Welcome to Data Science for Cognitive Neuroscience

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Leila Wehbe

Chris Holdgraf

Mark Lescroart

About us

- Fatma Imamoglu
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  Neuroscience PostDoc with Jack Gallant at Helen Wills Neuroscience Institute

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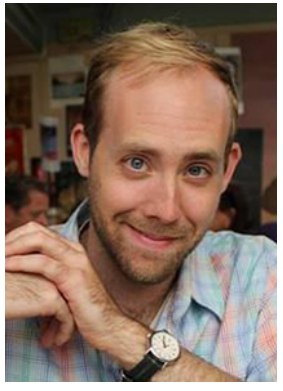
  Neuroscience PostDoc with Jack Gallant at Helen Wills Neuroscience Institute

- Chris Holdgraf
  Data Science Fellow at Berkeley Institute for Data Science
  Neuroscience Grad Student with Robert Knight at Helen Wills Neuroscience Institute



- Mark Lescroart
  Neuroscience PostDoc with Jack Gallant at Helen Wills Neuroscience Institute

The brain is noisy, complex, and really cool!

- Understanding the brain is one of the greatest challenges. However, the signals we record from the brain are notoriously noisy.
- Asking questions about the brain requires a keen understanding of the signals we record from it.
- Neuroscience increasingly uses applied statistics and machine learning to ask more sophisticated questions about brain function.
- This course will be a **practical introduction** to **data processing** and **analysis** using **predictive models** and cutting edge analytical techniques.

Office Hours

- Fridays, 11am-12pm

- Berkeley Institute for Data Science
  Doe Library 190 C

Learning Cooperatively

- Discuss your homework with your classmates
- Ask for help!
- Please do NOT copy the answers to homework assignments from others.

  It is important to try and show us that you are trying.

Grading

- Homework 50 %
- Attendance and participation 10%
- Midterm 20 %
- Final 20 %

- Homework will be graded for completeness
  - If you cannot solve the problem do NOT copy the answers from others.
  - Show us the different ways that you tried to solve the problem.

What about you?

Lecture 1
A Brief Introduction to Cognitive Neuroscience

Cognitive Neuroscience

Cognitive Neuroscience

- **Cognition** refers to a variety of higher mental processes such as thinking, perceiving, imagining, speaking, acting, and planning

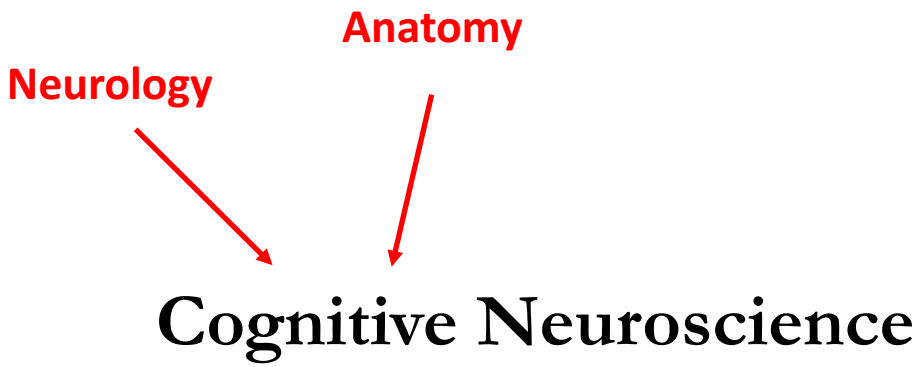
- Cognitive neuroscience is a brain based account to study mental processes

- Modern cognitive neuroscience research is made possible by technological advances

Many fields influence cognitive neuroscience

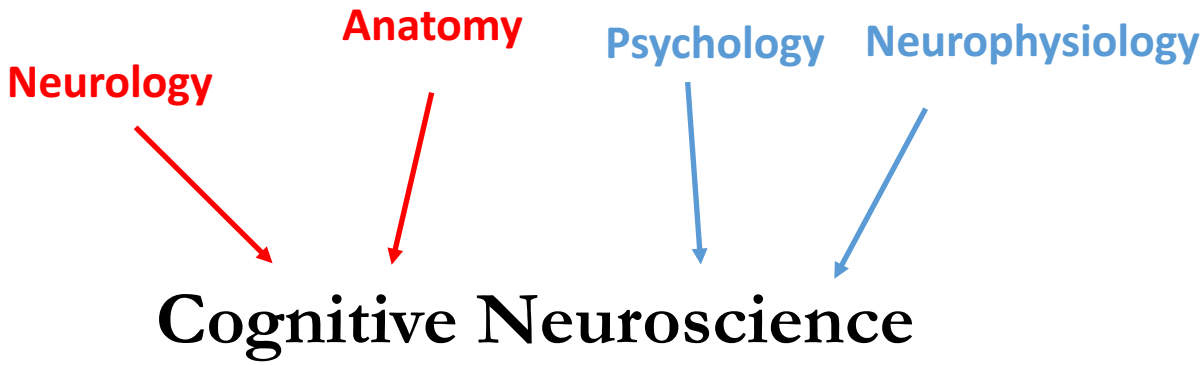
Fields that influence cognitive neuroscience

- **Localization**: Where does the process of interest occur?



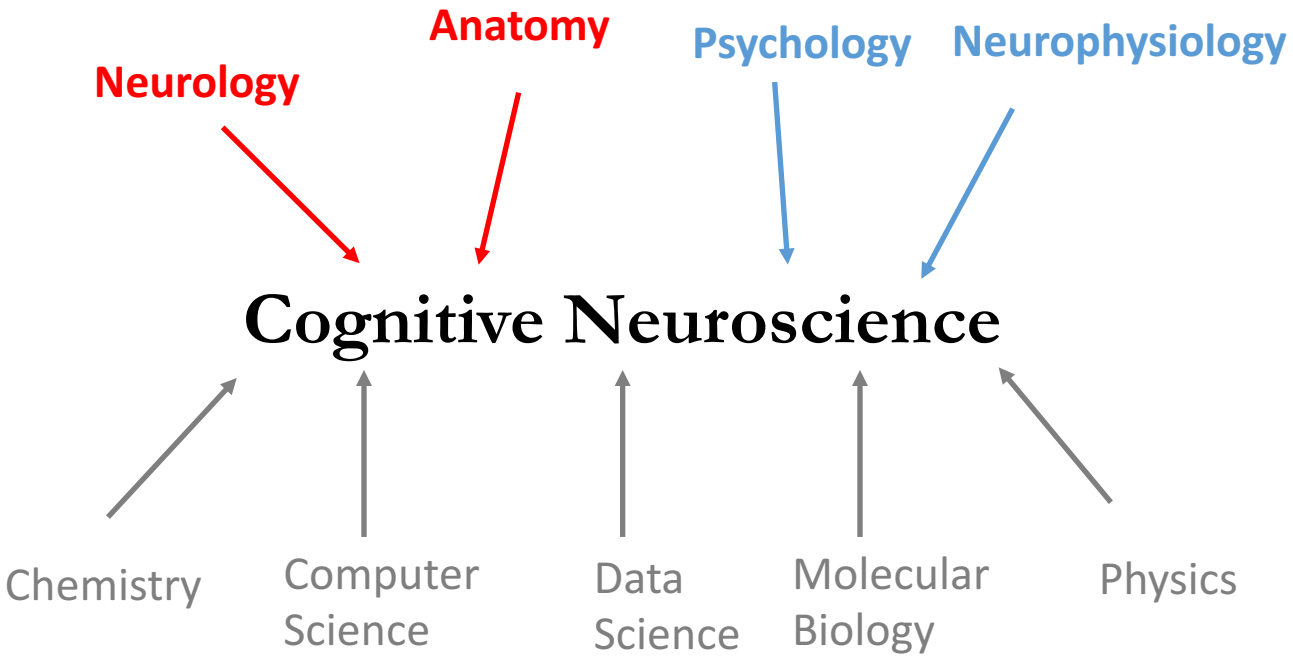
Fields that influence cognitive neuroscience

- **Localization**: Where does the process of interest occur?
- **Representation**: What information is represented at each location?



Fields that influence cognitive neuroscience

- **Localization**: Where does the process of interest occur?
- **Representation**: What information is represented at each location?
- **Technology**: How can we record and model the data?



A brief history of Cognitive Neuroscience

Problem to solve

How and where do mental processes (e.g. thinking, remembering, solving problems, telling jokes, making plans, etc.) emerge from?

A brief history of beliefs about cognition

- Babylonian and Egyptian physicians made detailed observations of various neurological and psychiatric conditions.

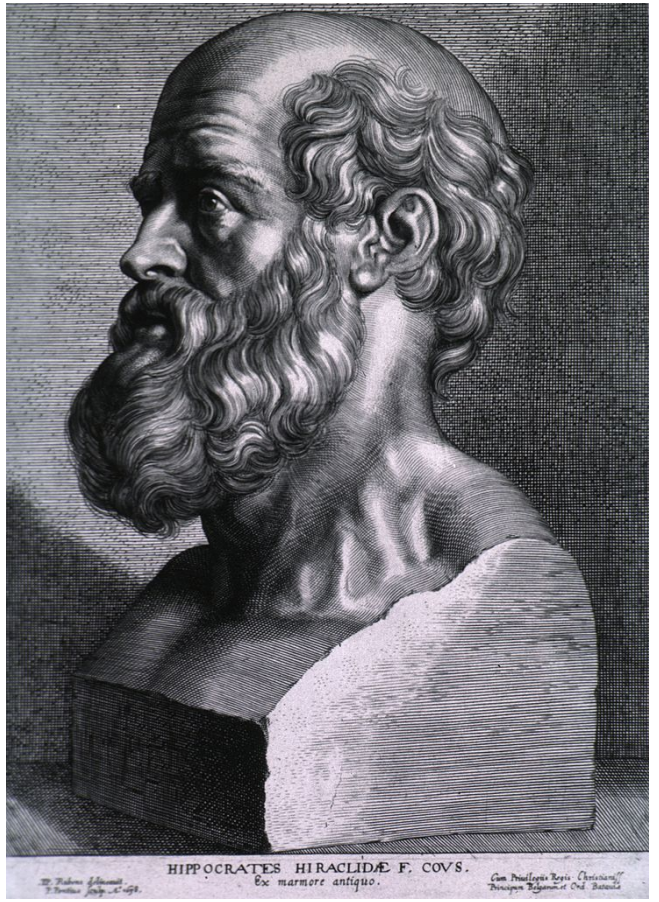
- Babylonians distinguished between various types of epilepsy
- However, they thought epilepsy was caused by demonic possession.

- Egyptians understood that brain injury could cause loss of function far from site of injury or on the opposite side of the body.
- However, they thought that the heart was the seat of intellect.

Babylonian tablet on Epilepsy, British Museum, London

A brief history of beliefs about cognition

- Alcmaeon of Croton (ca. 450 BC)
  - First dissection in Greece
  - Brain is the seat of mind and intelligence
- Hippocrates (ca. 400 BC)
  - Brain is the seat of intelligence
- Aristotle (ca. 400 BC)
  - The ratio of brain size to body size is larger in more intelligent species
  - Heart is the seat of intelligence
  - Brain: Coolant system for the blood
    (Larger intellects need larger coolant systems)



Engraving of Hippocrates,
Paul Rubens

A brief history of beliefs about cognition

- No distinction between the mental and physical
- Brain injuries effecting mental functions
- Dissected brains of non-human animals and observed brain injuries in Gladiators
- Localization of functions (the three souls)
  - The rational soul (High-level cognition): Brain
  - The spiritual soul (Vital functions, being alive): Heart
  - The appetitive soul (Desires, survival instincts): Liver

Galen of Pergamon (AD 120-200)

Mind-Body/Brain Problem

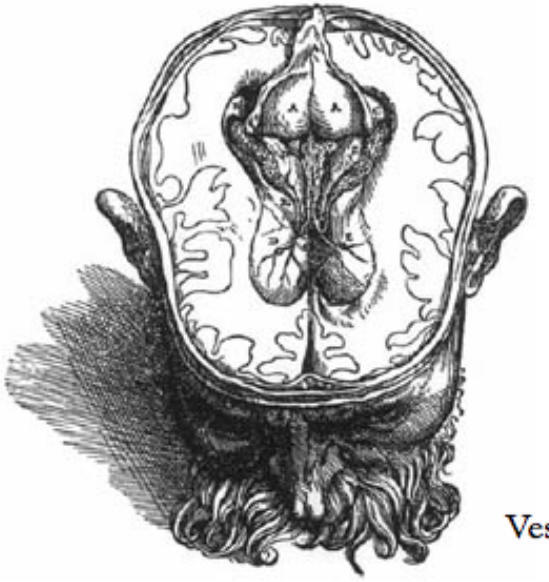
- How can a physical substance (like our bodies) give rise to our feelings, thoughts, emotions, and actions?

  Dualism: Mind and body are separate [Descartes, 1596-1650]

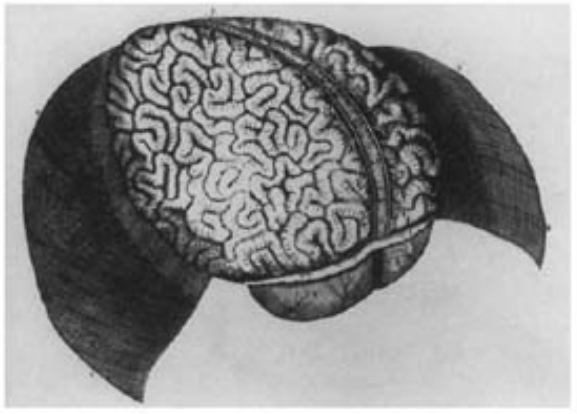
  Dual-aspect theory: Mind and body are the same [Spinoza, 1632-1677; Velmans, 2000]

  Reductionism: Mind can be explained solely in biological terms [Churchland, 1995; Crick, 1994]

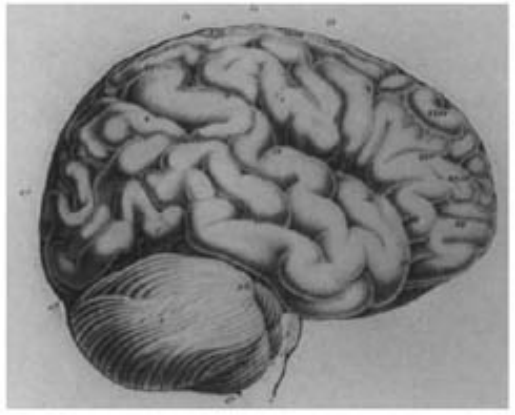
The lack of interest in the cortex until 19th c.



Vesalius (1543)



Viessens (1685)



Gall and Spurzheim (1810)

Problem to solve

How and where do mental processes (e.g. thinking, remembering, solving problems, telling jokes, making plans, etc.) emerge from?

Problem to solve

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- Does the whole biological tissue work as a unit with each part contributing to its work?

Problem to solve

How and where do mental processes (e.g. thinking, remembering, solving problems, telling jokes, making plans, etc.) emerge from?

- Does the whole biological tissue work as a unit with each part contributing to its work?

- Is the biological tissue full of individual processing units with each carrying out specific functions?

Brain mapping: Phrenology

- Localization of cognitive functions
- First attempt to map cognitive functions to the brain [Gall and Spurzheim, 1810]
- Shape and size of different regions represent different functions: E.g. language, color perception, hope, self esteem, moral functions, etc.
- The size of these regions produces distortions of the skull and correlates with differences in cognition and personality
- This "Anatomical Personology" was **not** based on quantitative measurements

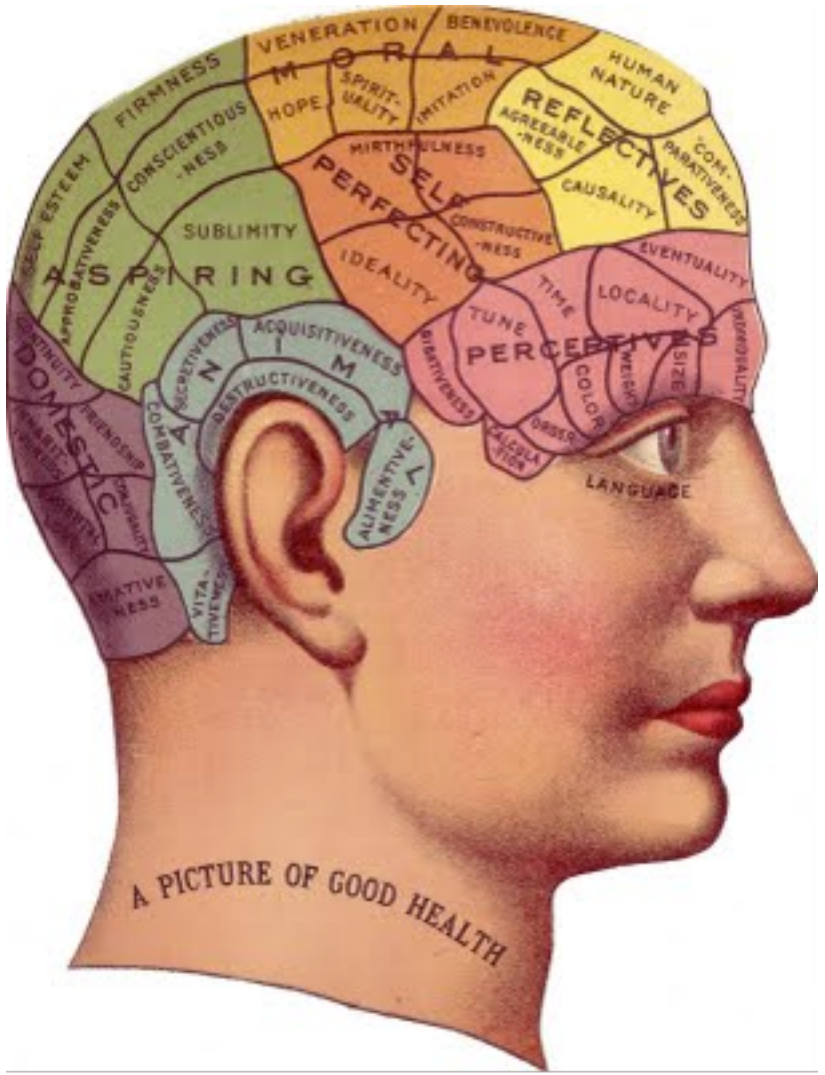


Image courtesy: Hope Wallace Karney

The localization debate

- Jean Pierre Flourens (1824) was an early leader in the fight against localism phrenology and Gall.
- He verified that large brain structures were related to general functions (for example, the cerebellum was responsible for good motor control).
- However, he held that more sophisticated abilities such as memory, intellect and reasoning were not localized
- Concluded that all sensations and perceptions occupy the whole brain

Jean-Pierre Flourens

The localization debate

- Marc Dax (1836) related speech disturbance to left hemisphere lesions after autopsies in humans
- John Hughlings Jackson (~1860) suggested a topographic organization in the cortex based on observations in epilepsy patients.
- Paul Broca (1861) provided the first clear evidence that language production (fluent speech) is localized in the anterior-lateral aspect of the left hemisphere.

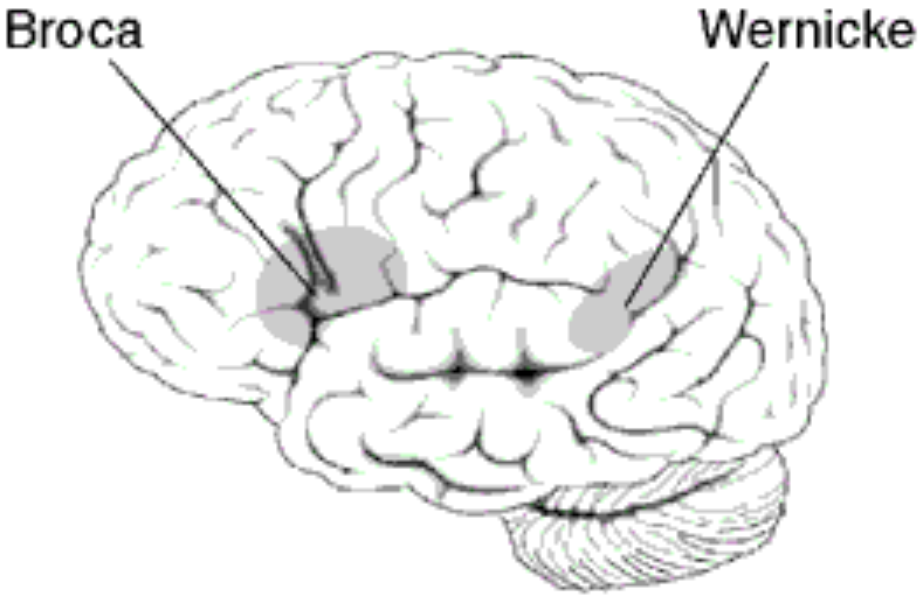


Image courtesy: NIH publication 97-4257, http://www.nidcd.nih.gov/health/voice/pages/aphasia.aspx

The electrical brain

- Volta and Galvani (~1780) showed that muscle of dead frogs' legs twitched with electric current
  - Animal electricity – Bioelectricity – Electrophysiology
- Richard Caton (1875) first recorded electrical impulses from the surface of living brains in rabbit and monkey
- Hans Berger (1924) recorded electrical impulses from the surface of human brains

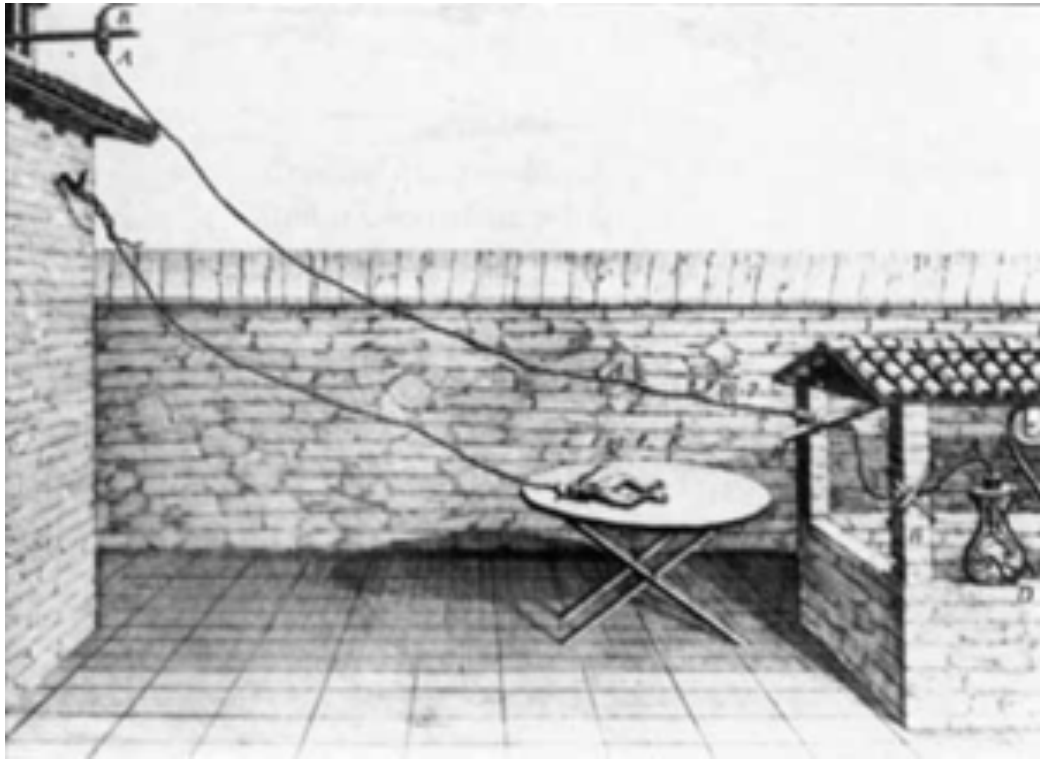
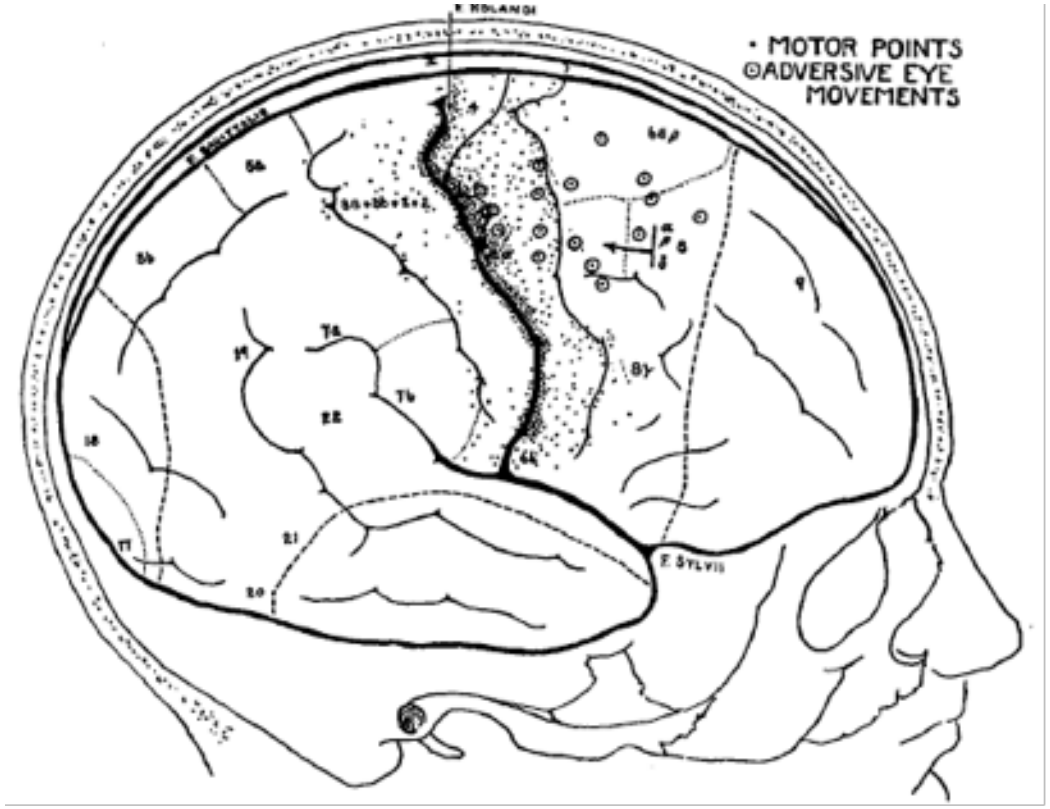


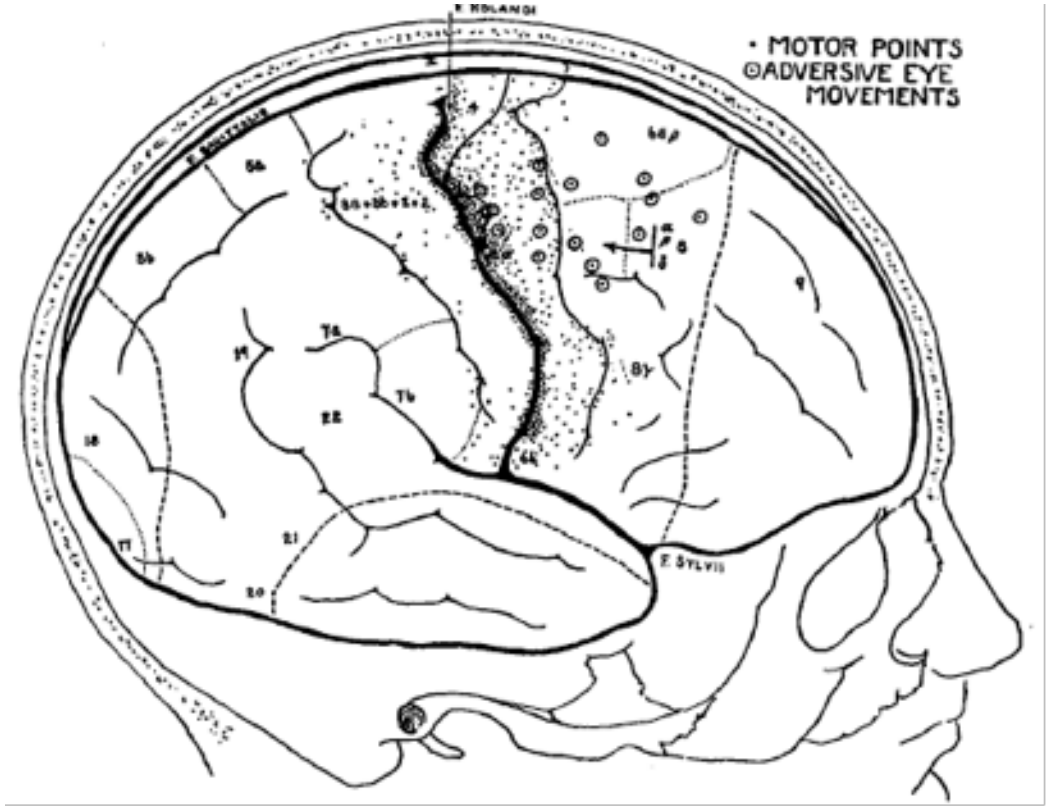
Image taken from:
https://en.wikipedia.org/wiki/File:Galvani-frog-legs.PNG

Brain mapping: Topographic organization

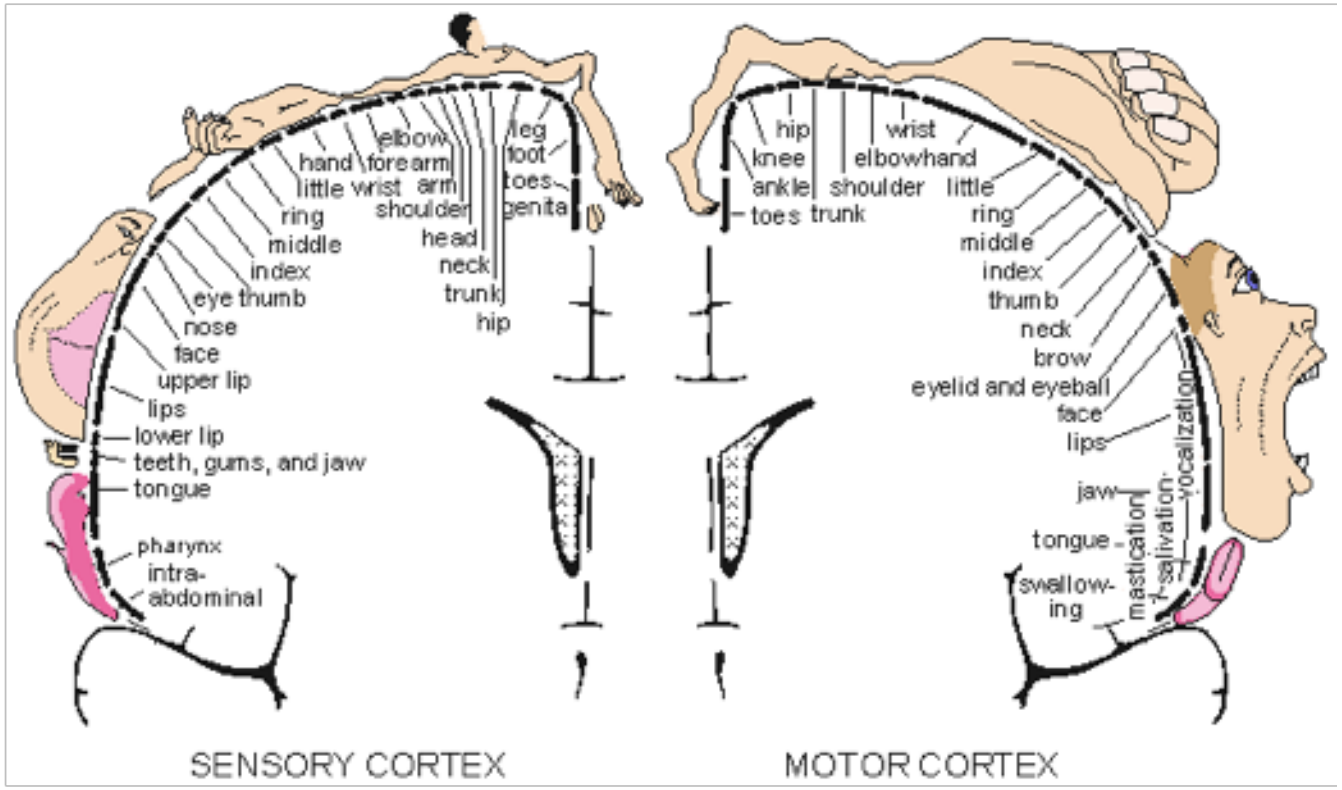


Penfield and Boldrey, 1937

Brain mapping: Cortical homunculus



Penfield and Boldrey, 1937



Penfield and Rasmussen, 1950

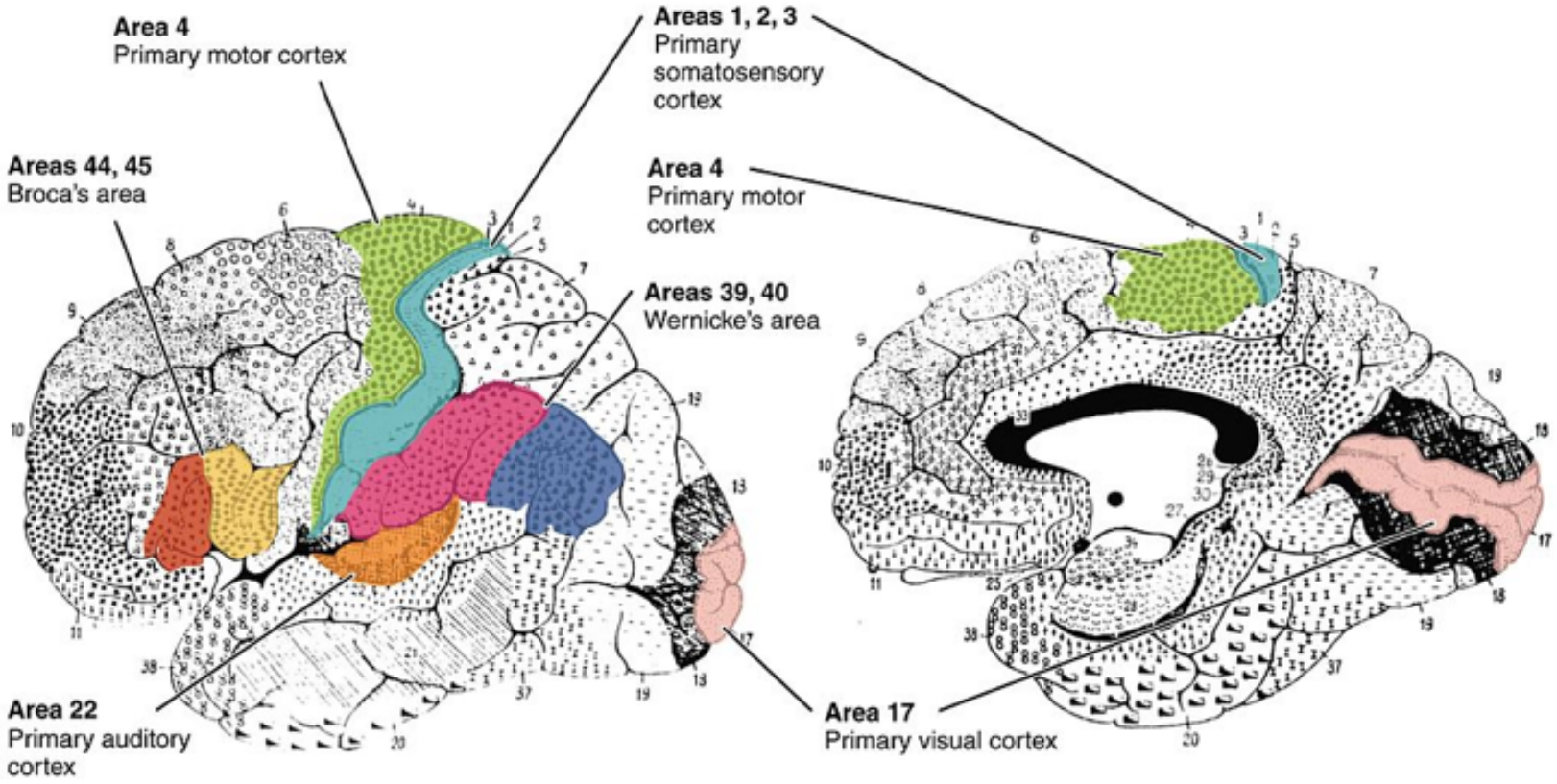
Electrical stimulation: Patient responses

Occipital lobe: "a star came down towards my nose”

Central sulcus: "those fingers and my thumb gave a jump"

Temporal lobe: "I heard the music again; it is like the radio"

Cytoarchitectonics: Broadmann areas

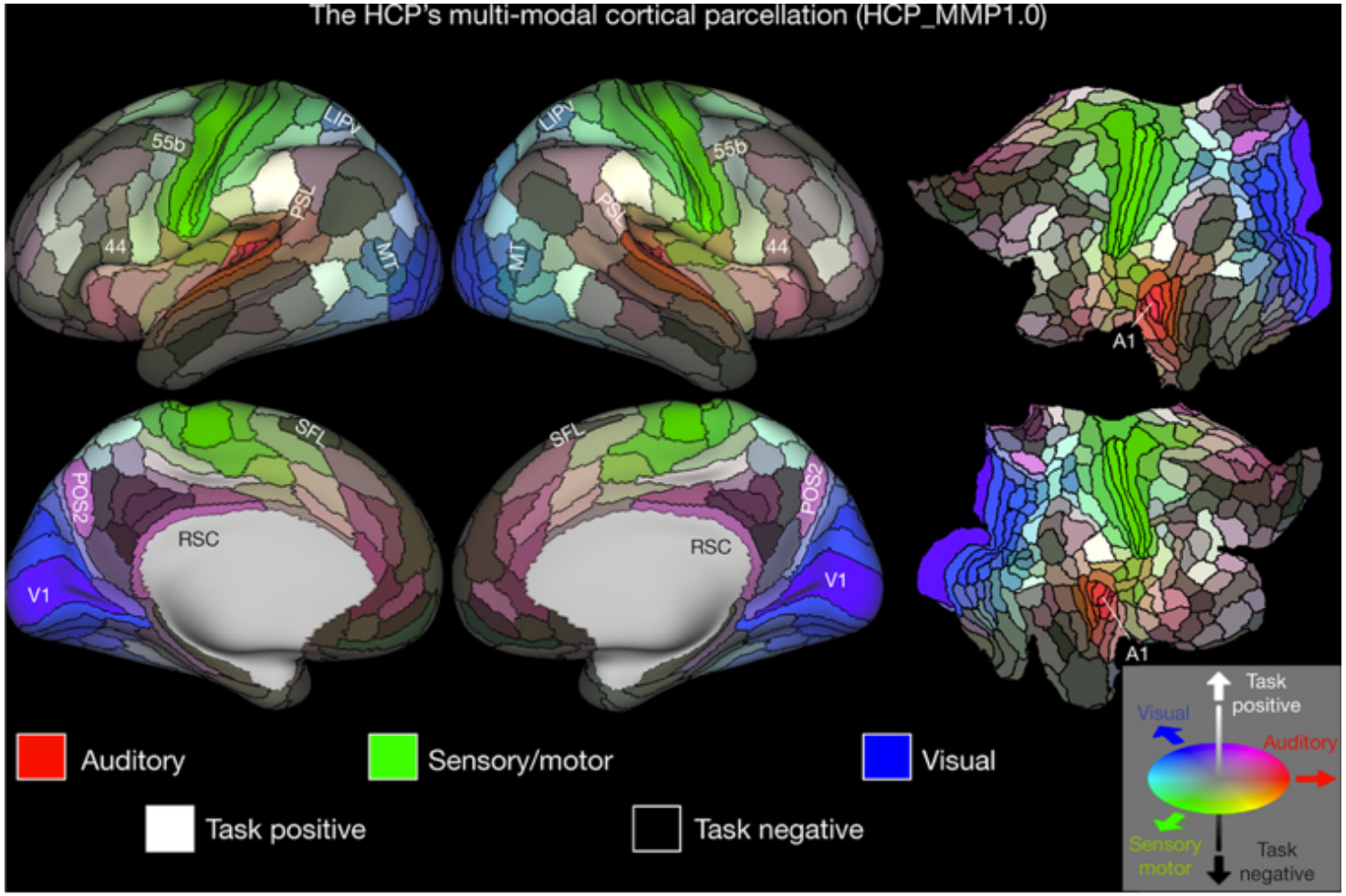


Brodmann's cytotechtonic map (1909): Lateral surface

Brodmann's cytotechtonic map (1909): Medial surface

Image courtesy: [OpenStax https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface](https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface)

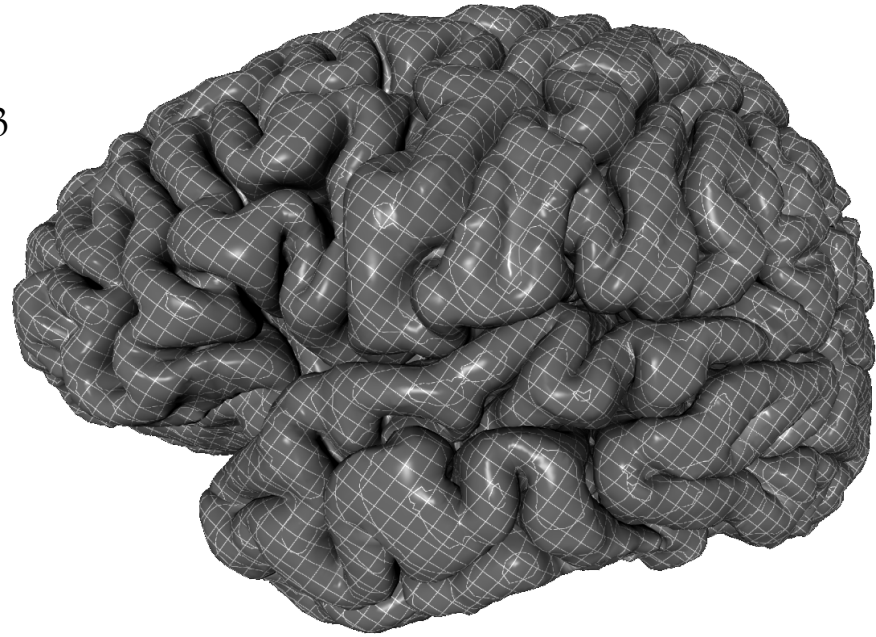
Human Connectome Project: Cortical Parcellation



Glaesser et al. 2016

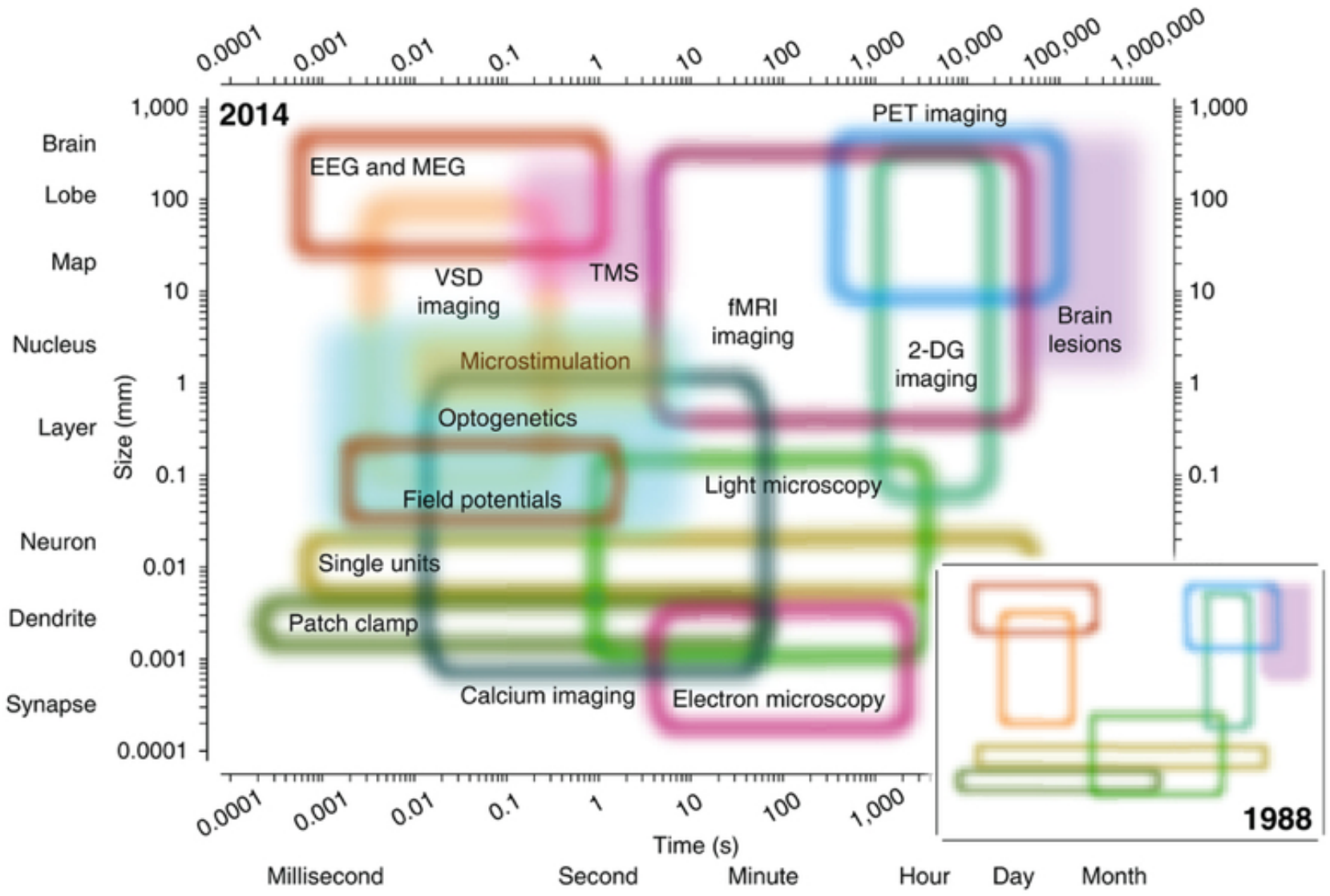
Numbers in the brain (rough estimates)

- Number of neurons in adult human brain: $8x10^{10}$ (80 billion)
- Number of neurons in adult cerebral cortex: $1.8x10^{10}$
- Number of synapses on typical cortical neuron: $6x10^{3}$
- Number of cortical columns: $1x10^{5}$
- Average loss of cortical neurons: 1 / second
- Total surface area of cerebral cortex: $2.5x10^{3}$ cm^{2}
- Thickness of cerebral cortex: 1.5-4 mm
- Number of cortical areas: 400 (???)



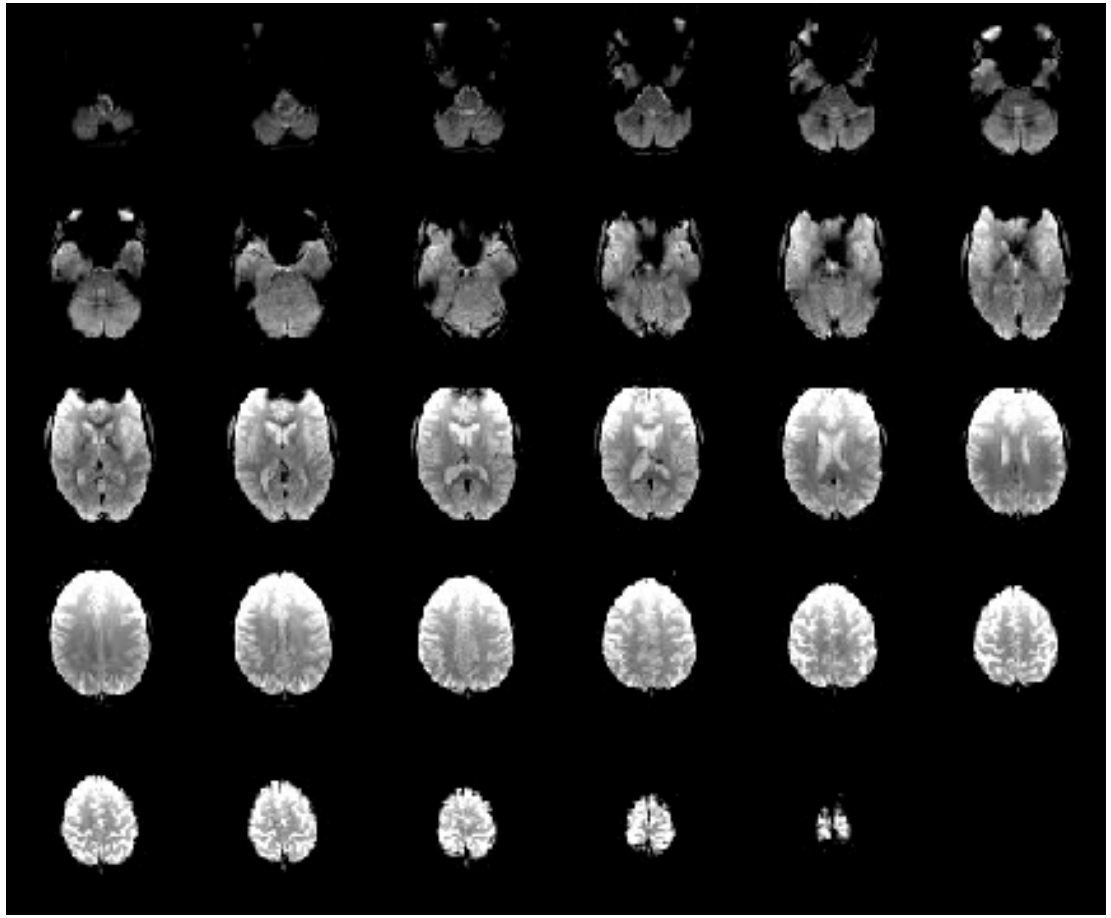
(see: https://faculty.washington.edu/chudler/facts.html)

Methods of Cognitive Neuroscience



Sejnowski et al., Nature Neurosci., 2014

Brain activity during an fMRI experiment



Functional MR imaging of human brain activity elicited by natural movies

Anwar Nunez-Elizalde and James Gao

Gallant Lab
University of California at Berkeley
(2015)

(movie courtesy of Damian Livesey
https://vimeo.com/19009646)

Neuron (nerve cell)

- Brains are composed of billions of neurons.
- Each neuron is a cell that processes and transmits information through electrical and chemical signals

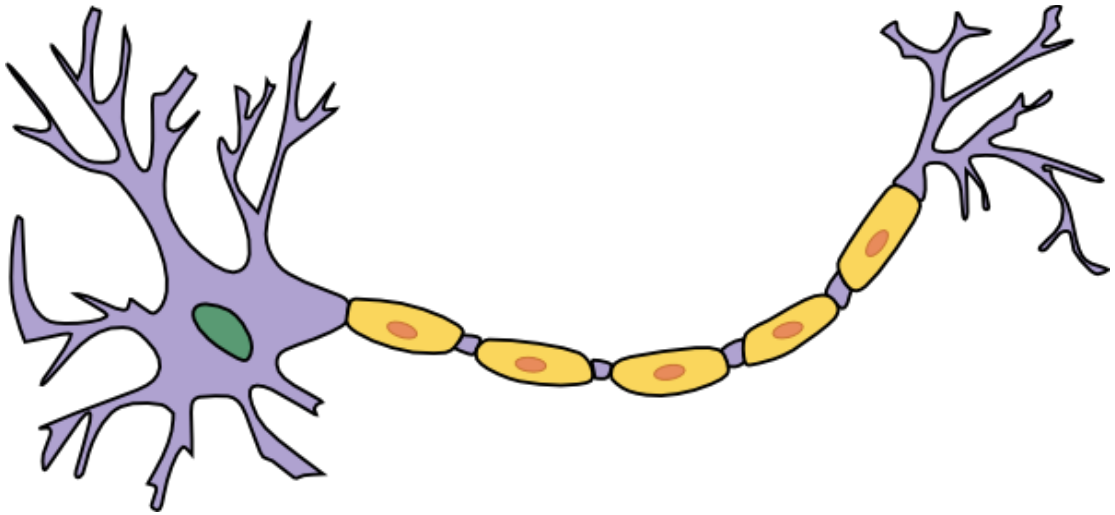
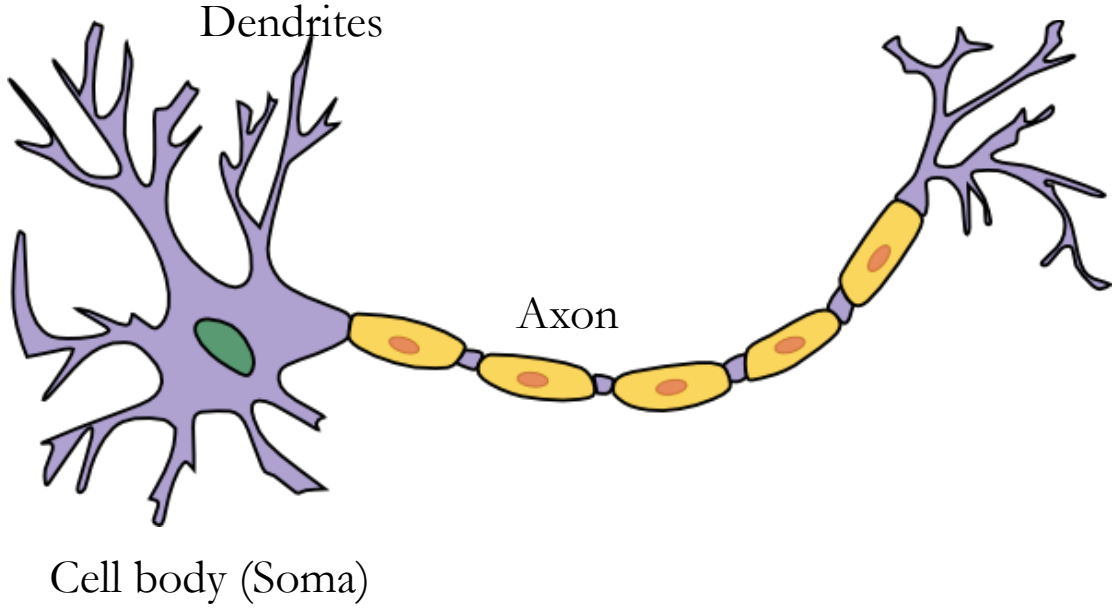


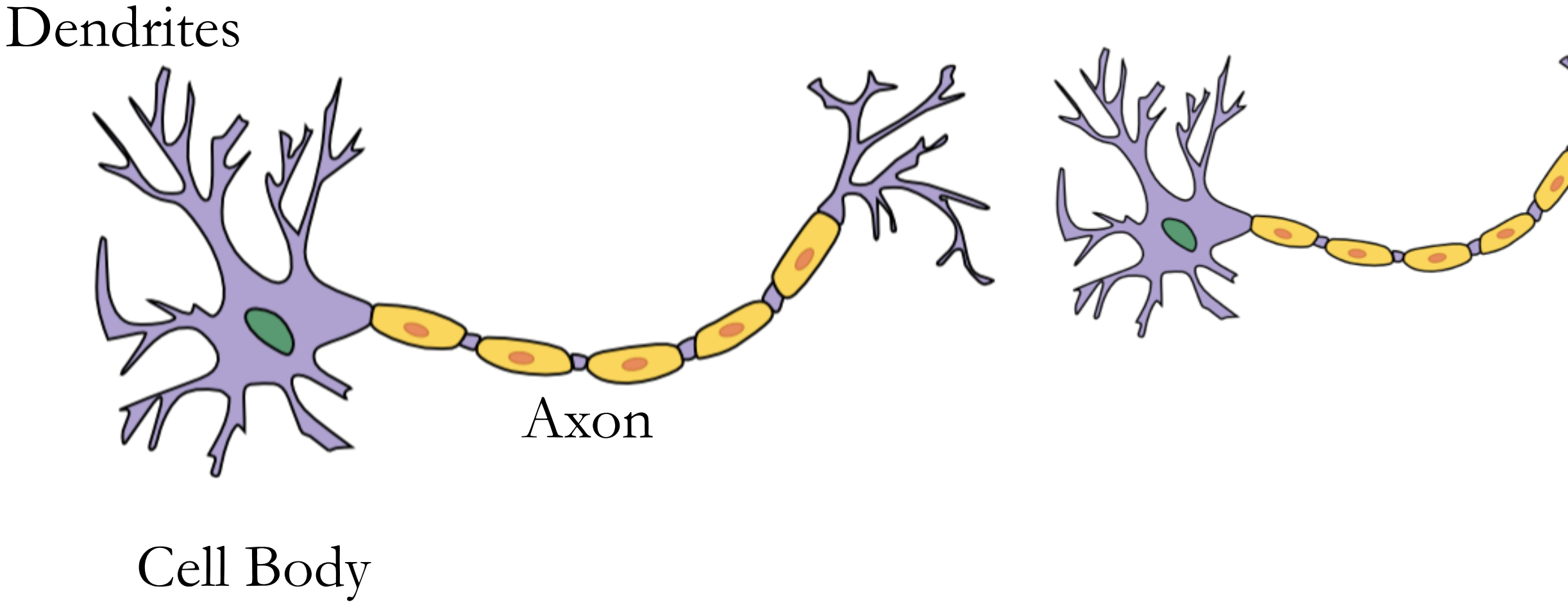
Image courtesy: http://www.wpclipart.com/medical/anatomy/cells/neuron/

Neuron (nerve cell)

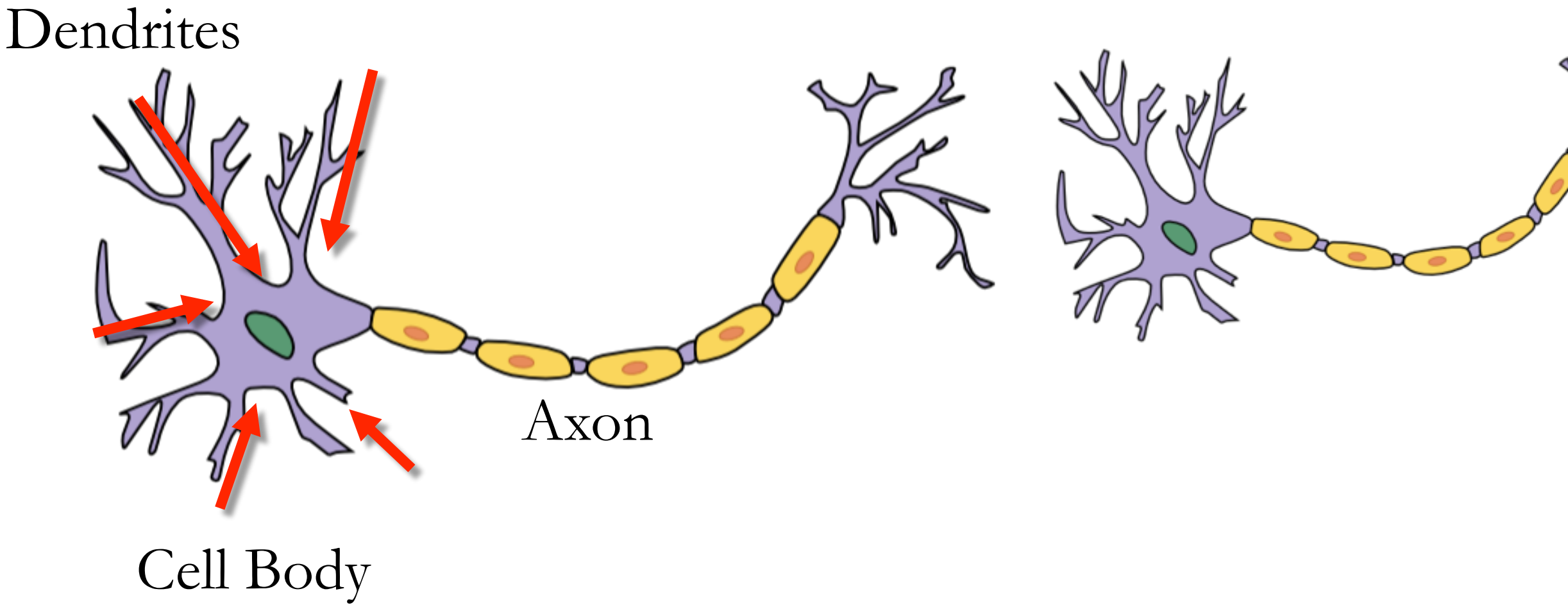
- Brains are composed of billions of neurons.
- Each neuron is a cell that processes and transmits information through electrical and chemical signals
- Constituents of a neuron:
  - a cell body (soma),
  - a collection of inputs (dendrites), and
  - an output (axon)



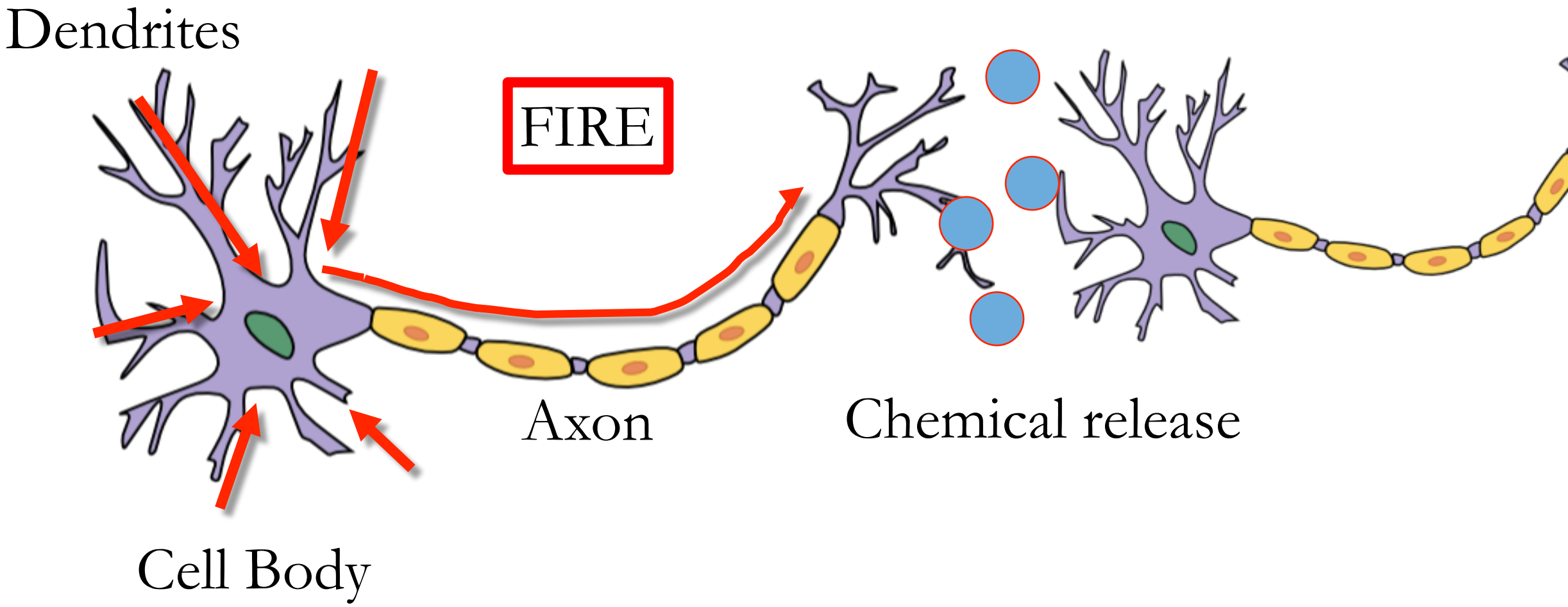
How do neurons communicate?

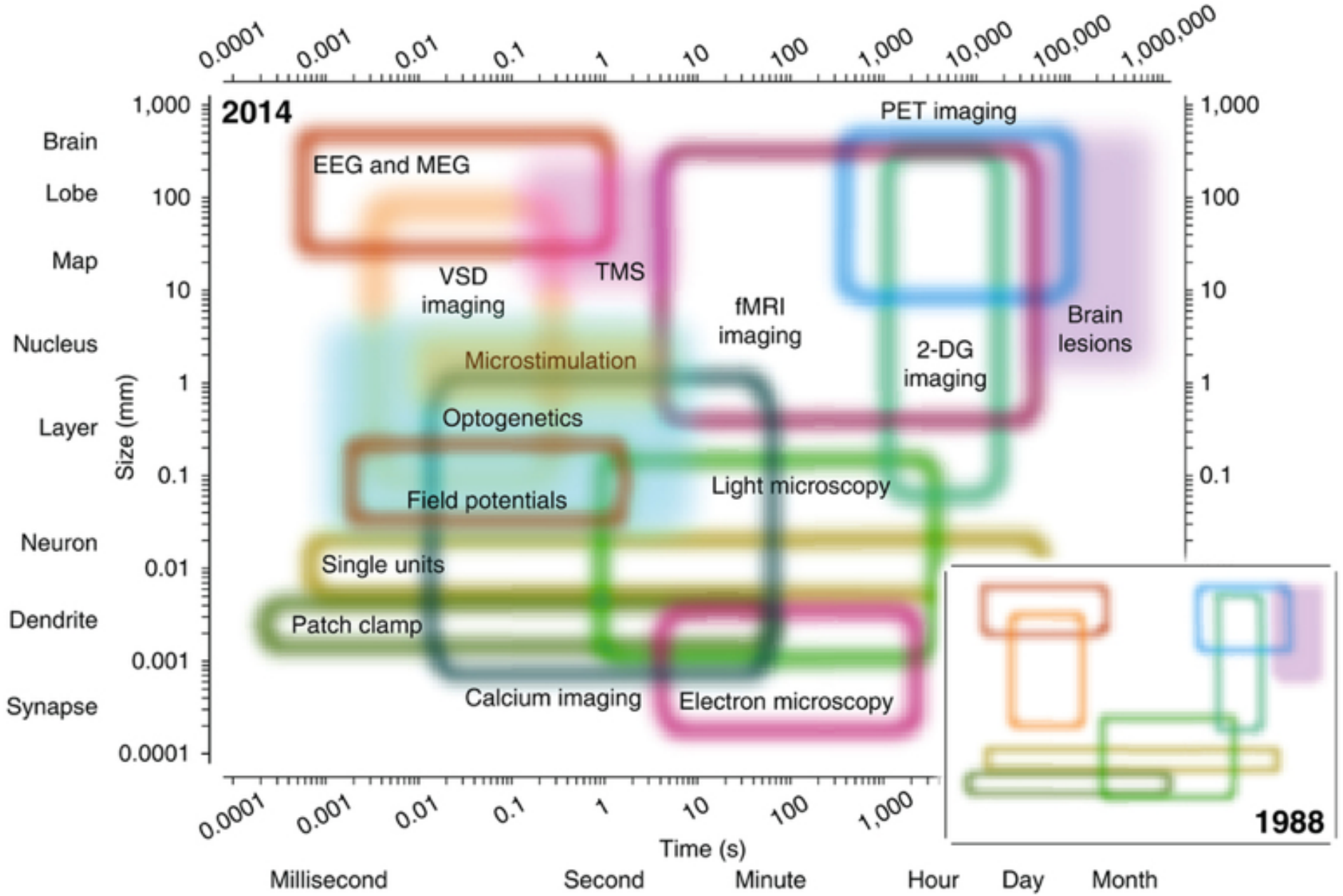


How do neurons communicate?



Neural firing





Sejnowski et al., Nature Neurosci., 2014

Single-cell recordings

- Measuring electrical activity using electrodes placed in or near single neurons
- Animal studies or studies with patients undergoing surgery (e.g. epilepsy)
- Analysis of cognitive functions that can lead to Brain Machine Interfaces (BMI)
- High temporal, low spatial resolution

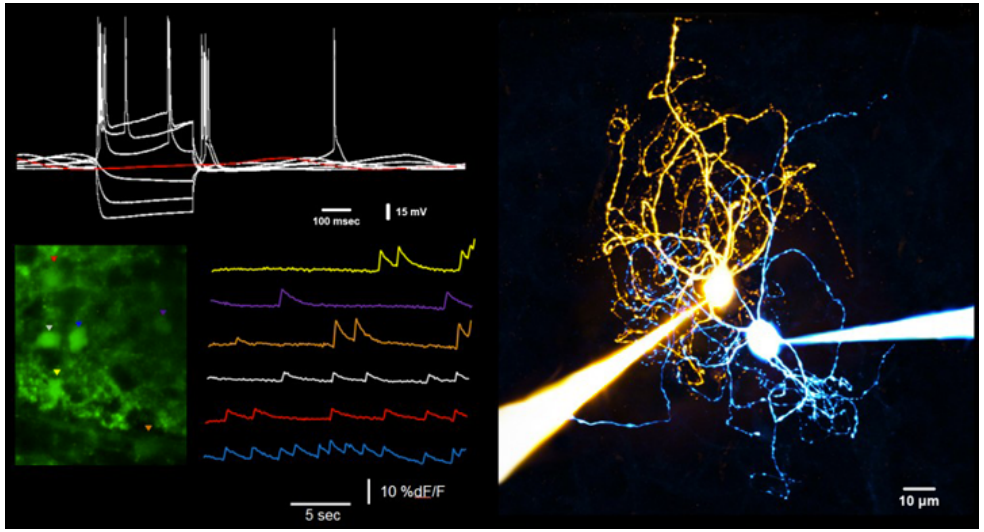


Image courtesy. http://depts.washington.edu/

➢ How do individual neurons encode information?

BMI: An example
Neural Controlled Prosthesis

Image courtesy: University of Pittsburg Medical Center (UPMC)

Electroencephalogram (EEG)

- Measuring electrical activity from neurons that reach the scalp using electrodes placed on the scalp
- Signal is derived from several sources in the brain (coarse sampling)
- EEG reflects many ongoing brain processes
- High temporal, low spatial resolution

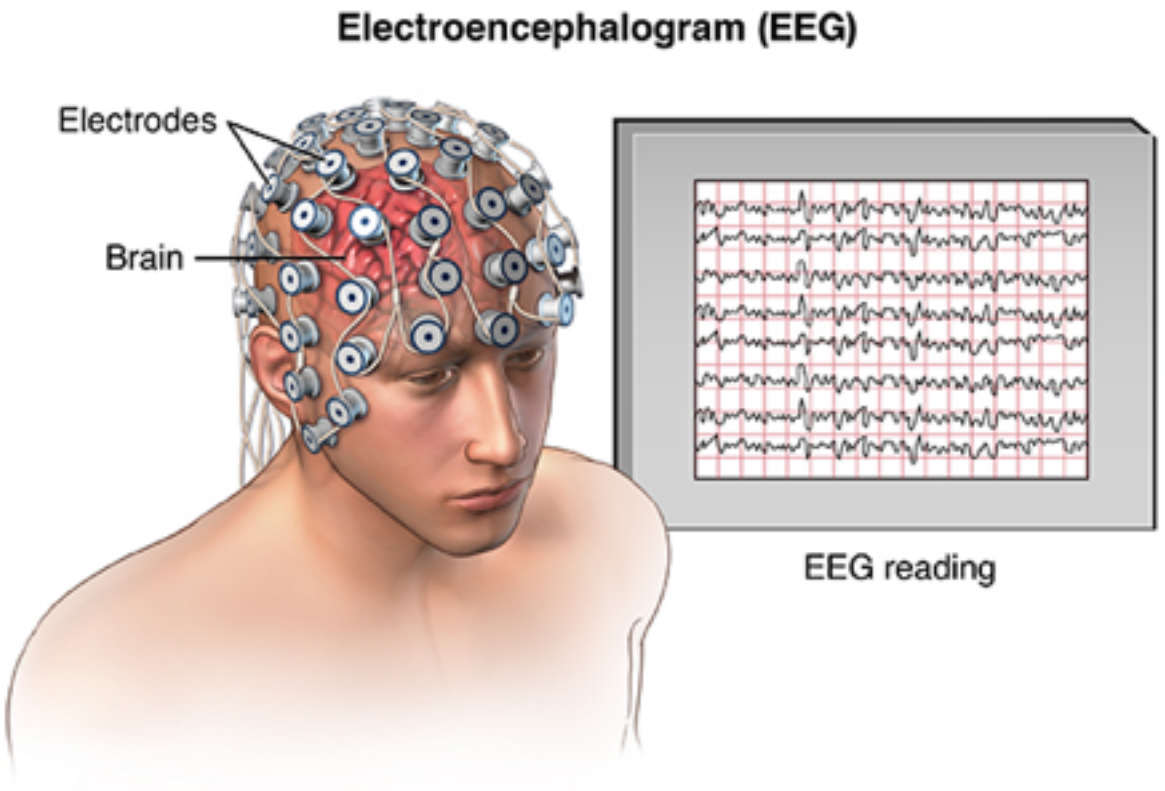
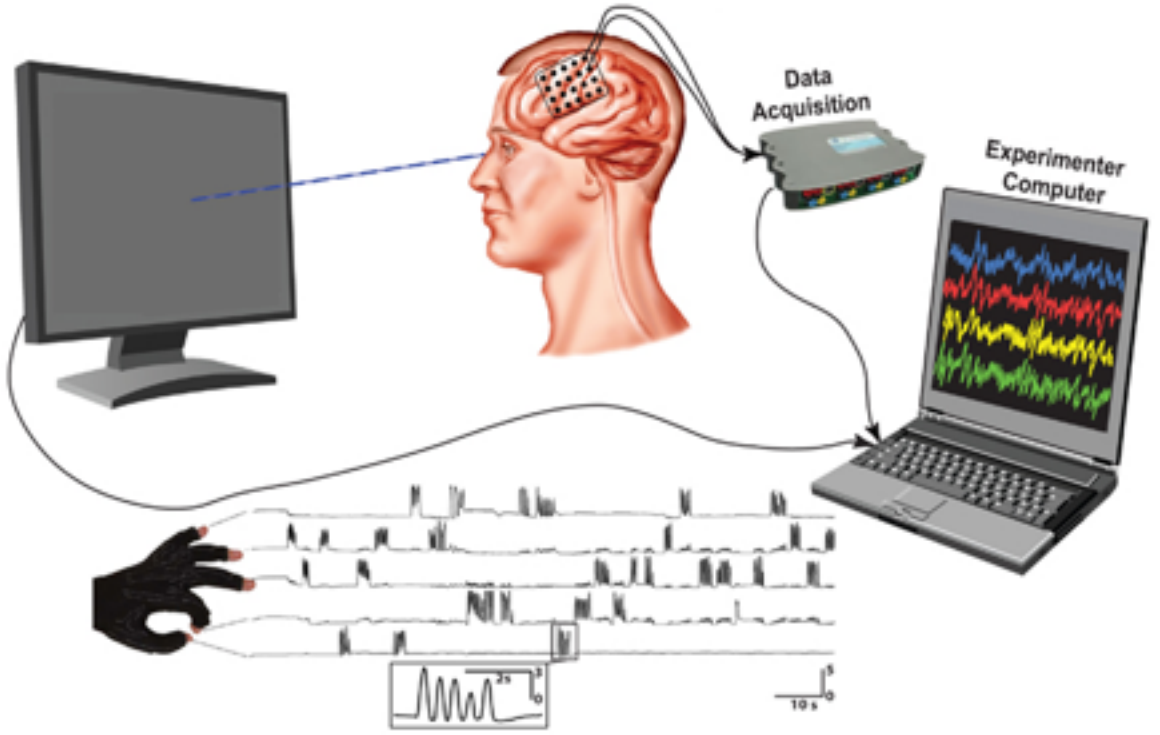


Image taken from: http://nbml.ir/

➢ How does a very large collection of neurons encode information?

Electrocorticography (ECoG)

- Measuring electric activity using electrodes placed on the surface of the cortex
- Similar to EEG but less signal distortion
- High temporal, low spatial resolution



Wang et al., 2011

➢ How does a specific collection of neurons encode information?

Magnetoencephalography (MEG)

- Electric activity of a neuron causes very small magnetic field changes
- MEG measures this change
- Magnetic field is less distorted then the electric field
- High temporal, low spatial resolution but better than EEG

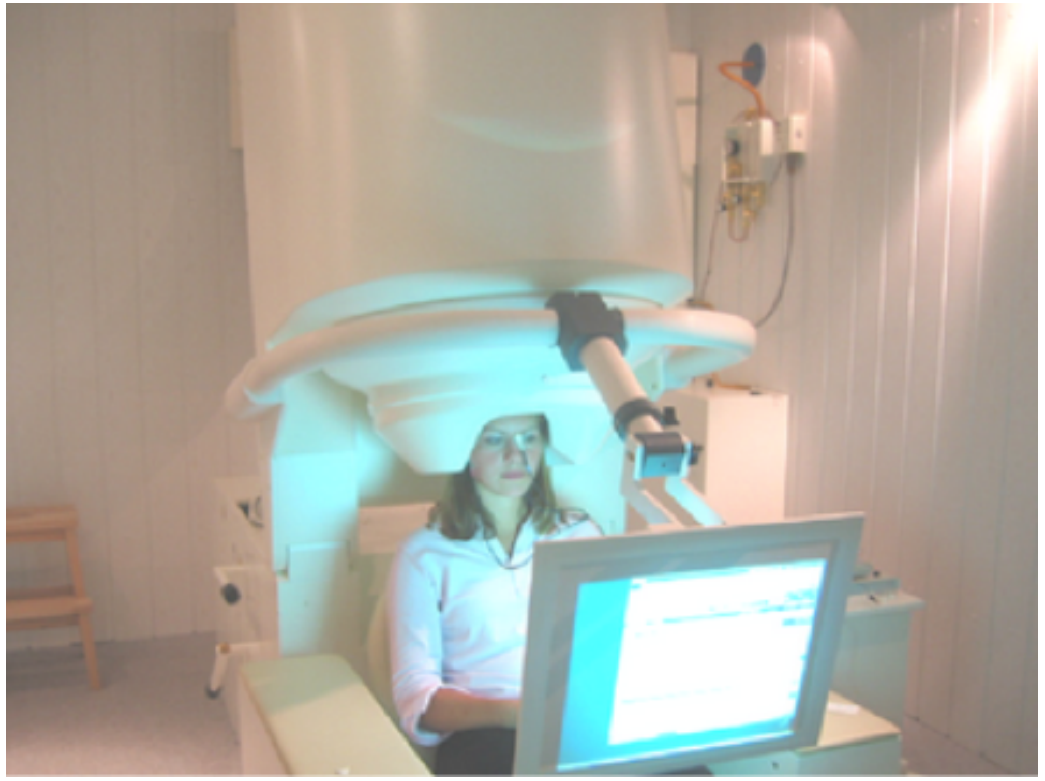
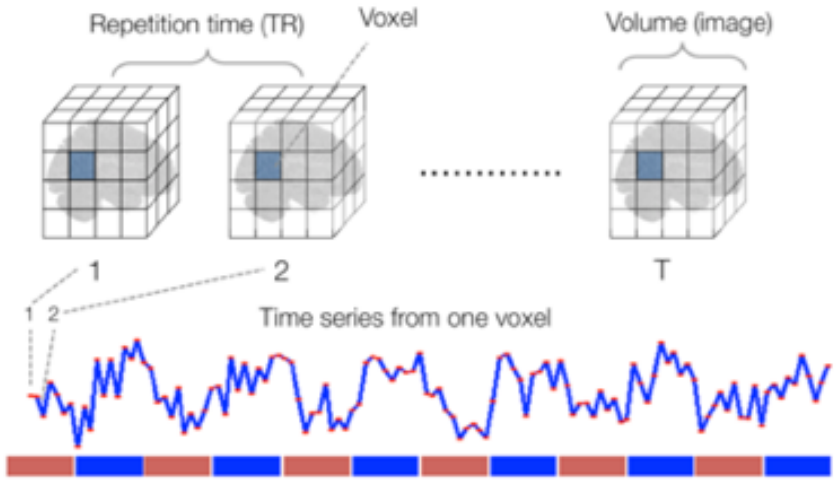


Image courtesy: http://megcommunity.org/what-is-meg

➢ How does a very large collection of neurons encode information?

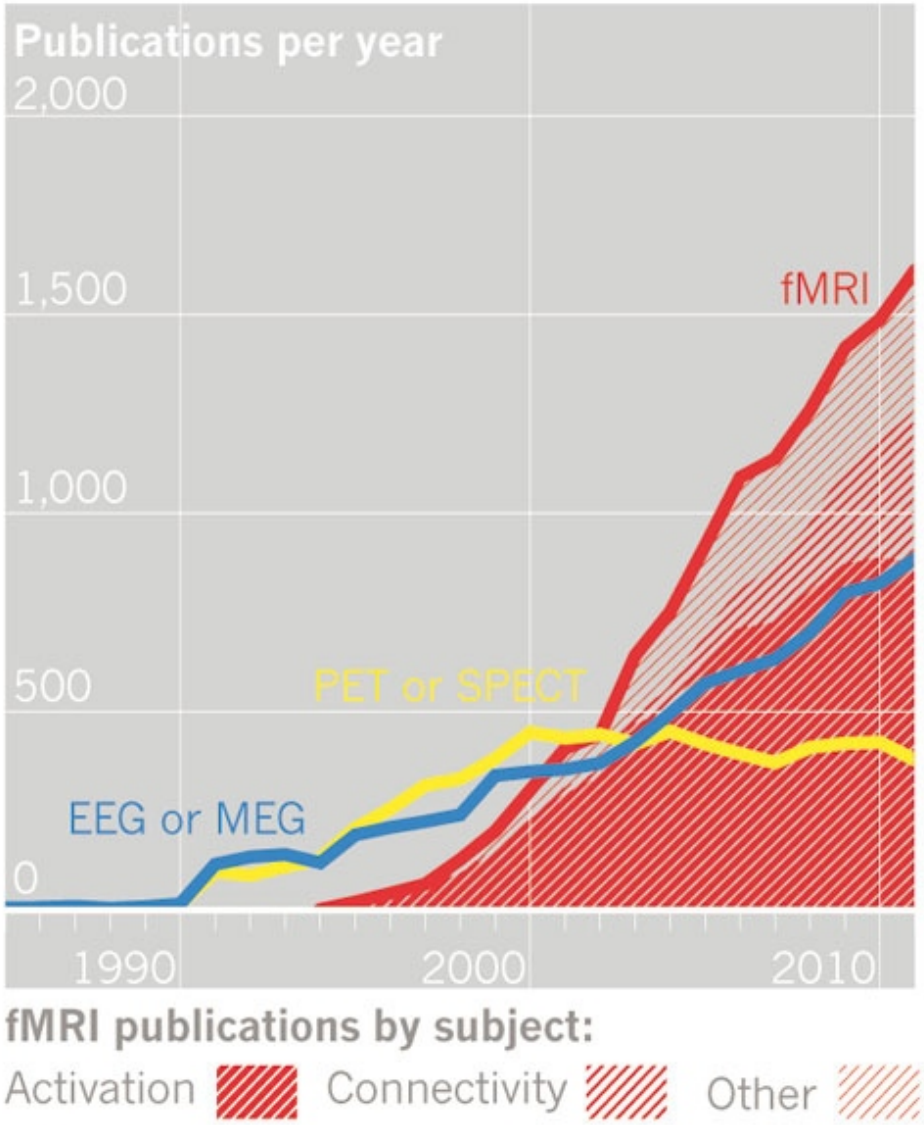
Functional Magnetic Resonance Imaging (fMRI)

- Measuring local variations in cerebral blood flow
- Uses MRI to measure oxygen content of the blood (hemodynamic response)
- Assumption: Increased blood flow to the brain regions that have high neural activity
- Blood oxygenation level-dependent (BOLD) signal: The ratio of oxygenated to deoxygenated hemoglobin
- Low temporal, high spatial resolution



https://leanpub.com/principlesoffmri

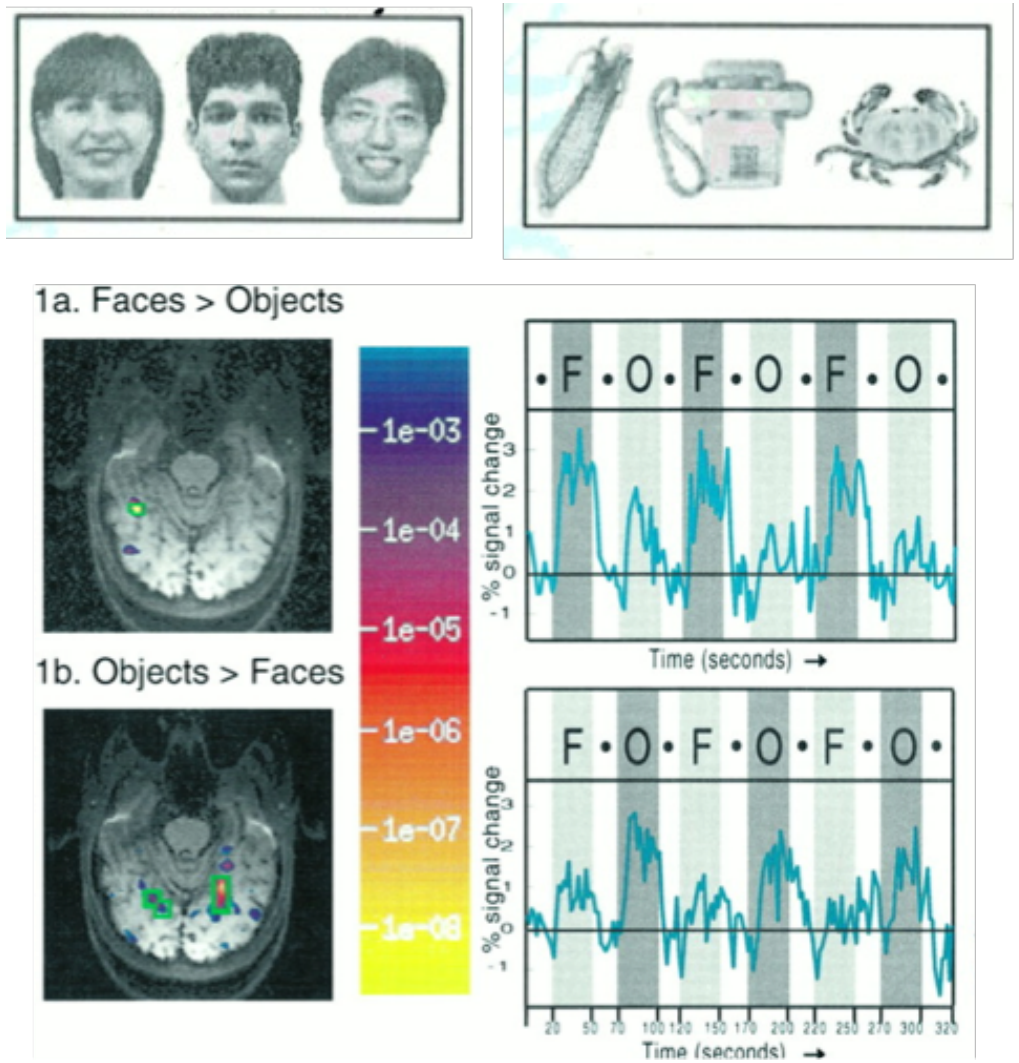
Growth of fMRI publications over years



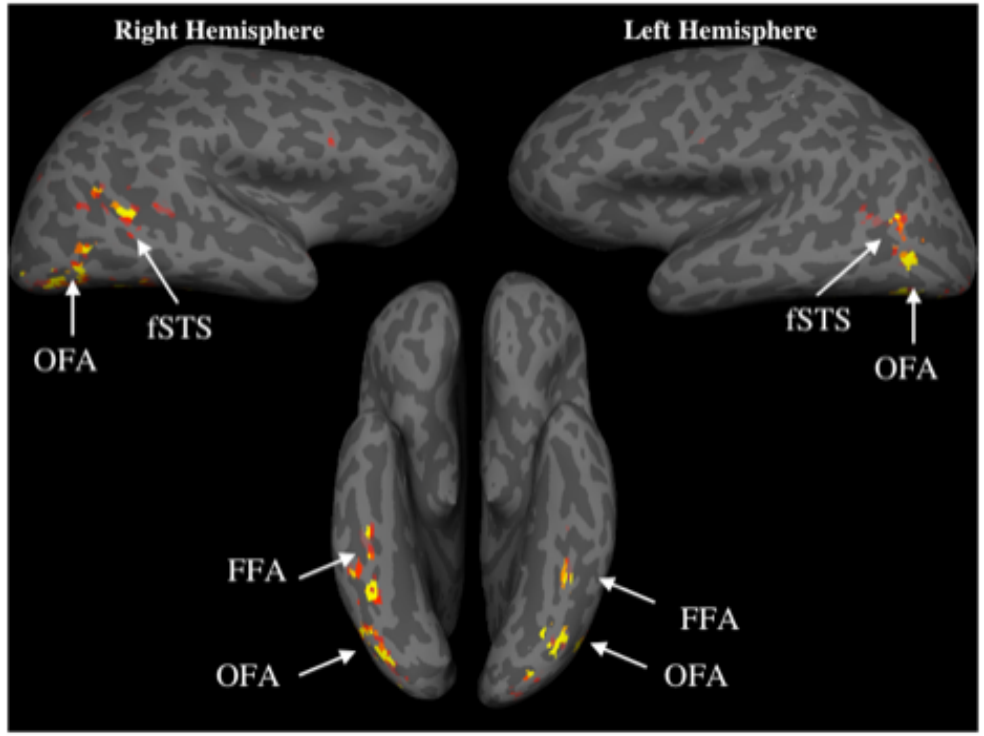
http://www.nature.com/news/brain-imaging-fmri-2-0-1.10365

What fMRI experiments
do you already know?

fMRI Example: Face Processing

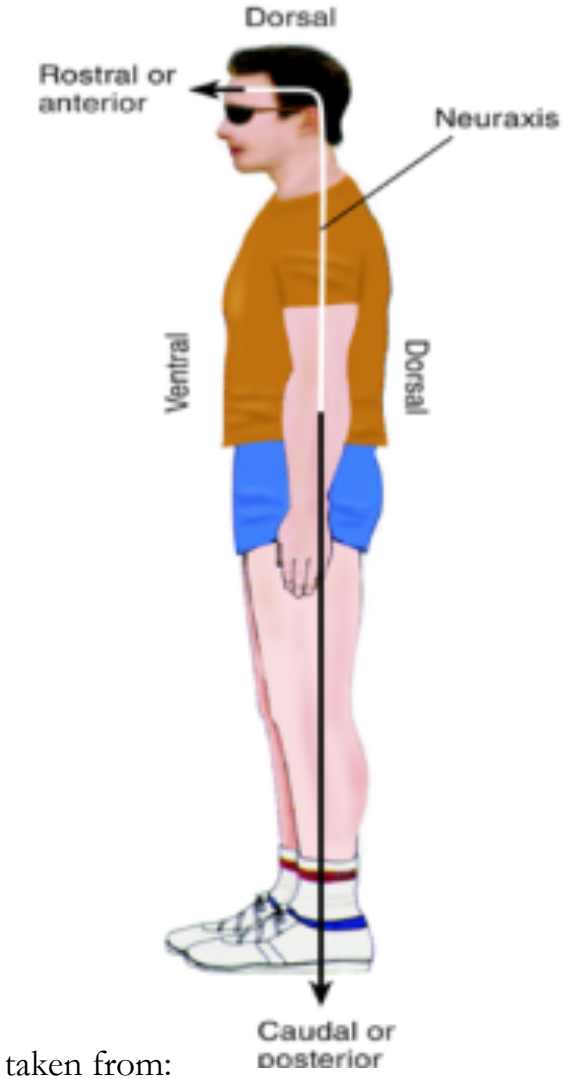


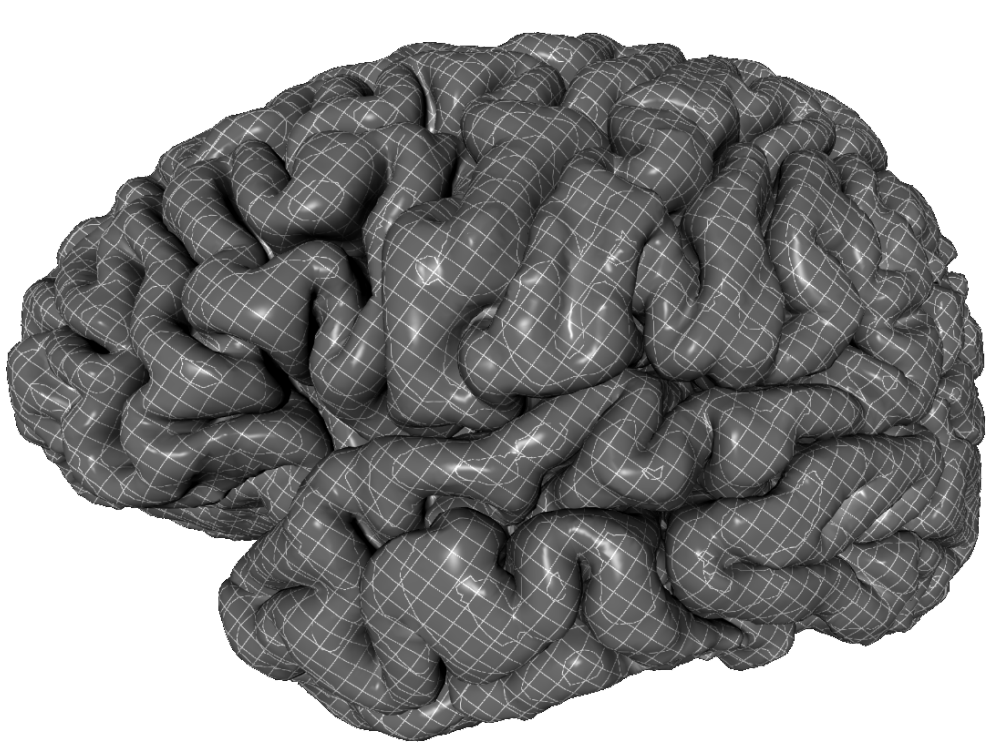
Kanwisher et al. 1997



Kanwisher and Yovel, 2006

The neuraxis in the human brain





Dorsal / Superior

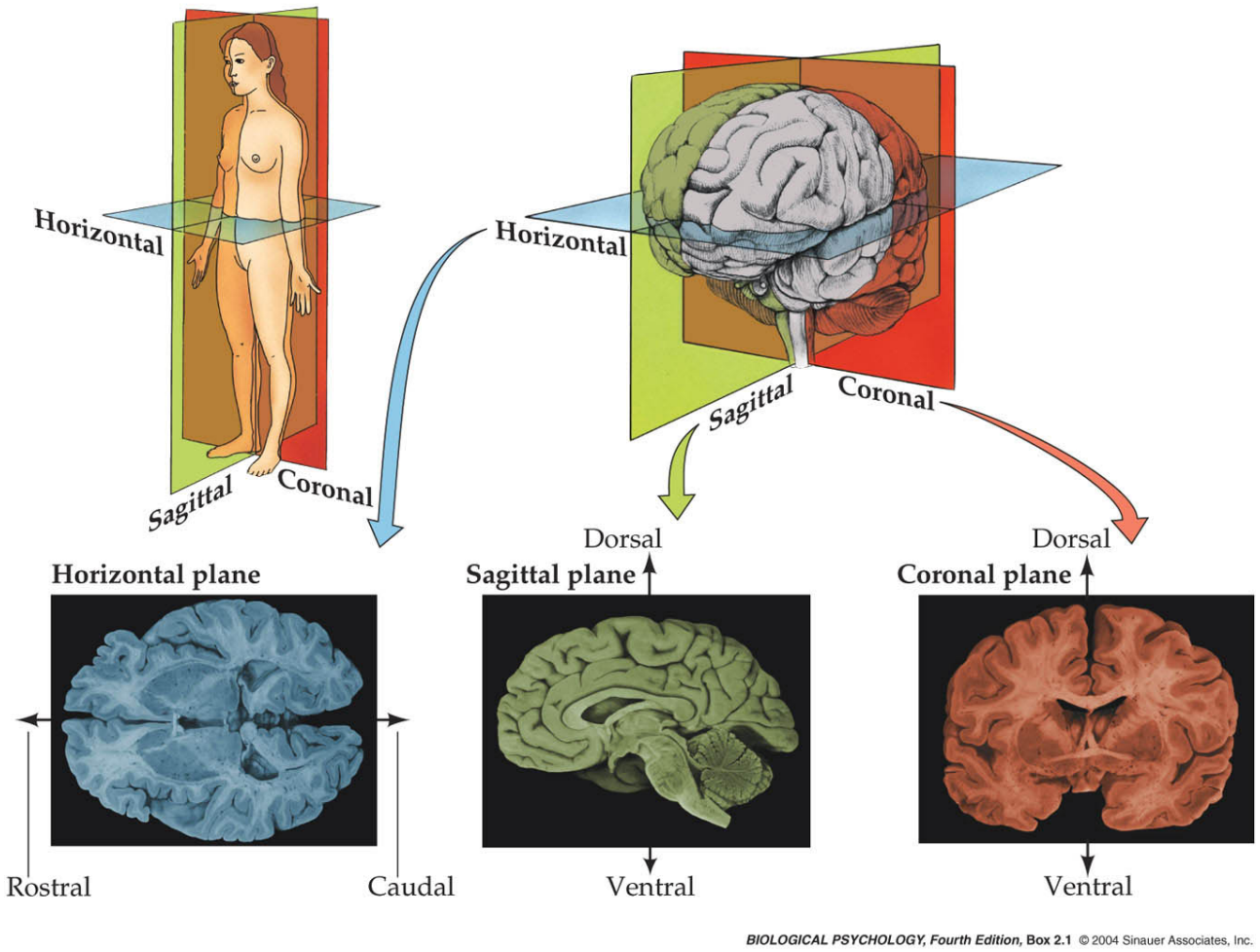
Ventral / Inferior

Anterior / Rostral

Posterior / Caudal

Left image taken from:
https://kevinbinz.com, 2016/01/07, neural-coordinate-systems

Transections and Planes



Major sulci and gyri of the cerebral cortex

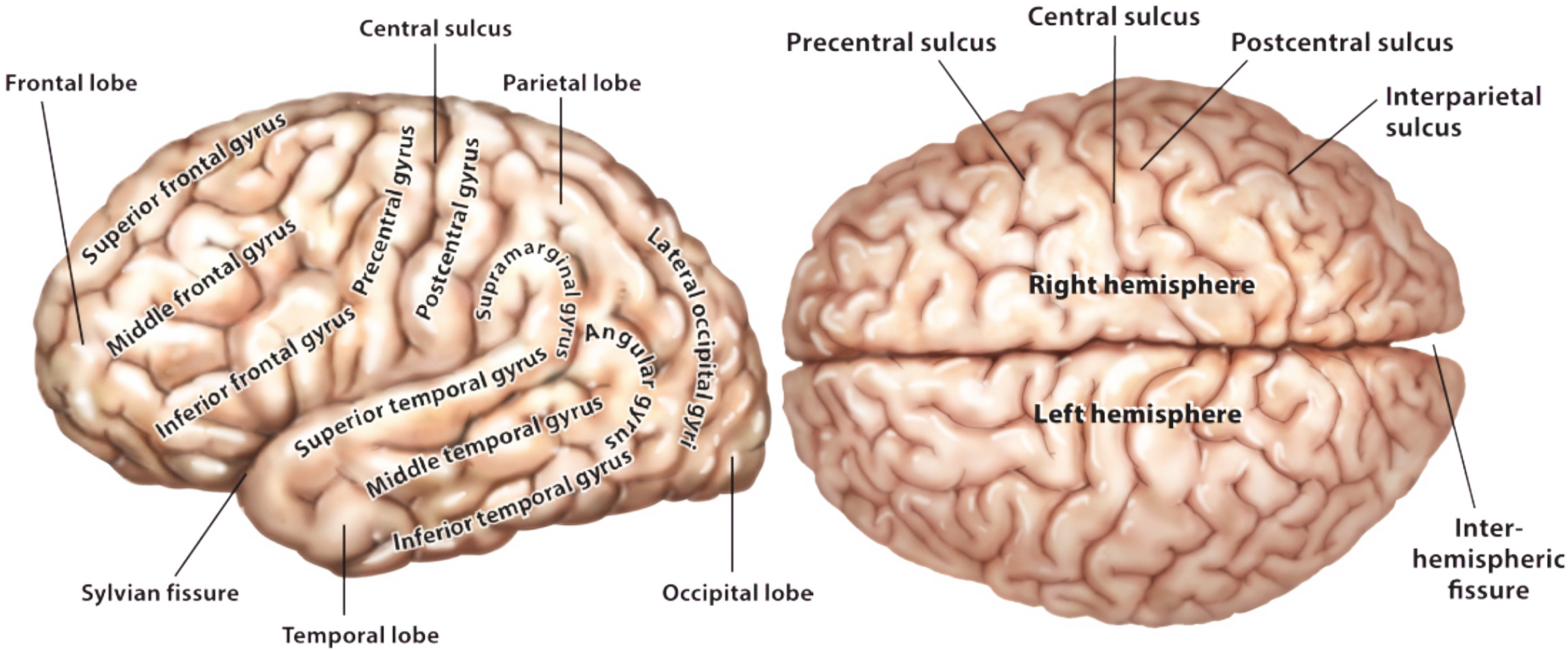


Image taken from: Gazzaniga, Ivry, Mangun, Cognitive Neuroscience, Figure 2.28, p.49

Major subdivisions of the cerebral cortex

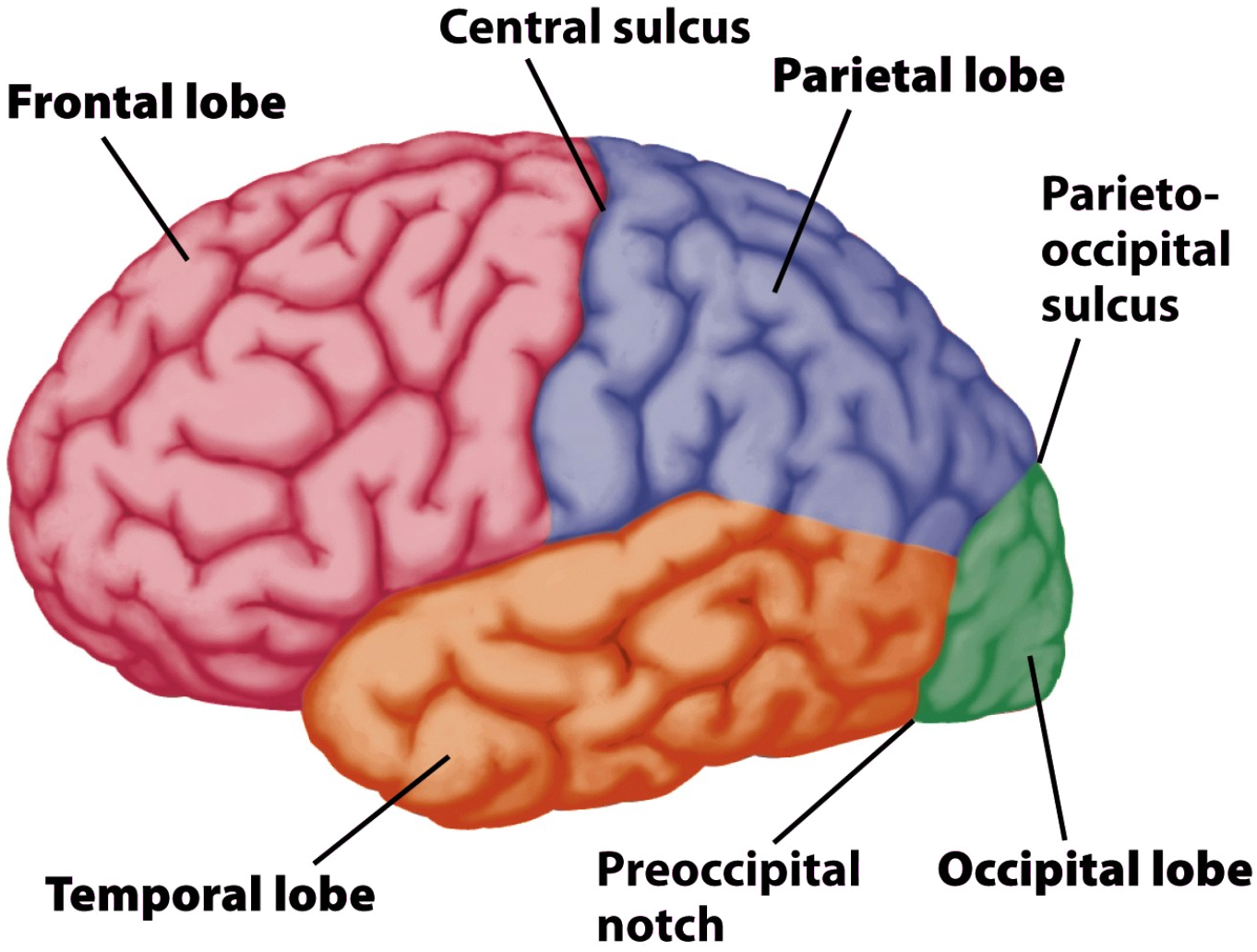
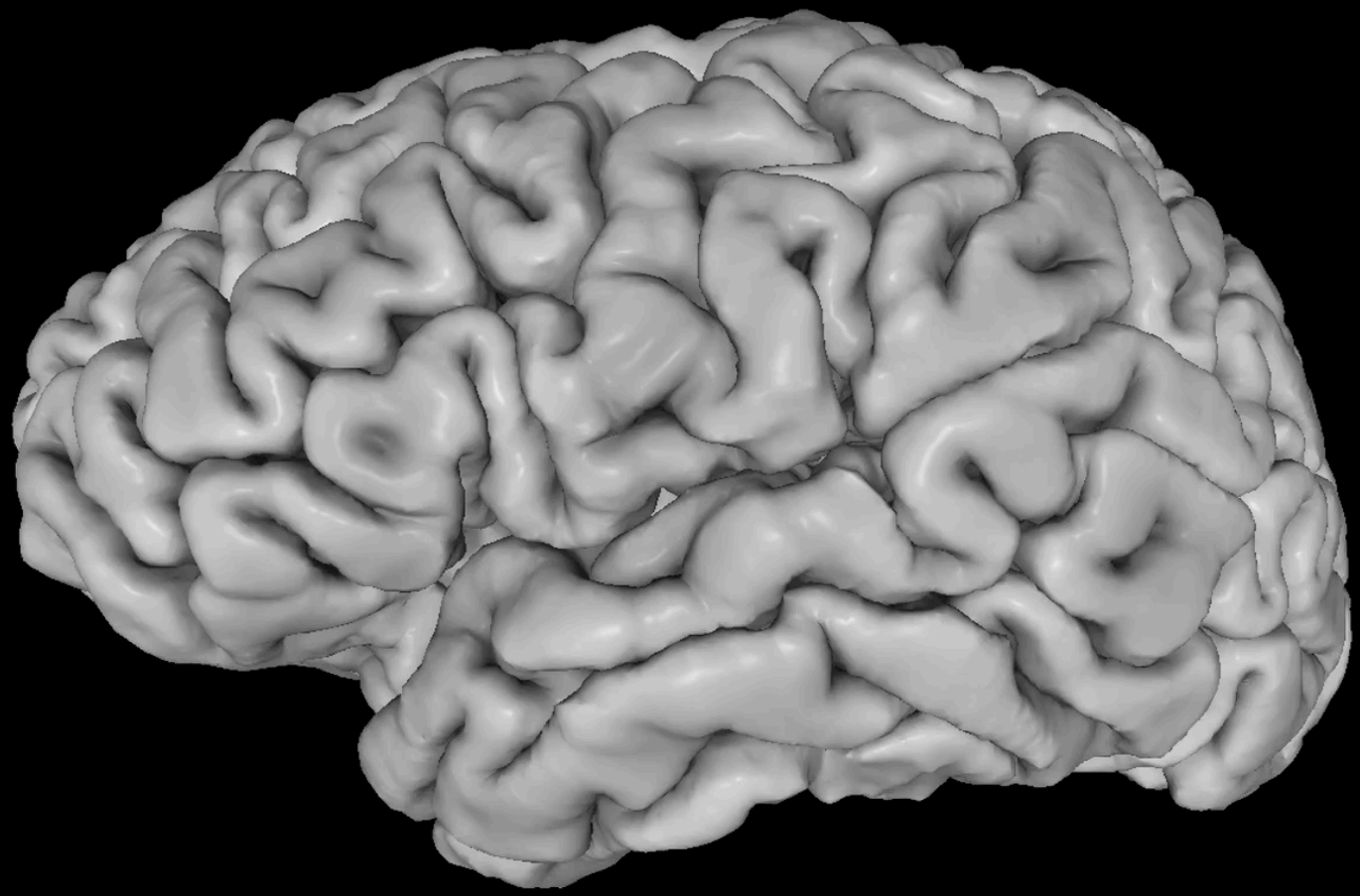


Image taken from: Gazzaniga, Ivry, Mangun, Cognitive Neuroscience, Figure 2.30, p.50



[Video courtesy: Mark Lescroart]

An interactive brain viewer
http://gallantlab.org/index.php/brain-viewer/