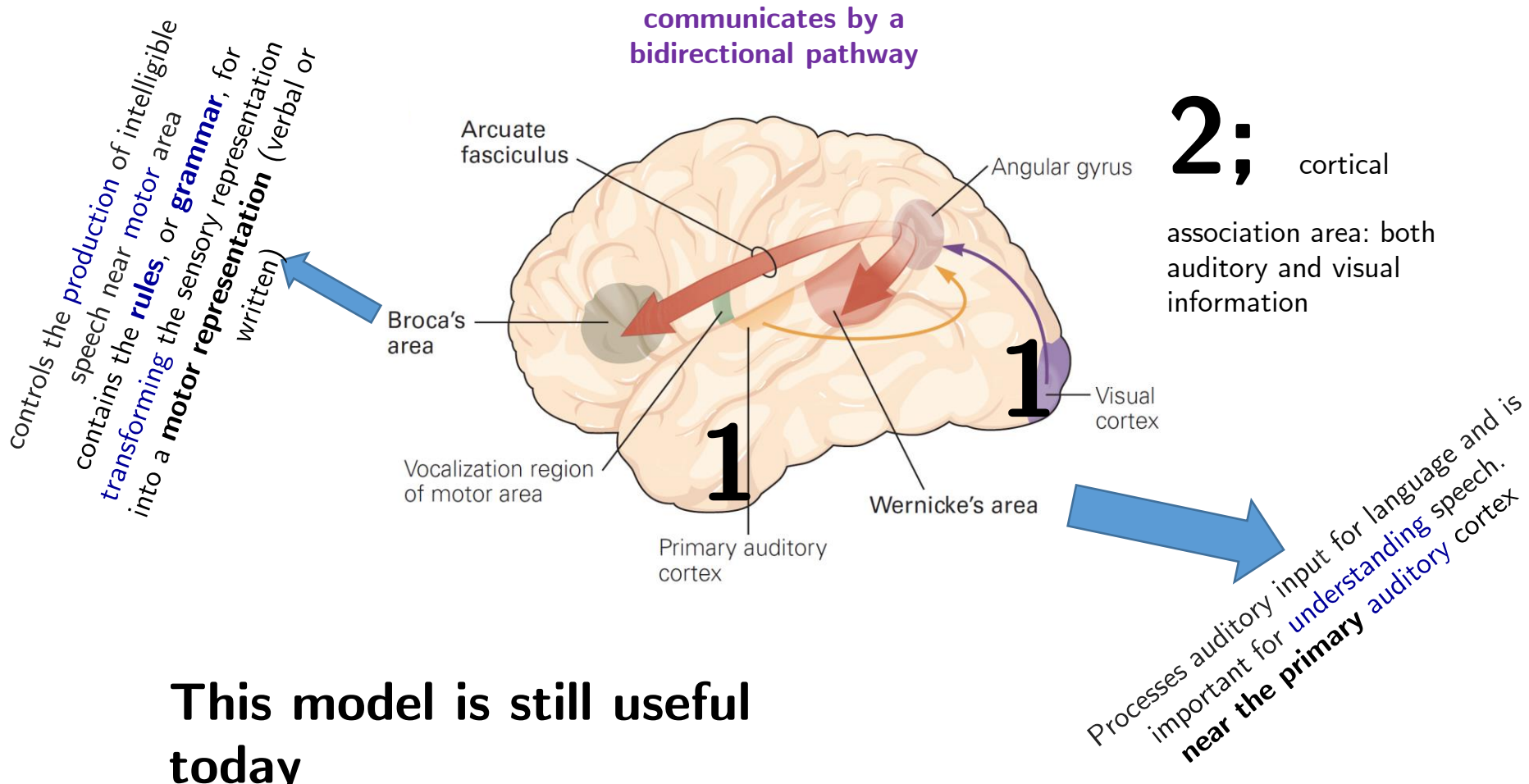
- He was 26 years old in 1876; another Dutch talent ☺
- He described another *type of aphasia*
  - A failure of **comprehension** rather than speech
  - Wernicke's patient **could form words** but **could not understand** language



Distributed processing; now a central tenet of neural science

- Wernicke, the first to advance the idea **of distributed processing**
- In between of phrenologists and cellular connectionists (**cortex as a mosaic of functionally specific areas**) in one hand and holistic aggregate-field (**mental function involved the entire cerebral cortex**) at the other hand, he proposed that:
  - Only the **most basic mental functions**, those concerned with simple perceptual and motor activities, are mediated by neurons in **discrete local areas** of the cortex.
  - **More complex** cognitive functions result from **interconnections** between several functional sites.

language involves separate motor and sensory programs



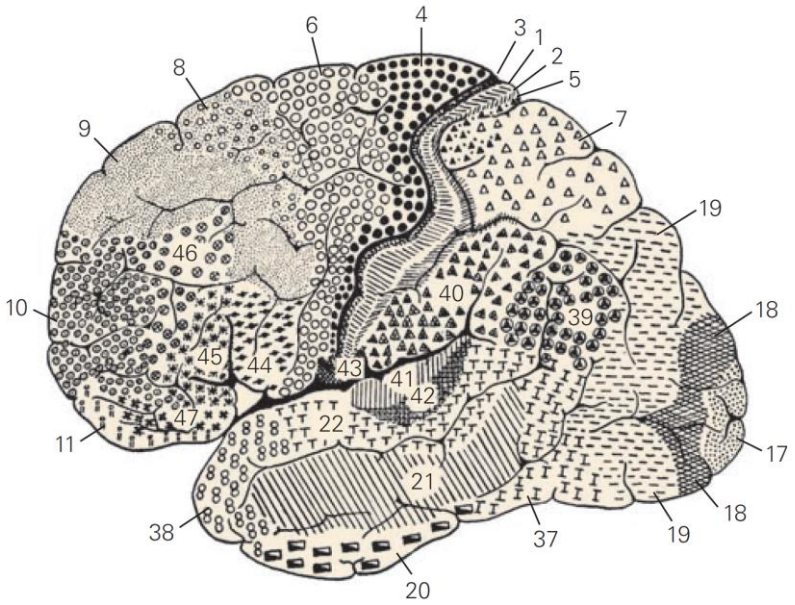
This model is still useful today

Wernicke's model predicted a third type of aphasia

- ***Conduction*** *aphasia:*
  - The **receptive** and **expressive** zones for speech are intact, but the neuronal fibers that connect them are destroyed
- Characterization:
  - Incorrect use of words *(**paraphasia**)*
  - They **cannot speak coherently**; they **omit parts of words** or **substitute incorrect sounds** and in particular they have difficulties **repeating phrases**.
  - They aware of their own errors, they are unable to put them right.

Cytoarchitectonic method: new school of cortical localization

- **Korbinian Brodmam** in Germany at the beginning of the 20th century
  - Distinguished functional areas of the cortex based on the **shapes of cells and variations in their layered arrangement**.
- **52** discrete functional areas
- This scheme is **still widely used** today and is continually updated



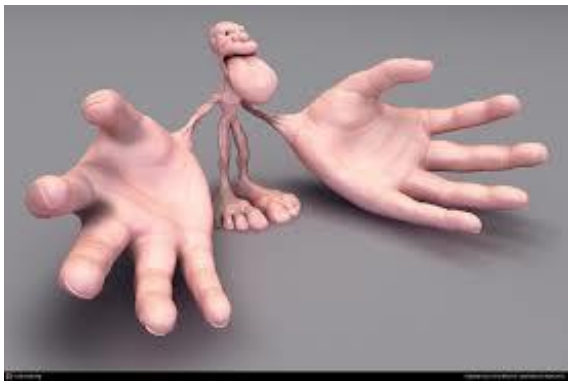
Brodmann's division of the human cerebral cortex

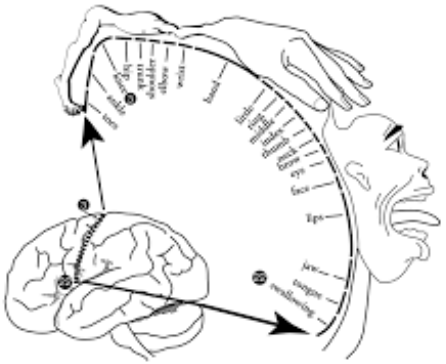
Capturing elicited electrical activity in brain by stimulation of body surface

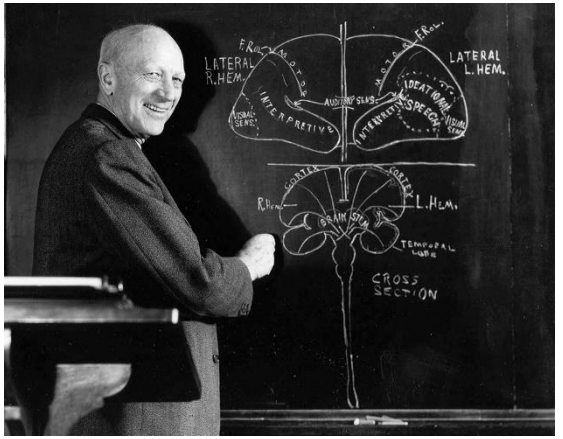
- late 1930s, Edgar Adrian, Wade Marshall, and Philip Bard in the United States
- Using elicited electrical activity produced by touching different parts of a cat's body, they established a **precise map** of the body surface in specific areas of the cerebral cortex described by Brodmann
- They proved that **functionally distinct areas** of cortex *can* be defined unambiguously according to:
  - **Anatomical** criteria such as cell type and cell layering
  - Connections of cells
  - Most importantly, behavioral function
- **Functional specialization** is a key organizing principle in the cerebral cortex

Brain stimulation in awake human

- Penfield and Ojemarm were able to **confirm in the living, awake, and conscious brain** that language areas of the cortex described by Broca and Wernicke (using epileptic patients).
- They also found other sites essential for language, like insula (there is complex network for language)





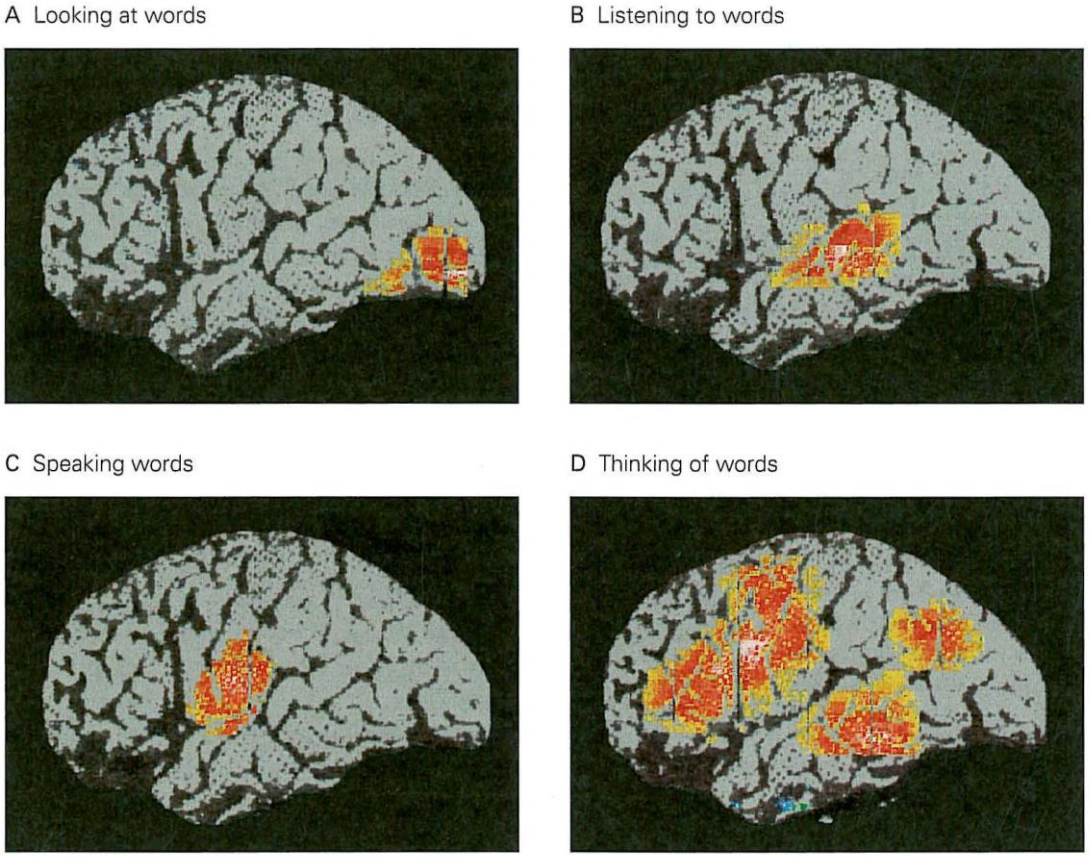


Penfield

Parvizi video

Today PET and imaging (fMRI) allow anatomical analysis

Positron emission tomography (PET) to understand specific regions of the cortex involved in the recognition of a spoken or written word



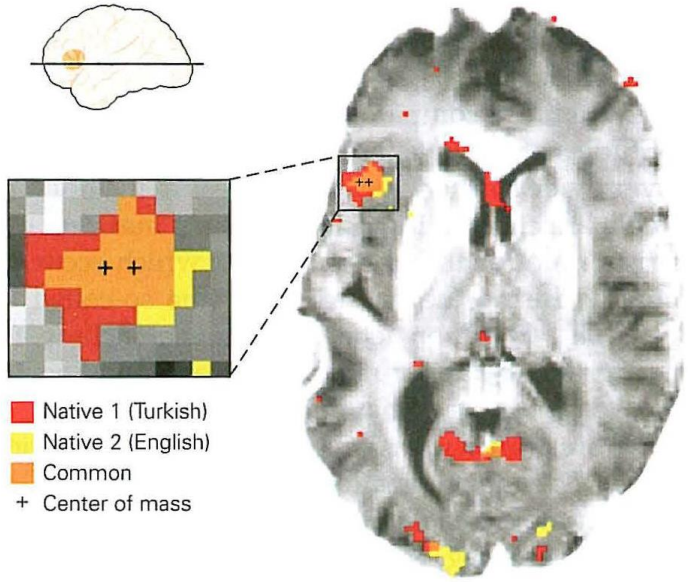
Subjects were asked to repeat a word presented

to respond to the word with an appropriate verb, for example, "brain" "to think."

Age at which a language is acquired is a significant factor in determining the **functional organization of Broca's area**.

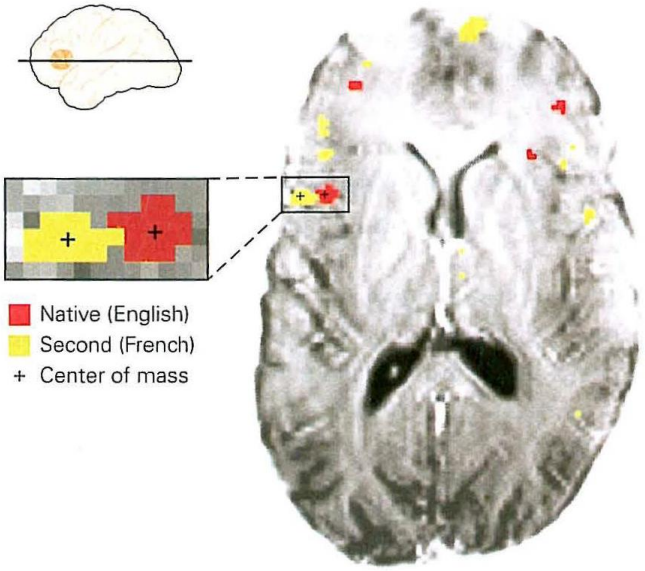
prior to the age of 7

A Early bilingual



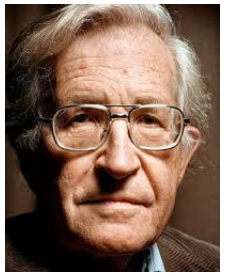
after age 11 years

B Late bilingual



Functional magnetic resonance images of the brains of bilingual subjects during generation of narratives in two languages.

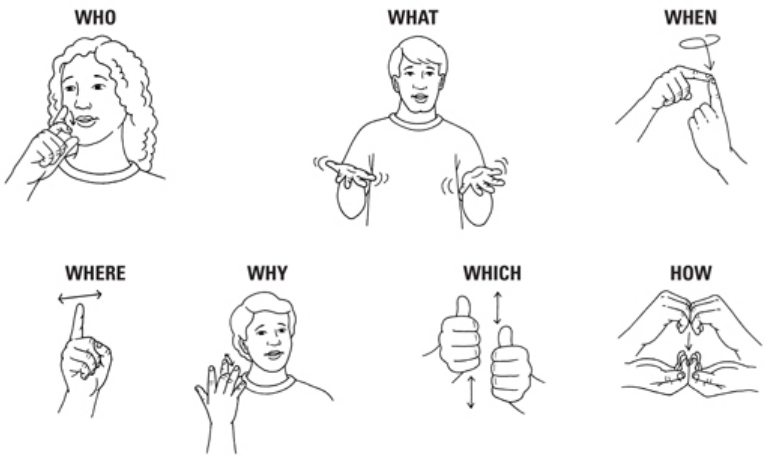
Language instinct



- Language is a uniquely human capability,
  - Charles Darwin suggested that the acquisition of language is an inborn instinct comparable to that for **upright posture**.
- In 1960 the linguist **Noam Chomsky** elaborated on Darwin's notion:
  - Children acquire a language so **easily** and naturally because humans, unlike other primates, have the **innate capability** of **generalizing** to a complete and coherent language **from a limited sample of sentences**.
  - All **natural languages share** a **common design**, which he called ***universal grammar***.
- Broca's area does not increase for ***artificial language*** (language that violates the rules of universal grammar)

Spoken language represents only **one of a family** of **language skills** mediated by the left hemisphere

- Deaf people can become **aphasic for sign** language as a result of lesions in the **left hemisphere**,
- language is **independent** of pathways that process the sensory and motor modalities

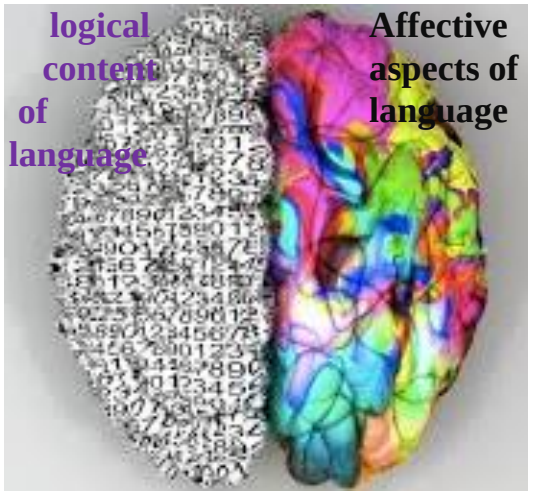


Localization of language appears to be inborn but . . .

- Children in whom the **left** cerebral hemisphere is severely **damaged** early in life can still develop an essentially **normal** grasp of language
- At a cost, for the ability of these children to **locate objects in space** or to **reason spatially** is much reduced

Affective states are also mediated by local, specialized systems in the brain

- It was believed that **emotion** must be an expression of whole-brain activity.
- The neural systems governing emotion have **not been mapped as precisely** as the sensory, motor, and cognitive systems



Damage to the **right temporal area** corresponding to:

- Wernicke's area in the left → disturbances in comprehending emotional aspects of speech (get sad or happy from a person's tone of voice)
- Broca's area in the left → difficulty in expressing emotional aspects of speech

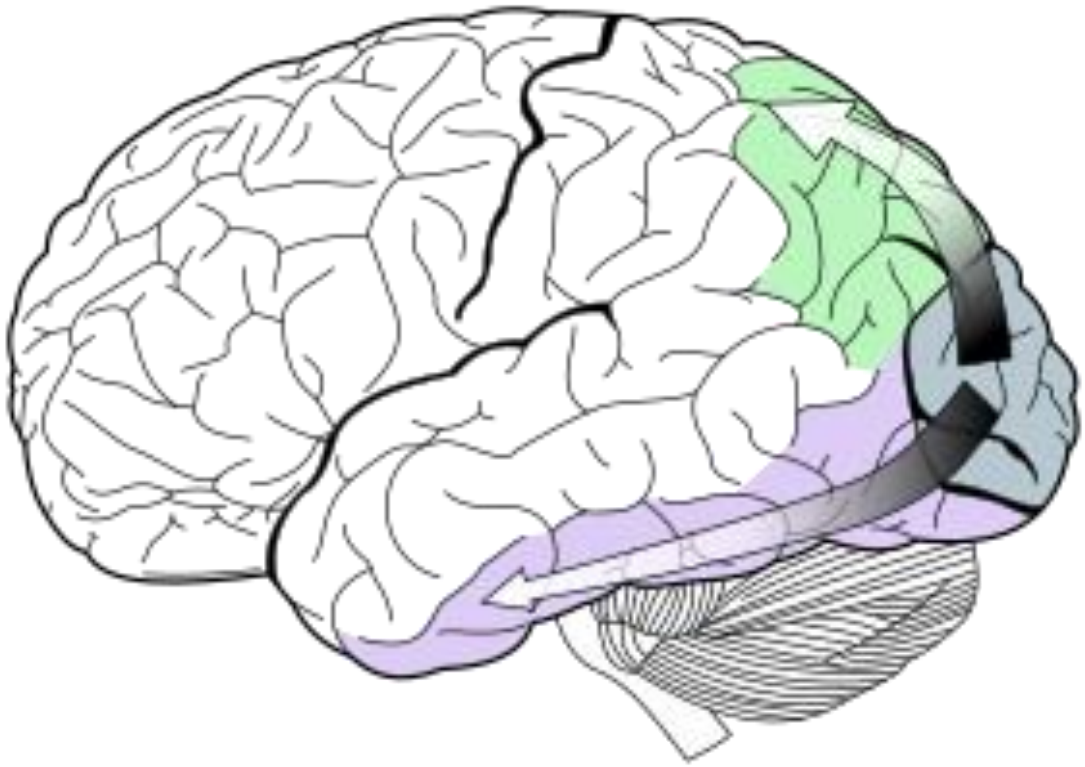
Clues to the areas in the brain that regulate affective states

- **Ictal** phenomena:
  - Emotional changes, some of which occur only fleetingly during the seizure itself. Feelings of **unreality; dejavu, fear, anger; delusions**
- Patients with epileptic **foci outside the temporal lobe** typically show no abnormal emotion and behavior.
- **Stimulation** of the subthalamic nucleus improve the tremor and produce unusual emotional states including **euphoria**
- Amygdala is another part
  - Amygdala seizures, the increased activity leads to excessive expression of emotion (irritative vs. destructive lesion)

Cognitive abilities result from . . .

- Perception, movement, language, thought, and memory are all made possible by the interlinkage of **serial** and **parallel processing** in discrete brain regions, each with **specific functions**.
- It **is not serial instead** there are several parallel pathways in a communications network that can interact and **ultimately converge upon a common set of target cells**
- Mental function can be broken down into subfunctions.
- Knowledge about **grandmother** is **not stored as a single representation** but rather is subdivided into distinct categories and stored separately (different regions for voice, face, and etcetra)

Visual processing as an example



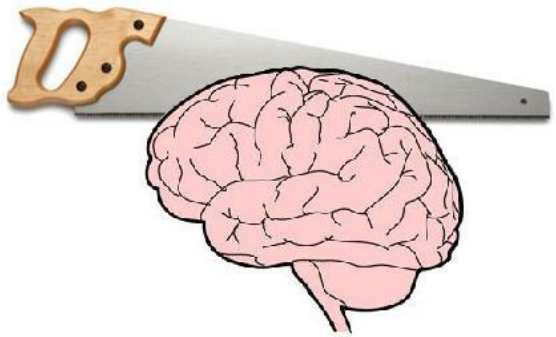
Even “I” mediated by local, specialized systems in the brain

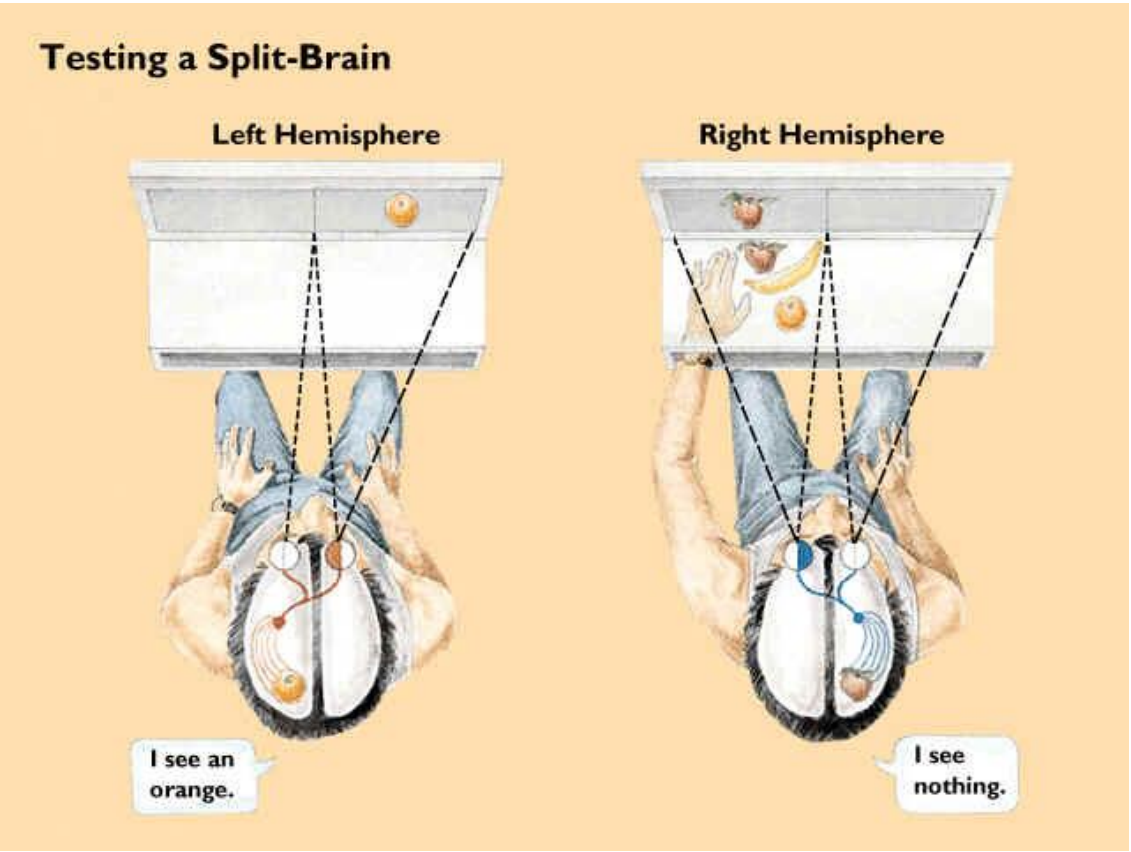
- The most **astonishing example** of the modular organization of mental processes

- **Each hemisphere** mediating **its own sense** of awareness.
  - "I" -is achieved through the connection of independent circuits in our two cerebral hemispheres

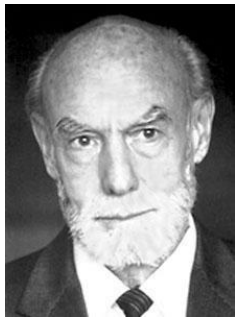
Split brain

- Split brain subject remarkable discovery that even **consciousness** is not a **unitary process**:
- Each hemisphere had a consciousness that was able to function **independently** of the other.
  - Looking at the book in the left hand was boring (right hemisphere could not read)
  - Another patient would put on his clothes with the left hand while taking them off with the other.
- **Each hemisphere has a mind of its own!**



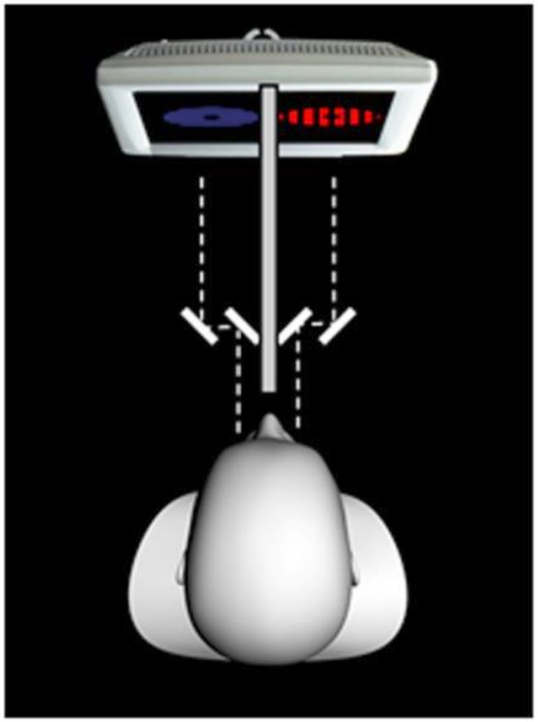


- He could name items in right not left
- If he was asked to pick out an object among an assortment in front of him using only his left hand, subject choose correct item
- If the patient was asked again what the object was, he could not vocally name what it was

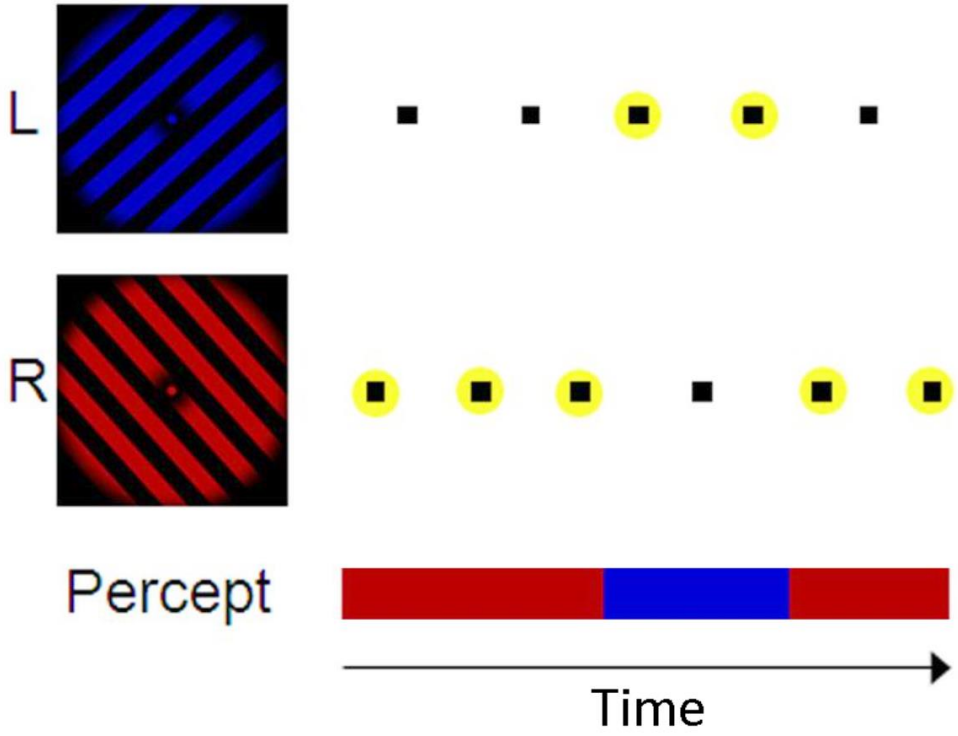


Dr. Sperry

Binocular Rivalry



Target Detection Task



Neural representation of consciousness

- Neurobiologists do not **concern themselves with the issue of subjectivity** in conscious experience.
- They **concentrate** on the **neural correlates of consciousness**
- **Simplest manifestation** of consciousness:
  - **Selective attention** in visual perception
- Two opposite views for consciousness:
  - **Crick and Koch**: special and restricted **population** of neurons are responsible
  - **Dehaene and Edelman**: consciousness is a **global** property
- **Main goal of system neuroscience** is to find the neural representation of **consciousness** and **self-awareness**