AIL4230: Basics of Computational Neuroscience

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Fall 2024

Administratrivia

- Evaluation
  - Major: 40% (~30% post-minor, 10% based on combining what you learnt throughout the course)
  - Minor: 30%
  - Assignments: 20% (hands on computational work, roughly 4 through the semester)
  - Class participation: 10% (pop-up quizzes that will promote interactions in the class)
- Attendance
  - Class participation will take care of attendance. No separate requirement.
  - NOTE: Exams will be based on whatever is covered **in the class**. This may or may not include things covered in the prescribed textbooks / reference books. Therefore attend all classes and take proper notes.
- Contacting me
  - No specific office hours, but can pre-arrange a time and meet
  - Typically available immediately after the class (or before if pre-arranged)
  - Do not email me as far as possible. Keep all communication on Google Classroom (this helps me keep all information in one place. Otherwise I may misplace something important you communicated)

Administratrivia 2

Textbooks:

1. Gerstner, Wulfram, Werner M. Kistler, Richard Naud, and Liam Paninski. Neuronal dynamics: From single neurons to networks and models of cognition. Cambridge University Press, 2014

Reference books:

1. Dayan, Peter, and Laurence F. Abbott. Theoretical neuroscience: computational and mathematical modeling of neural systems. MIT press, 2005
2. Izhikevich, Eugene M. Dynamical systems in neuroscience, MIT press, 2007

Online course material:

1. Introduction to Computational Neuroscience: https://nptel.ac.in/courses/102/106/102106023/

Backgrounds

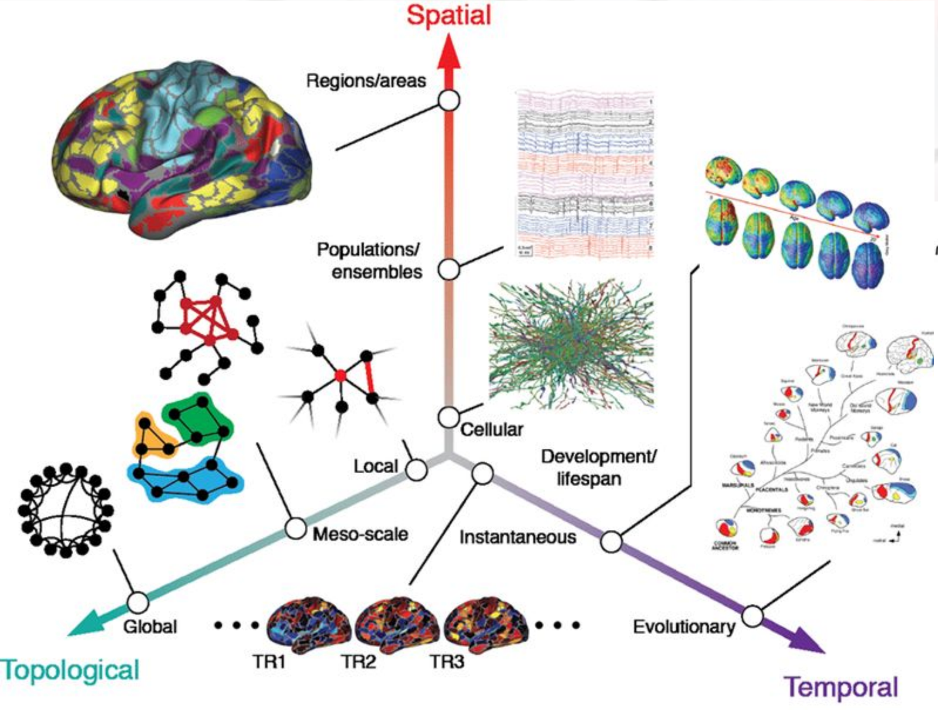
- What are your interests (that are relevant to this course)?
- Why are you taking this course?

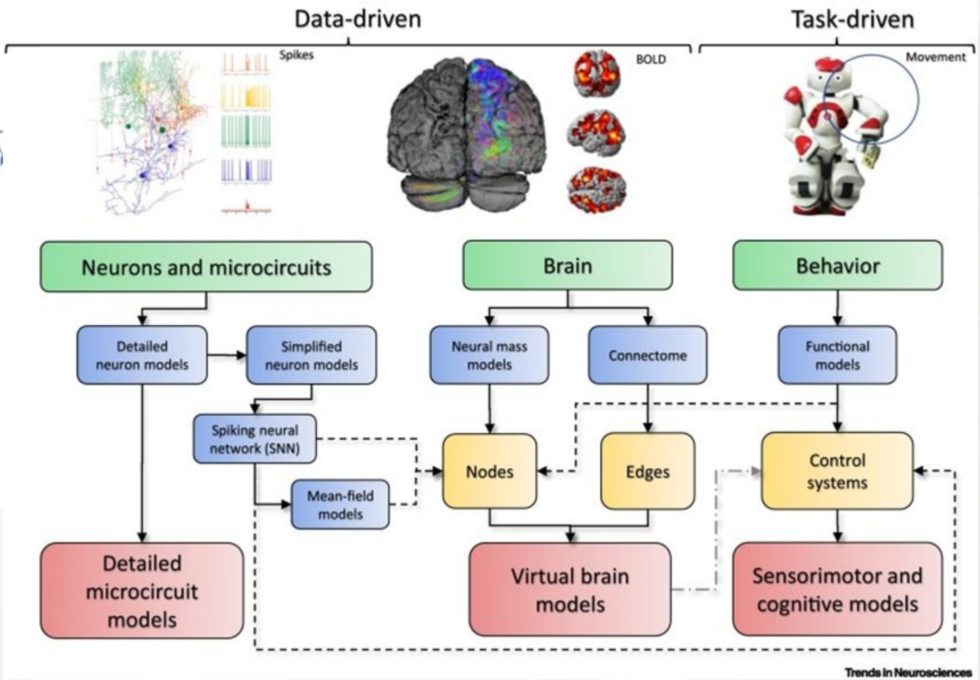
- Labels are no limitations!
- Physics → ecology and evolution of microorganisms → computational neuroscience → doing experiments on humans (sign up!)
- The brain is complex and needs a bit of everything to even begin understanding
- This course will surely push your boundaries: a pinch of biology, a big spoonful of physics, and models!

What this course is about

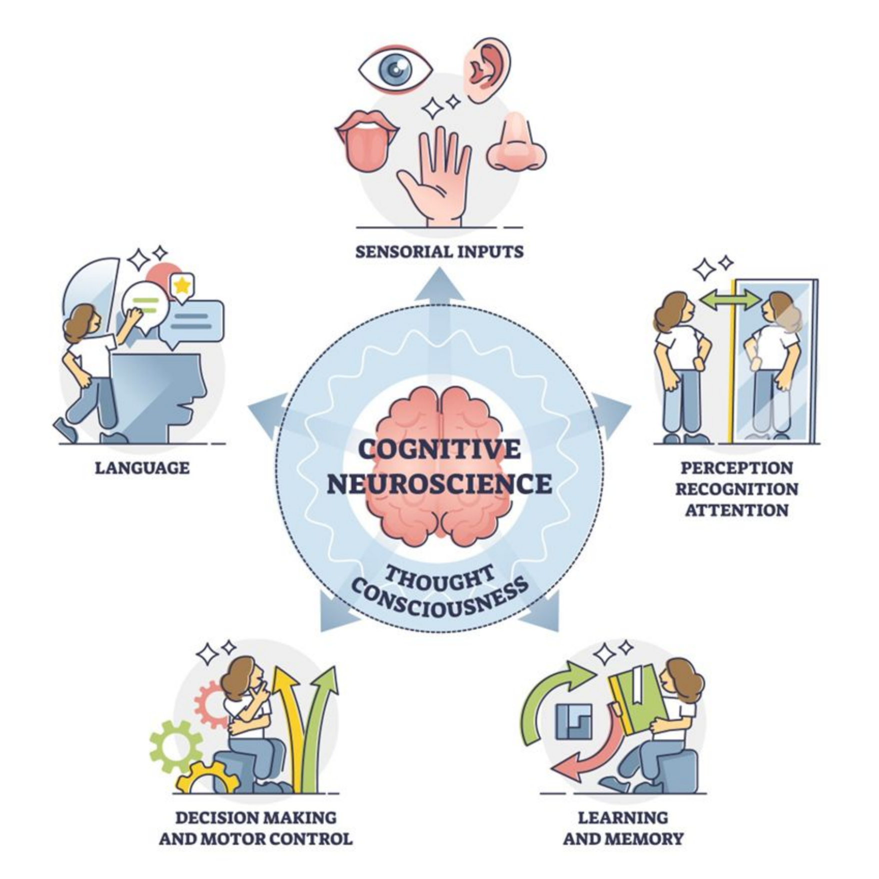
- What do you think?
- What are the different contexts in which computational approaches might be necessary in neuroscience?
- Building models of the brain is just one application of computation
- Models
    - What is a model?
    - What is the purpose of building models?
    - What are the different types of models?

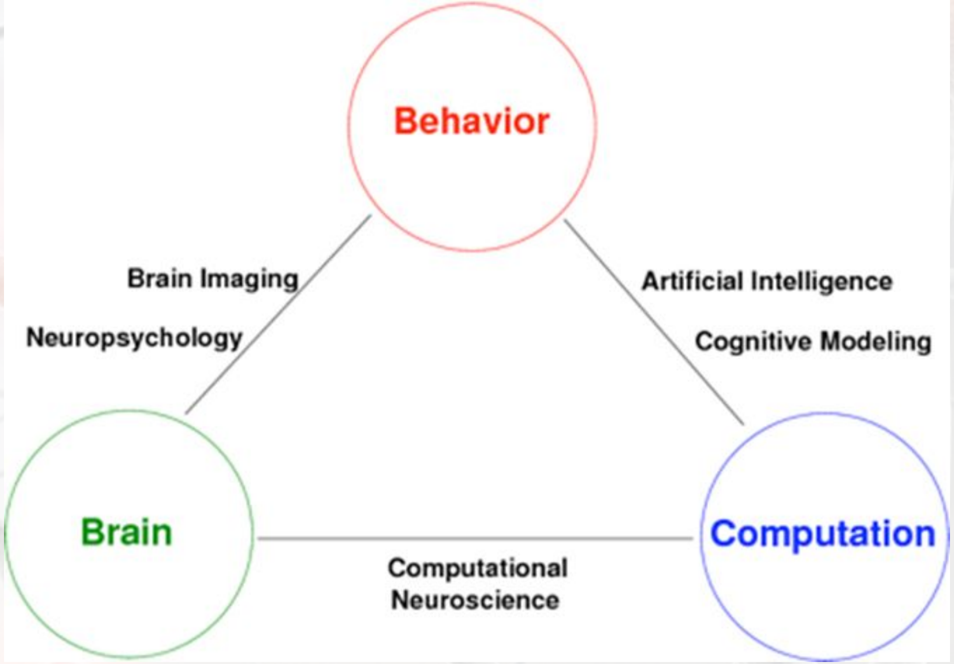
(Mechanistic) Understanding of the brain



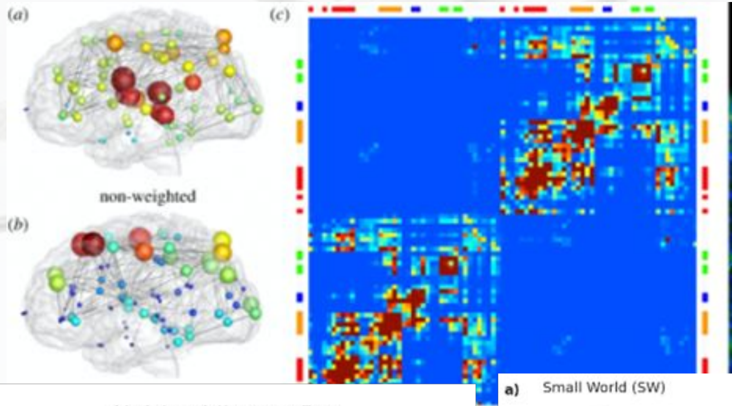


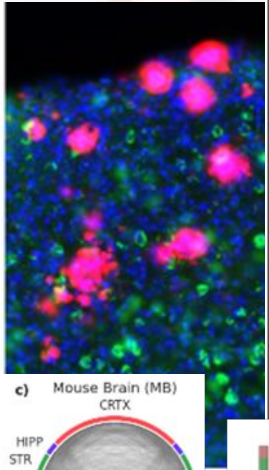
(Functional) Understanding of the brain: how do we ......?

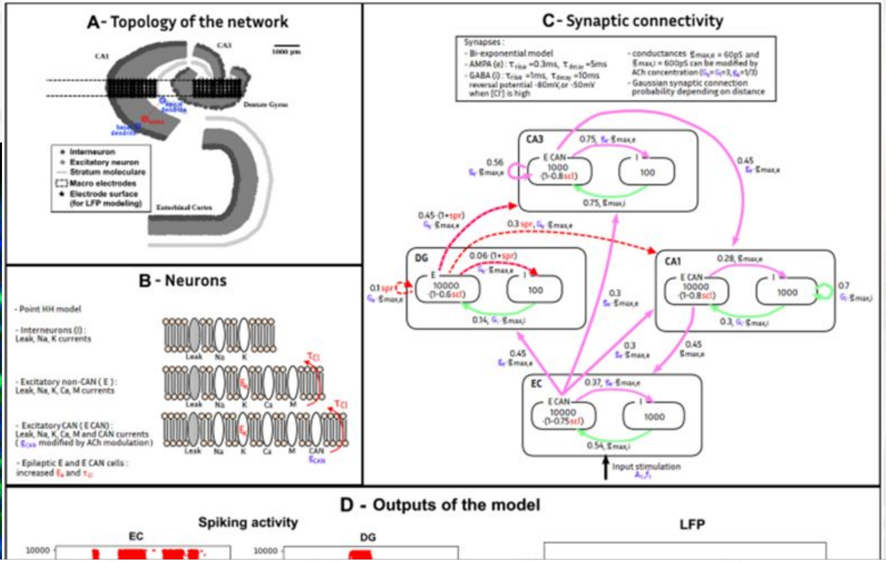


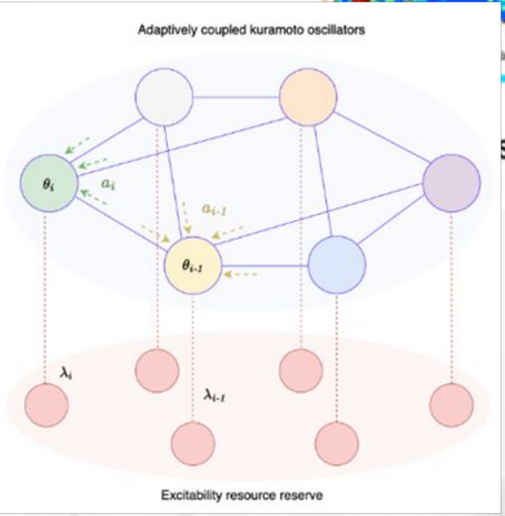


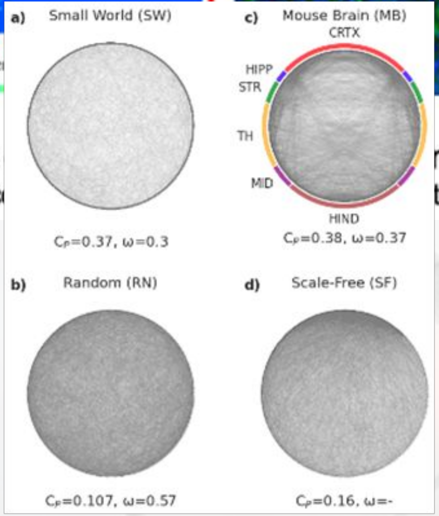
Understanding diseases

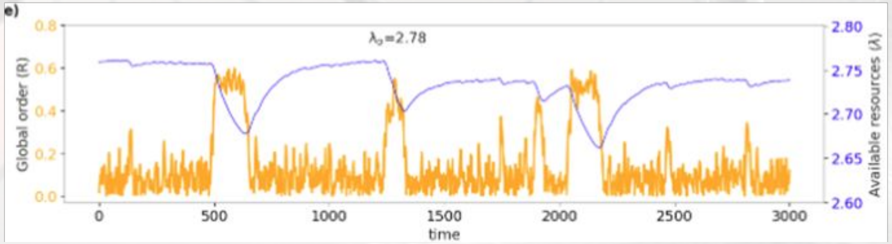




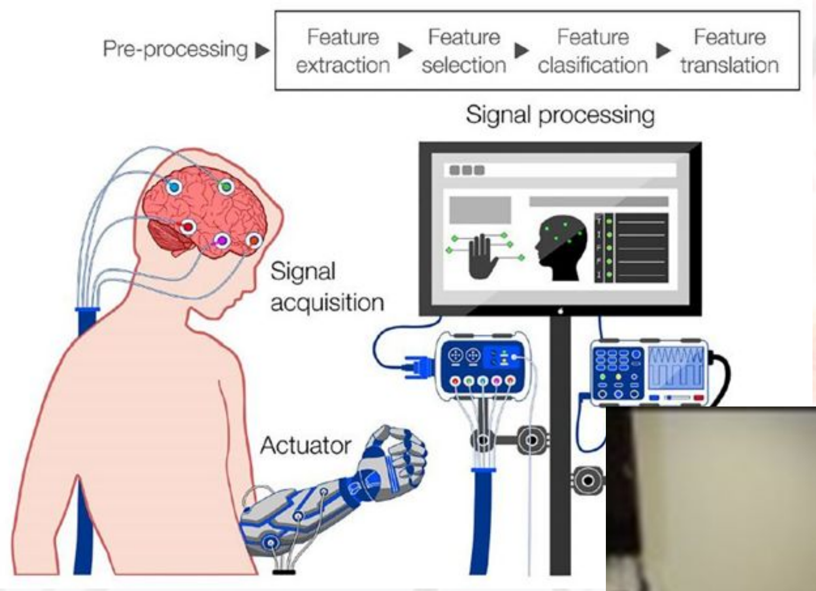


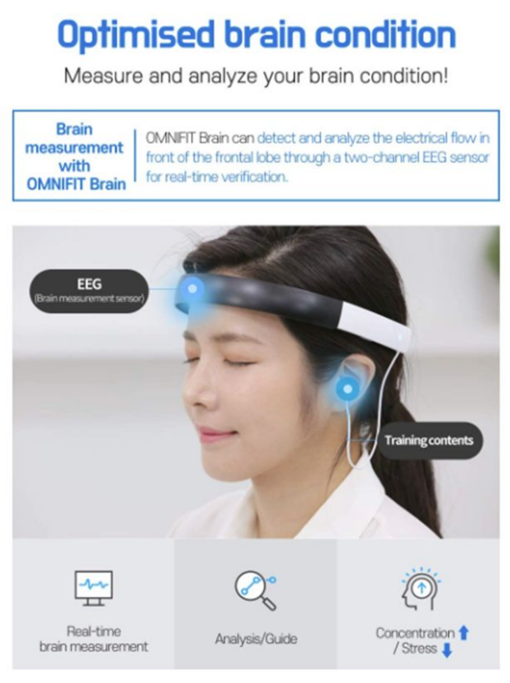






New ways to interact with the world: BCIs



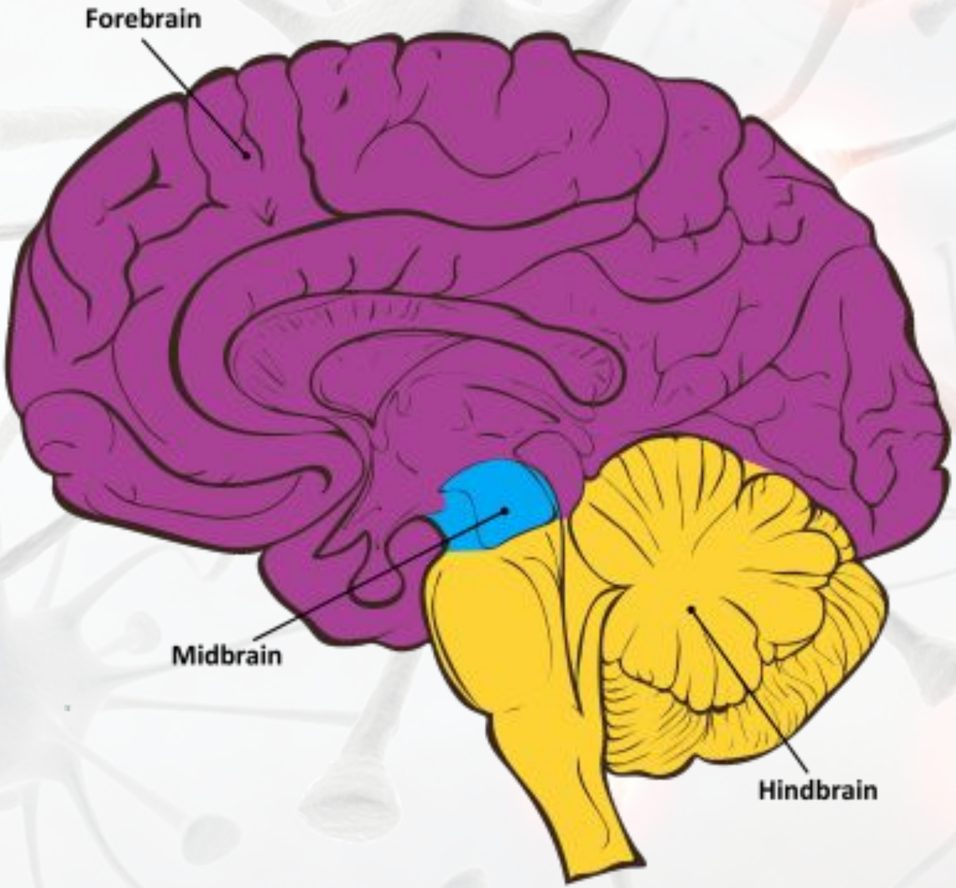


A primer on the brain

https://mpfi.org/wp-content/uploads/2019/04/Brain_Facts_BookHighRes1.pdf

https://www.ninds.nih.gov/health-information/public-education/brain-basics/

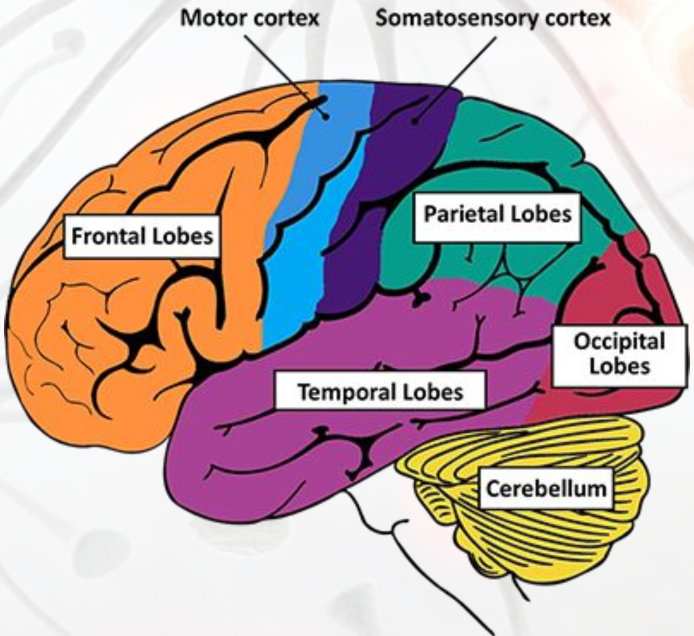
The human brain - basic anatomy

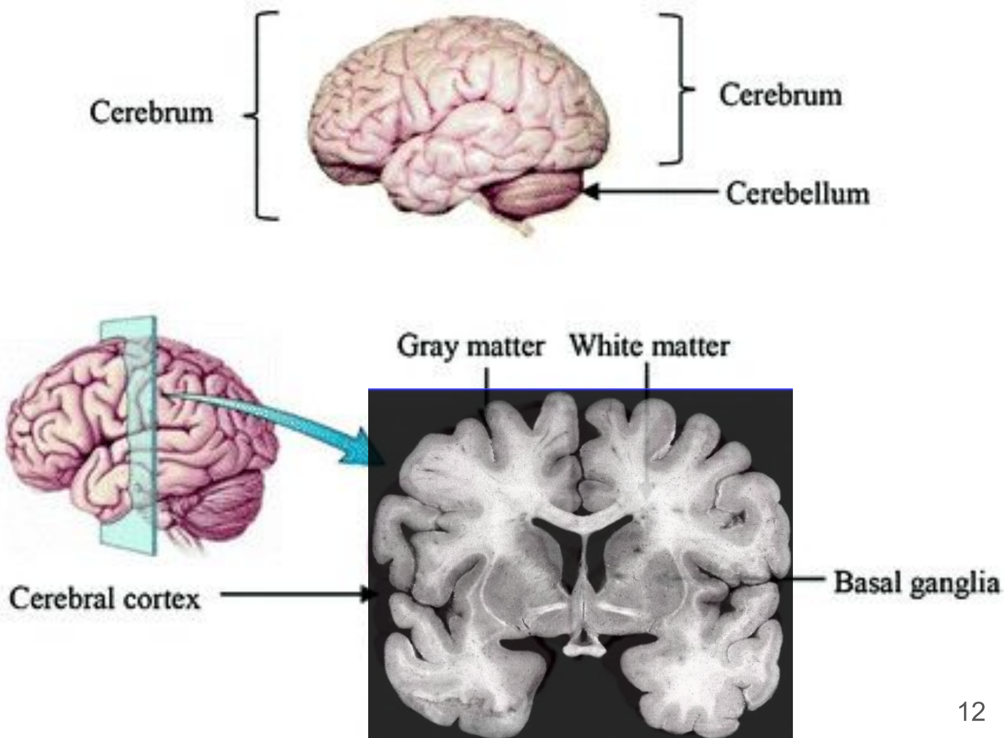


- The hindbrain controls the body's vital functions such as respiration and heart rate.
- The cerebellum coordinates movement and is involved in learned movements.
- The midbrain controls reflex actions, eye movements and other voluntary movements.
- The forebrain is the largest and most highly developed part of the human brain

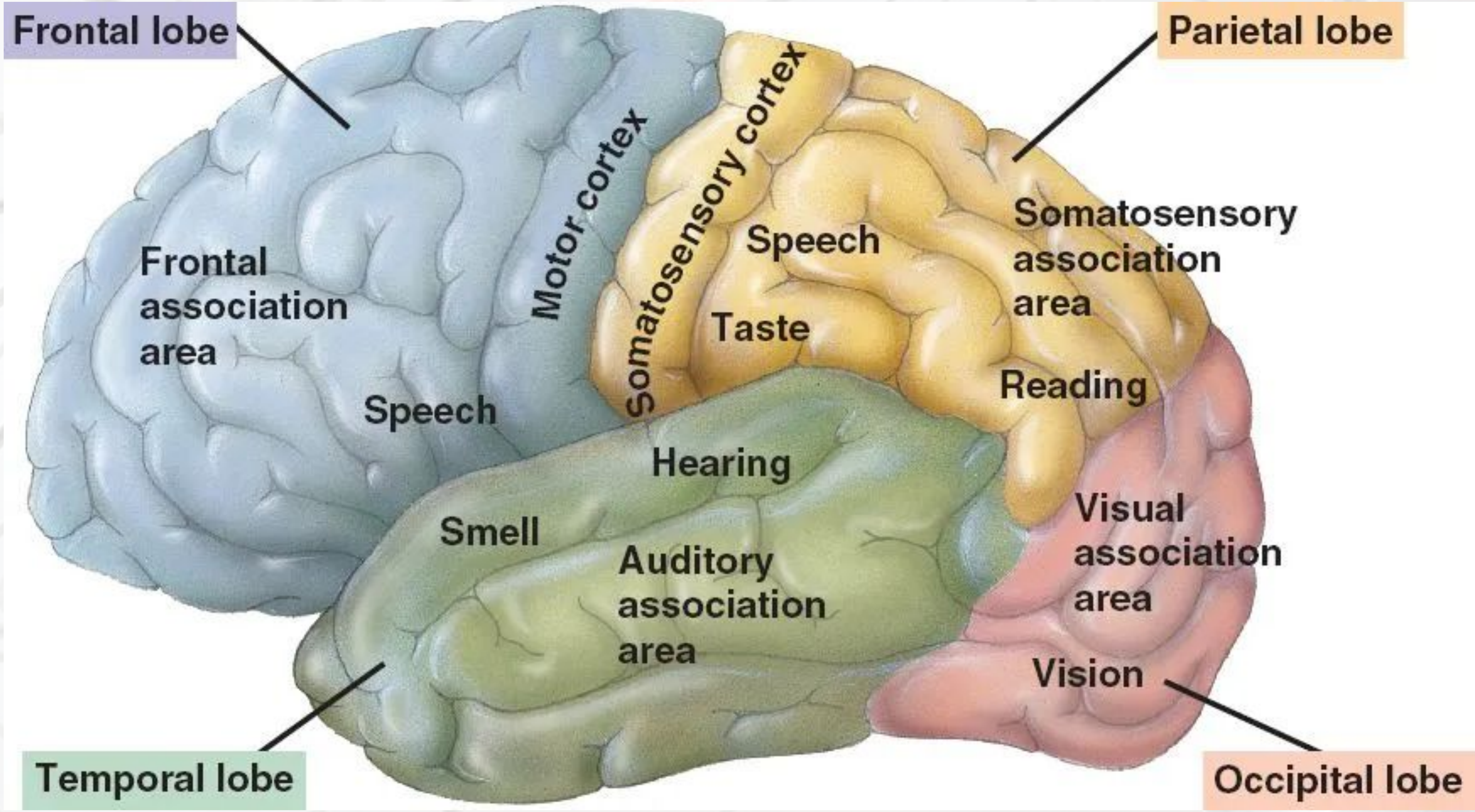
The human brain - basic anatomy

- Gray matter: Where thinking happens!
- White matter: Communication between thinking centers
- Cerebral cortex | neocortex | cortex: Most developed and ‘thinking’ part
- Subcortical: Memory, emotion etc.

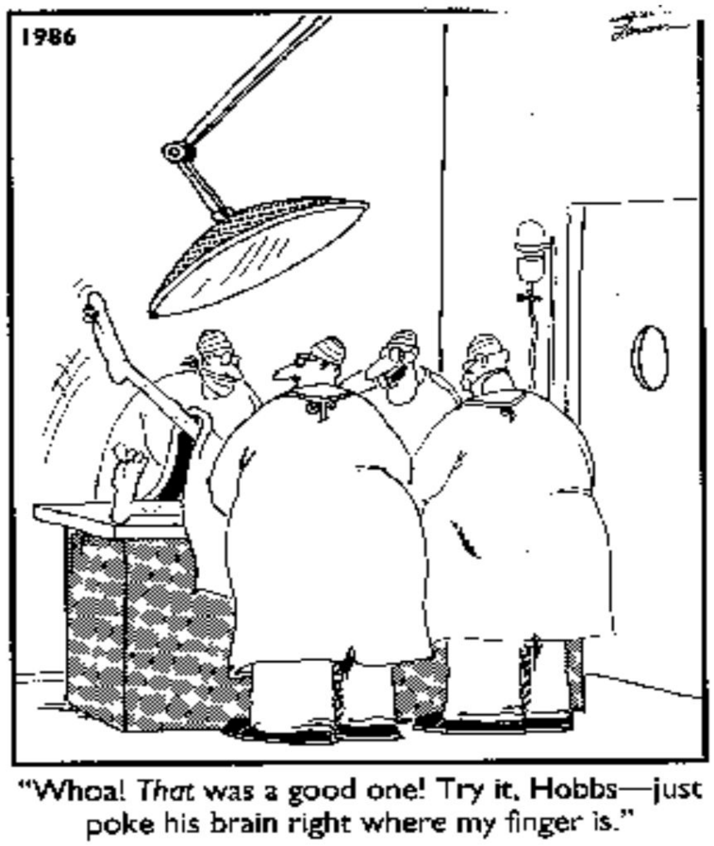




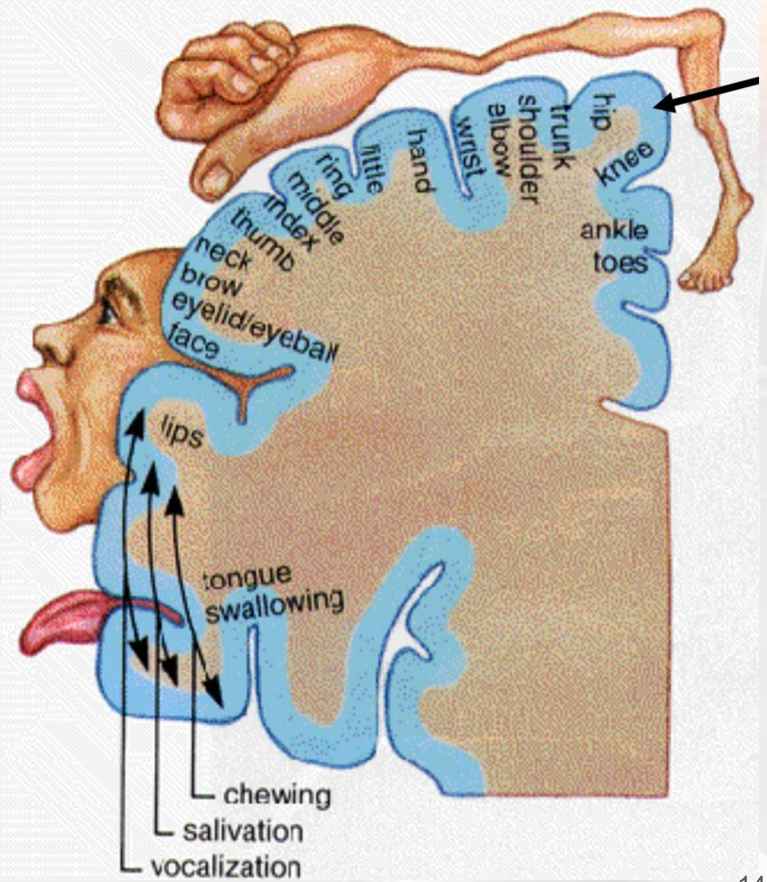
Different parts of the cortex for different functions



Homunculus: the little person inside your brain



Copyright: Gary Larson

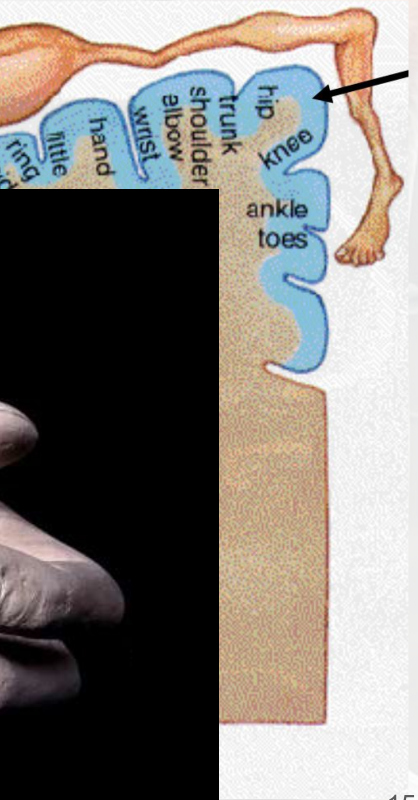


Homunculus: the little person inside your brain

Different brain regions represent different parts of the body for movement or sensation

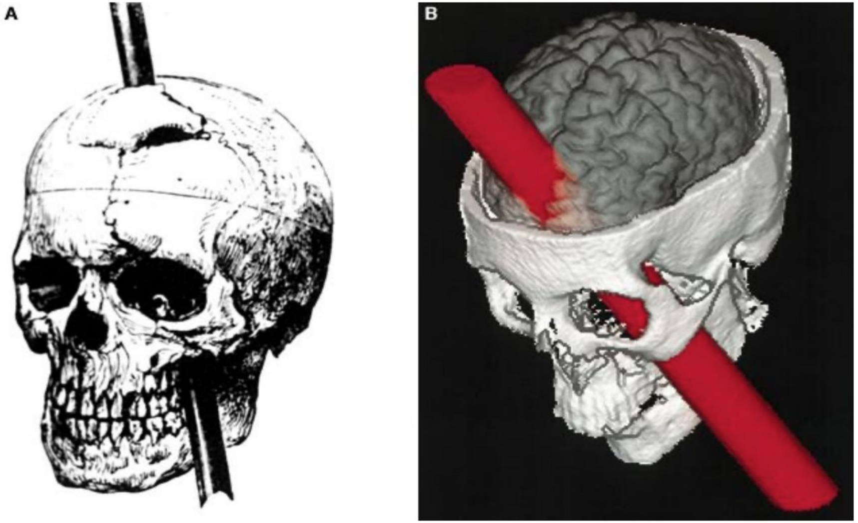
Why are the different body parts shown so disproportionately?

Which one is motor and which is sensory? Why?



Different parts of cortex for different functions

Phineas Gage: Phineas Gage was a railroad worker in the 19th century living in Cavendish, Vermont. One of his jobs was to set off explosive charges in large rock in order to break them into smaller pieces. On one of these instances, the detonation occurred prior to his expectations, resulting in a 42 inch long, 1.2 inch wide, metal rod to be blown right up through his skull and out the top. The rod entered his skull below his left cheek bone and exited after passing through the anterior frontal lobe of his brain.



Frontal

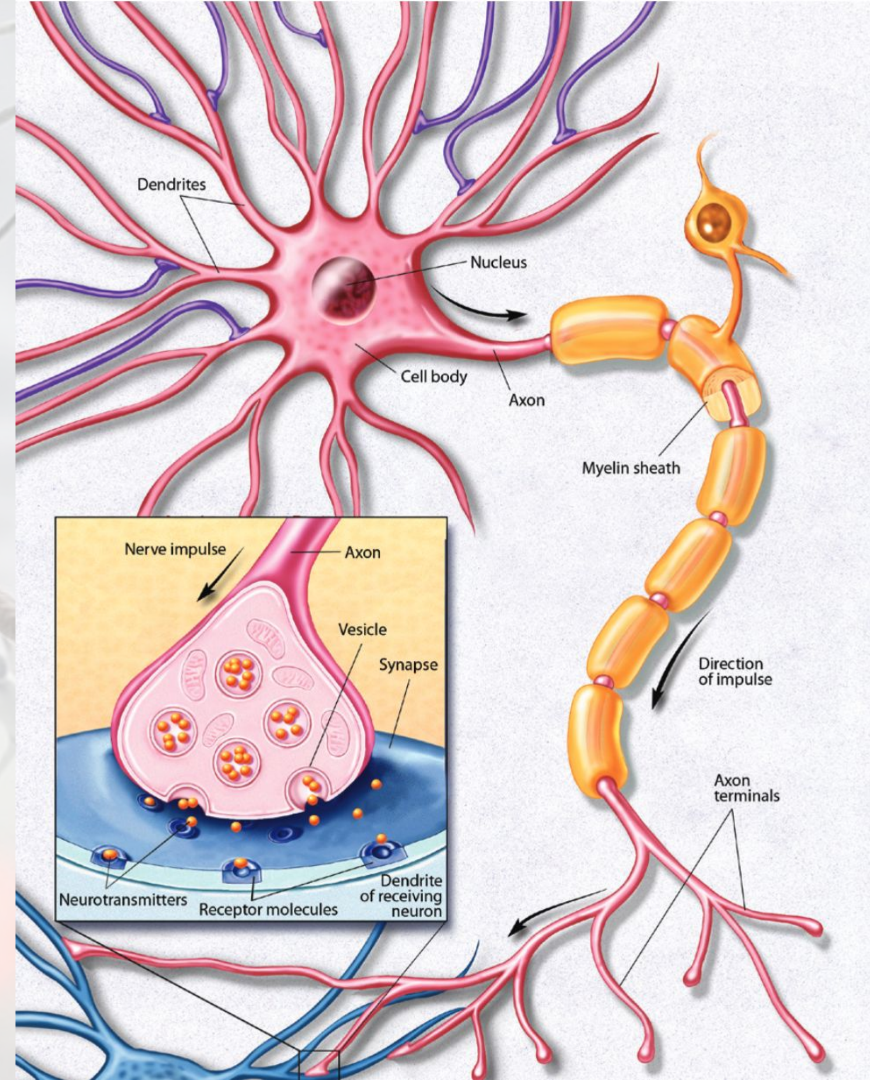
Different parts of cortex for different functions

Remarkably, Gage never lost consciousness, or quickly regained it (there is still some debate), suffered little to no pain, and was awake and alert when he reached a doctor approximately 45 minutes later. He had a normal pulse and normal vision, and following a short period of rest, returned to work several days later. However, he was not unaffected by this accident.

A: **Gage's personality, reasoning, and capacity to understand and follow social norms had been diminished or destroyed. He illustrated little to no interest in hobbies or other involvements that at one time he cared for greatly. 'After the accident, Gage became a nasty, vulgar, irresponsible vagrant. His former employer, who regarded him as "the most efficient and capable foreman in their employ previous to his injury," refused to rehire him because he was so different.'**

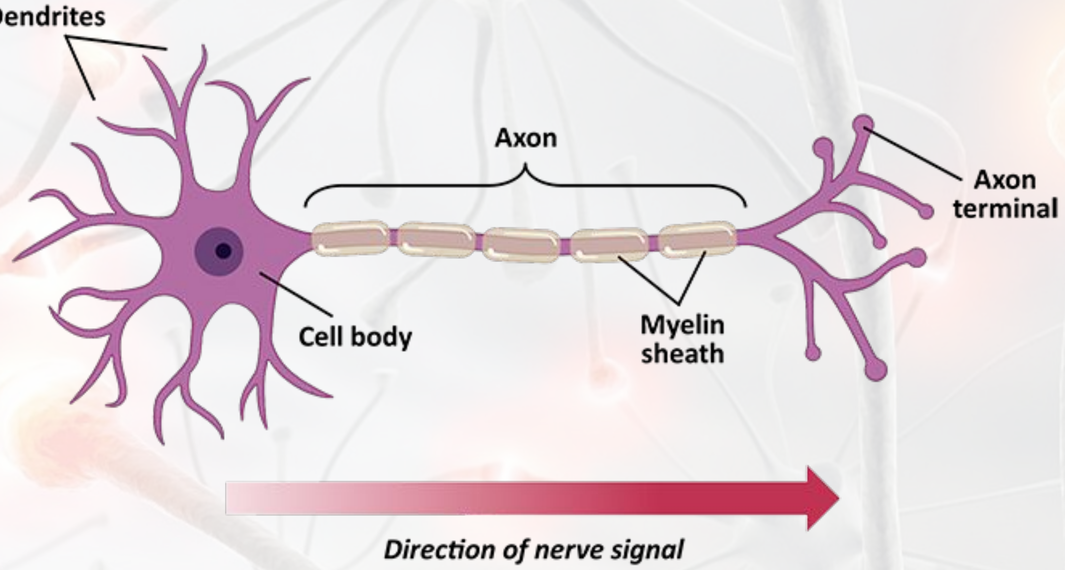
http://www.sruweb.com/~walsh/gage5.jpg

How does the brain work?



Neurons

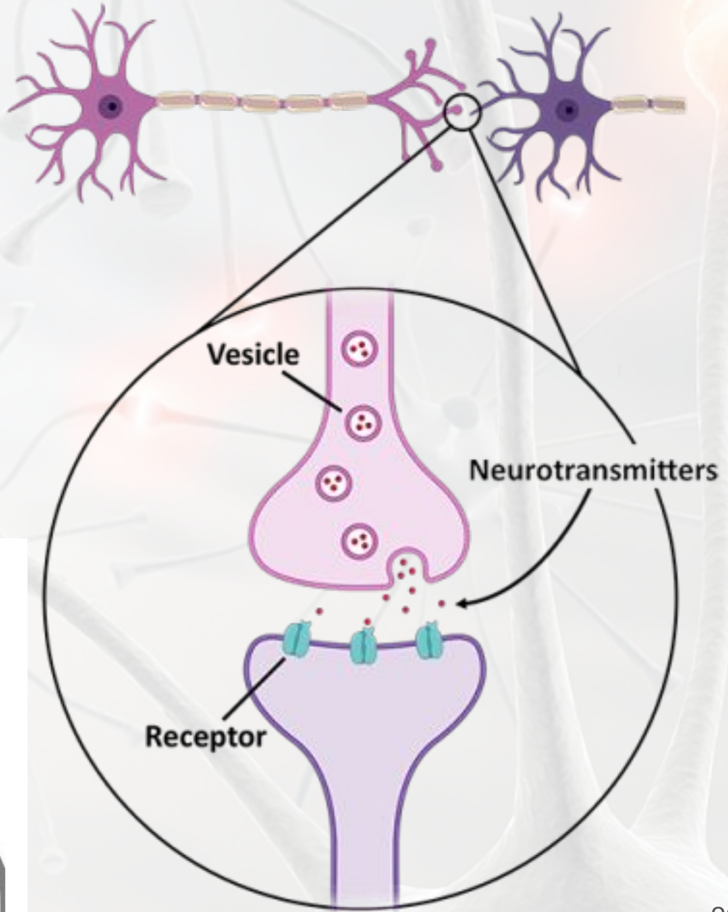
- The primary functional unit in the brain is a cell called the neuron
- Neurons consist of three parts: the cell body, dendrites, and the axon

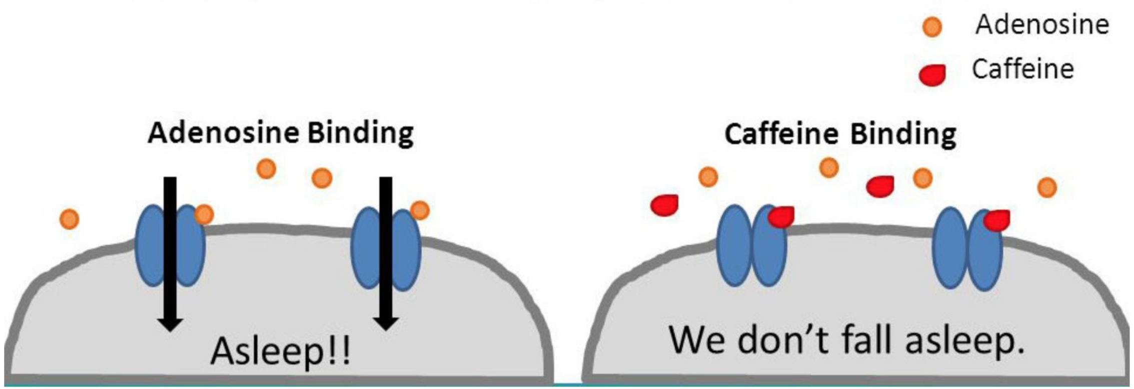


- Dendrites – Collect electrical signals from upstream neurons
- Cell body – Integrates incoming signals and generates the output
- Axon – Passes the generated output signal to the downstream neuron

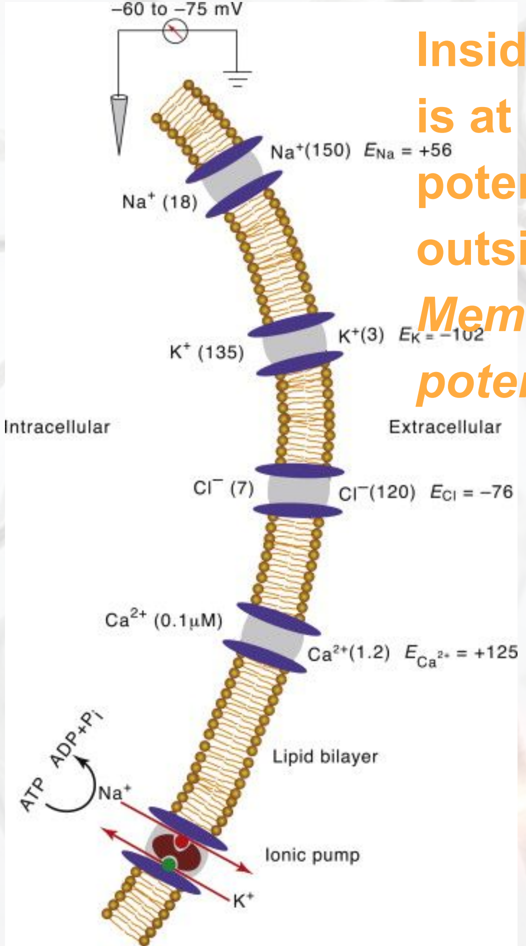
Synapses – connections between neurons

- When the signal from cell body reaches the end of the axon it stimulates the release of tiny sacs called vesicles
- These vesicles release chemicals known as neurotransmitters into the synaptic cleft
- The neurotransmitters cross the synapse and attach to receptors on the neighboring cell



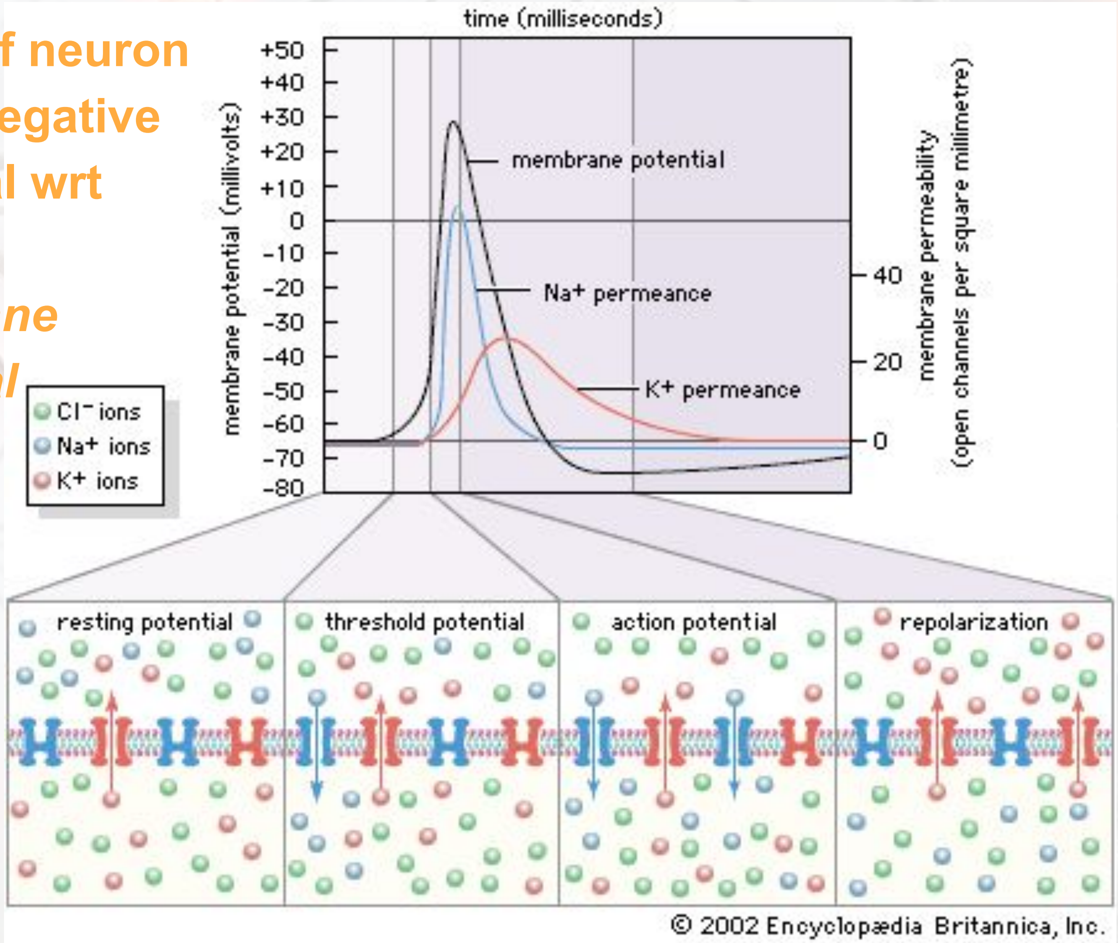


Action potentials – the signals inside neurons

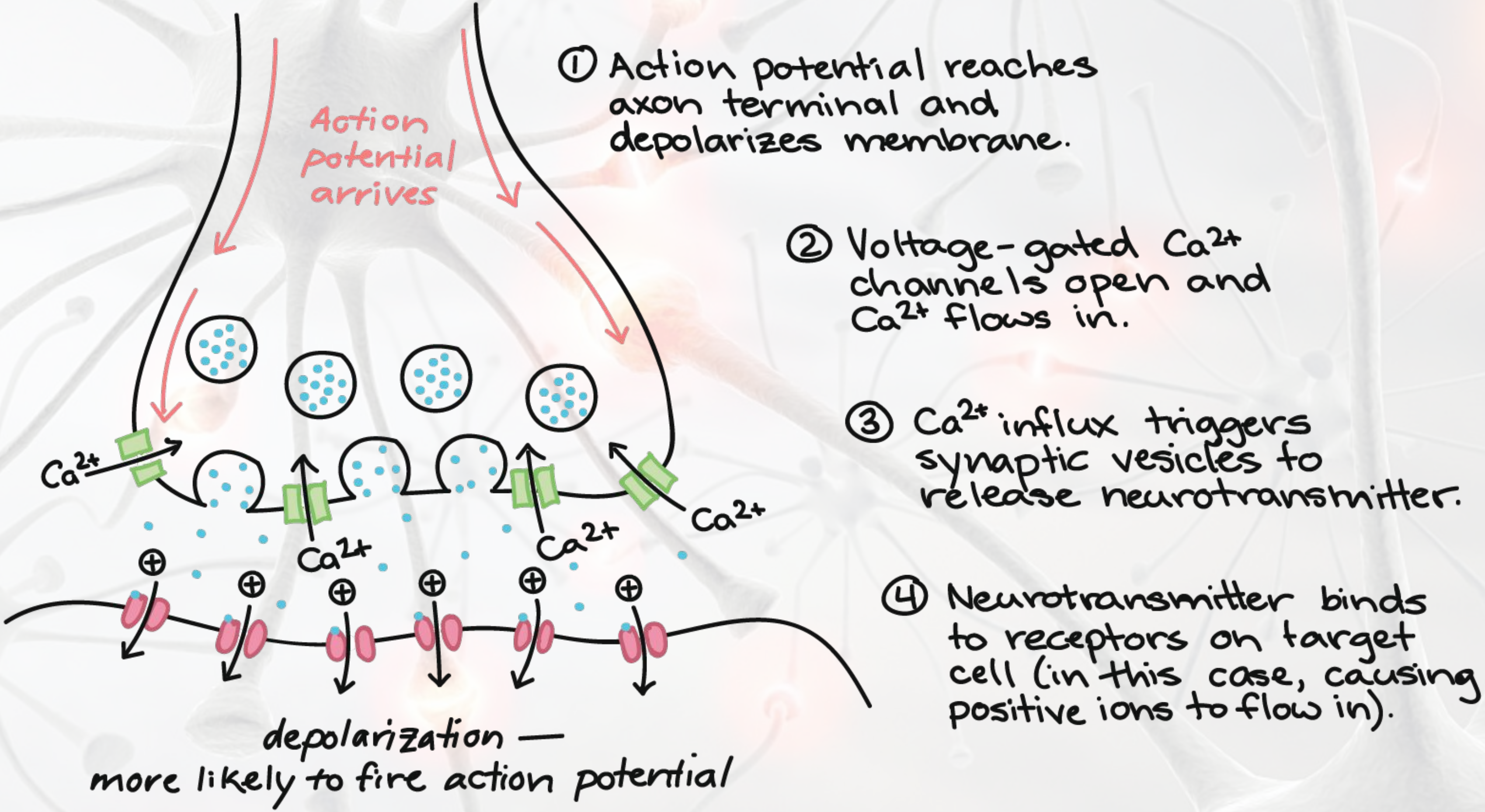


Inside of neuron is at a negative potential wrt outside!

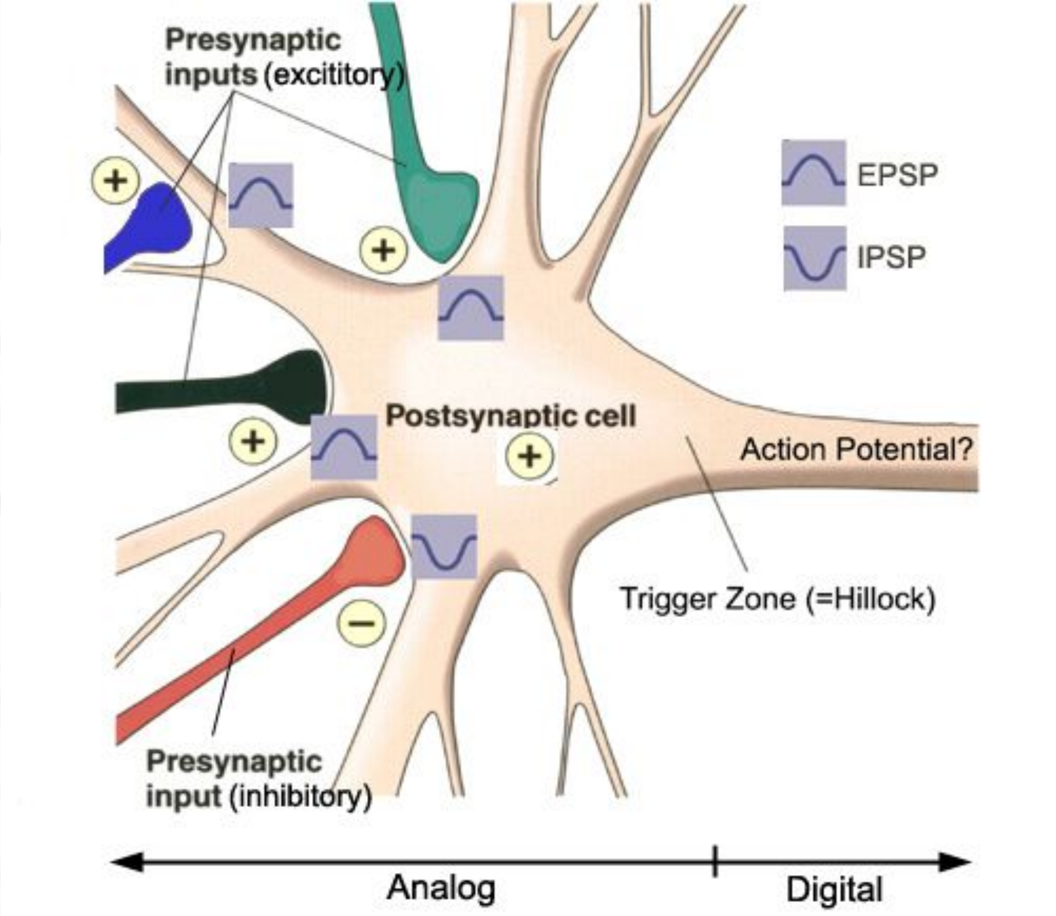
Membrane potential



Action potential – generation



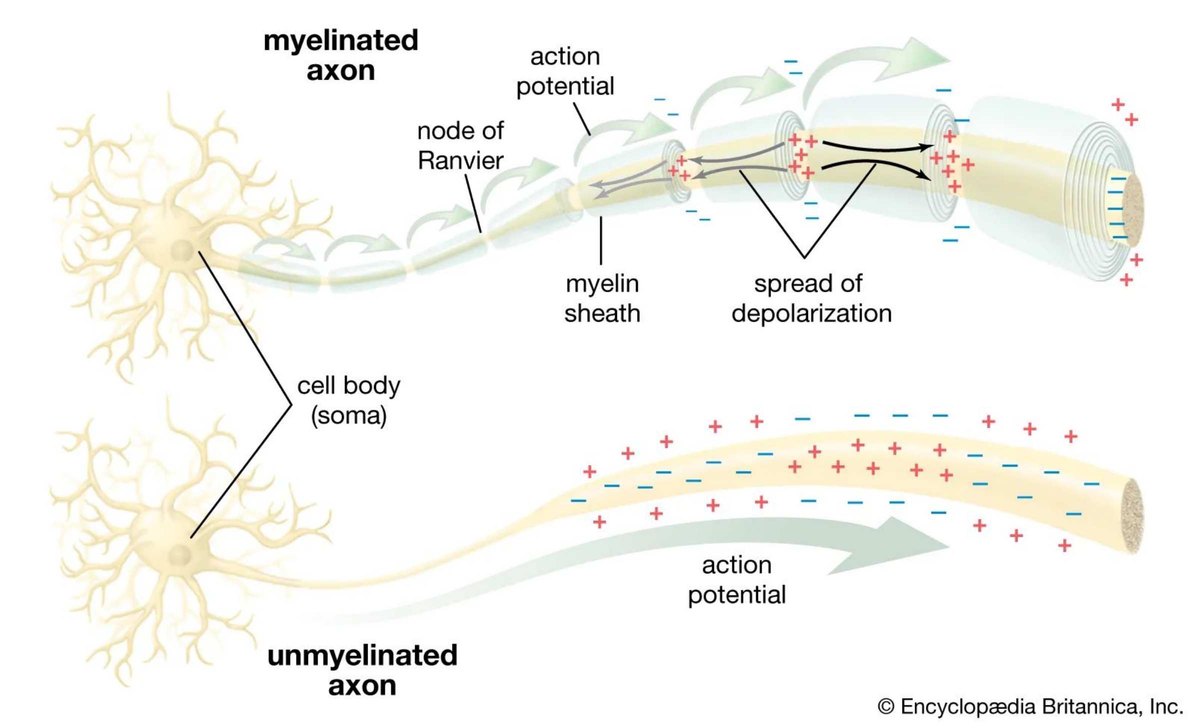
Action potential – integration



Different types of neurons (and neurotransmitters):

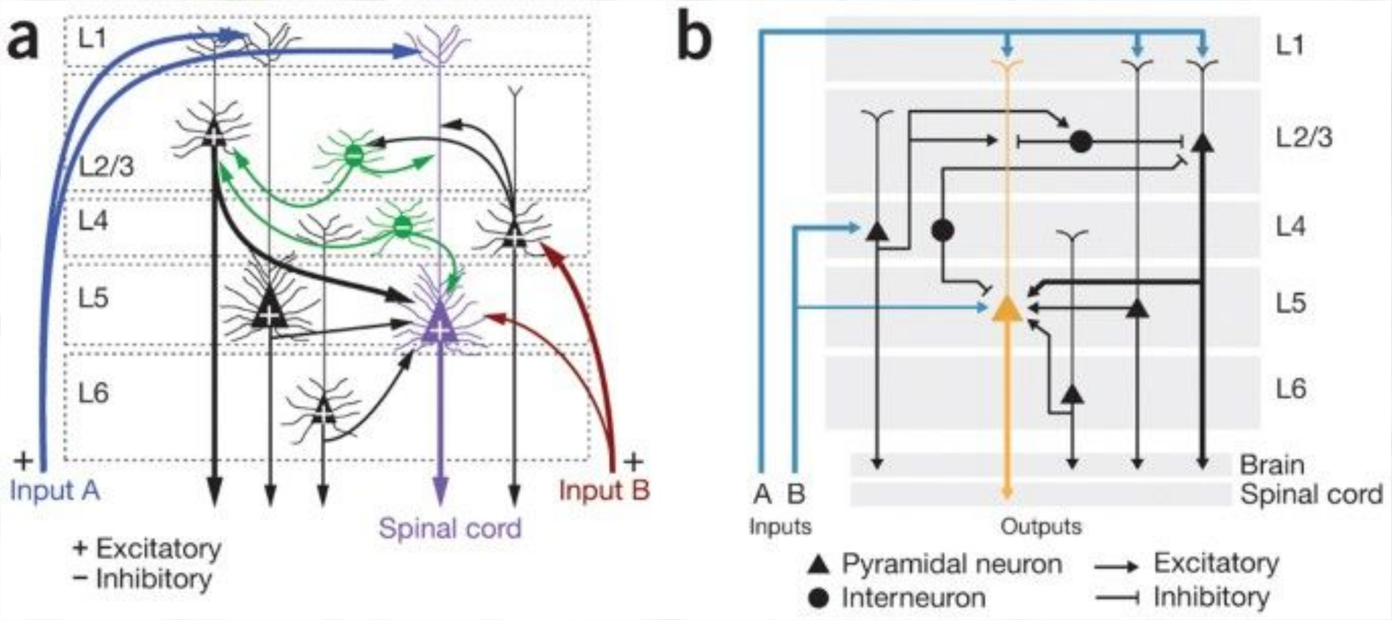
- Inhibitory: suppress the probability of firing of postsynaptic neuron (hyperpolarization)
- Excitatory: enhance the probability of firing of postsynaptic neuron (depolarization)
- *Excitatory (/Inhibitory) Post Synaptic Potential

Action potential – transport



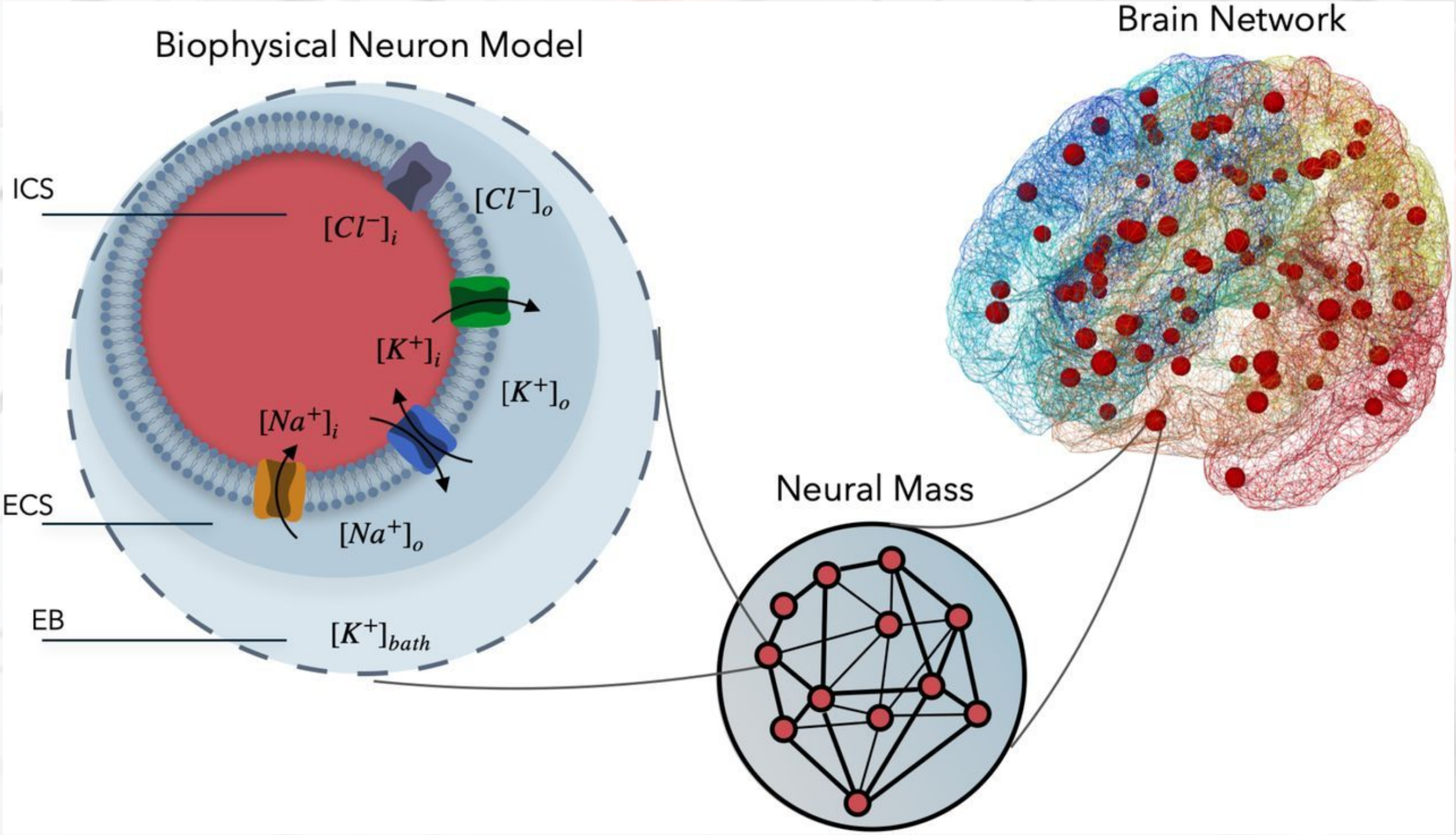
- Unmyelinated axon: AP flows along the axon as neighboring ion channels open and close
- Myelinated axon: AP jumps from one node to the next; much faster, and lower energy loss

From neurons to circuits

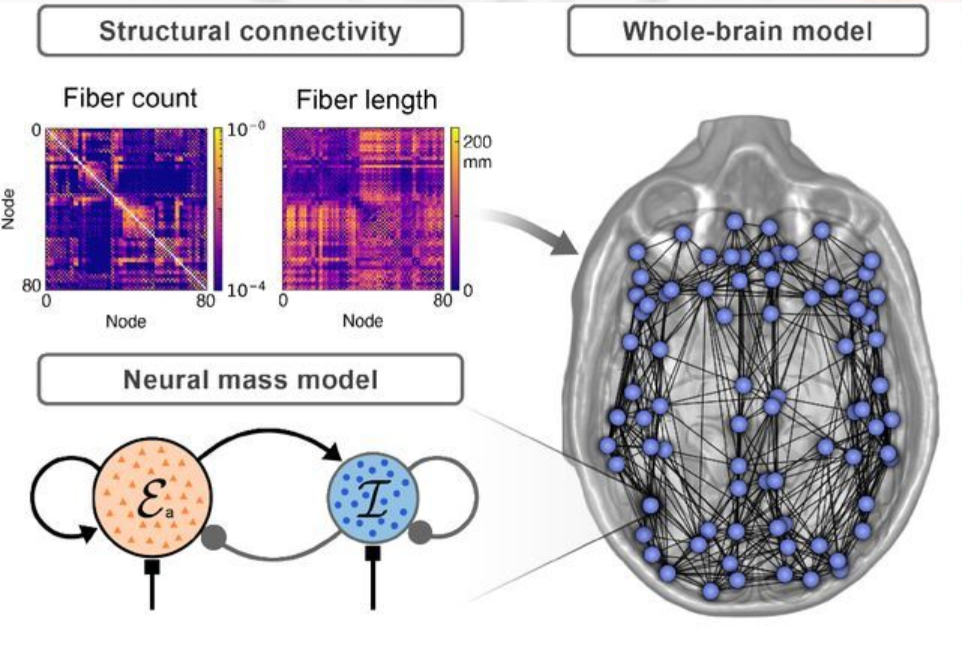


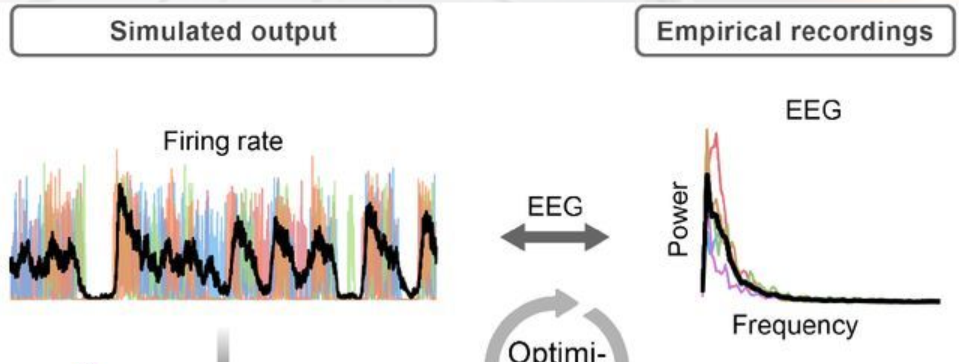
- How are specific micro-computations implemented? For example:
- How do sensory and motor systems form a feedback loop for guiding movement?
- How do neurons compute error between predicted and actual sensory inputs?

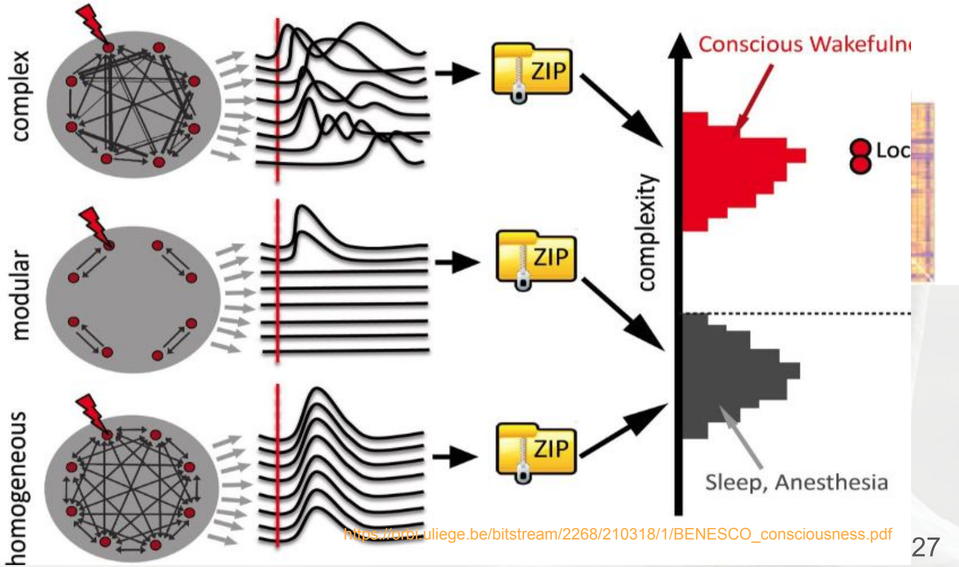
From circuits to neural masses



Whole-brain models







https://orbi.uliege.be/bitstream/2268/210318/1/BENESCO_consciousness.pdf

Overview of topics