Computational Neuroscience

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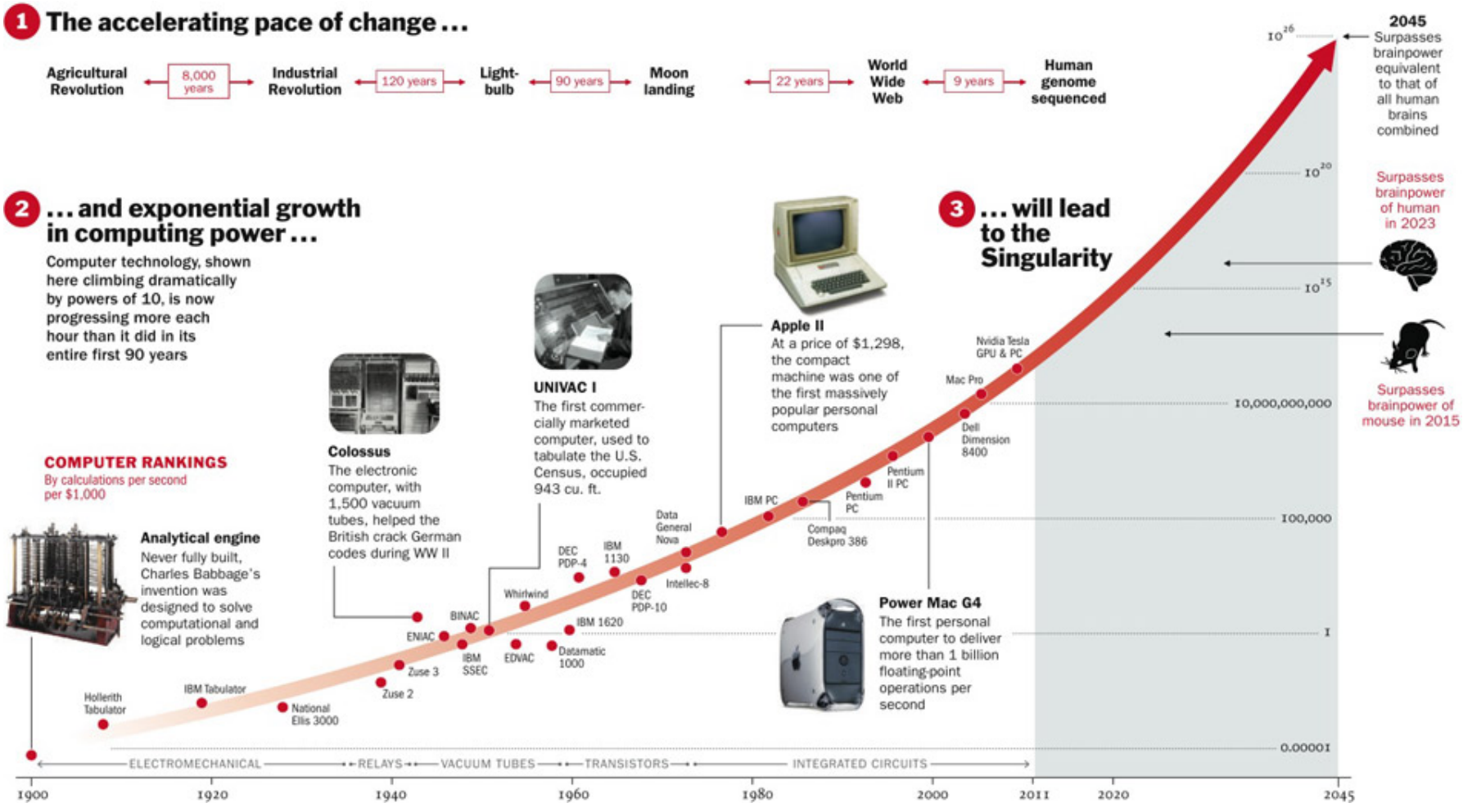
Singularity (2045)



What is intelligence?

- Mainly assumed characteristics
  - Thinking
  - Logical reasoning
  - Mainly assumed characteristics
- How about:
  - Drinking a glass of water?
  - Recognizing friends?
  - Preparing a meal?

Who is intelligent?

- Is a bacteria intelligent?
- Are ants intelligent?
- Ant colonies?
- Mice?
- Babies?

Who is intelligent?

- Is a bacteria intelligent?
- Are ants intelligent?
- Ant colonies?
- Mice?
- Babies?
- Machines?

Garry Kasparov v.s. Deep Blue

What is intelligence?

- Intelligence is a descriptive term.
- Descriptive terms are rather arbitrary (relative to your perspective).
- Are there common denominators

Intelligence: what it is for?

- Our brain has not evolved to solve mathematical proofs!
- It controls our behavior to ensure our survival.
- Natural intelligence is always manifested in behavior.
- We have to understand behavior and its underlying mechanisms to understand intelligence.
- To behave a body is needed (embodied intelligence).

Intelligence: Deffenitions

Are there general definitions about intelligence? (sadly not)

Journal of Educational Psychology (1921) asked 14 experts for definitions of intelligence:

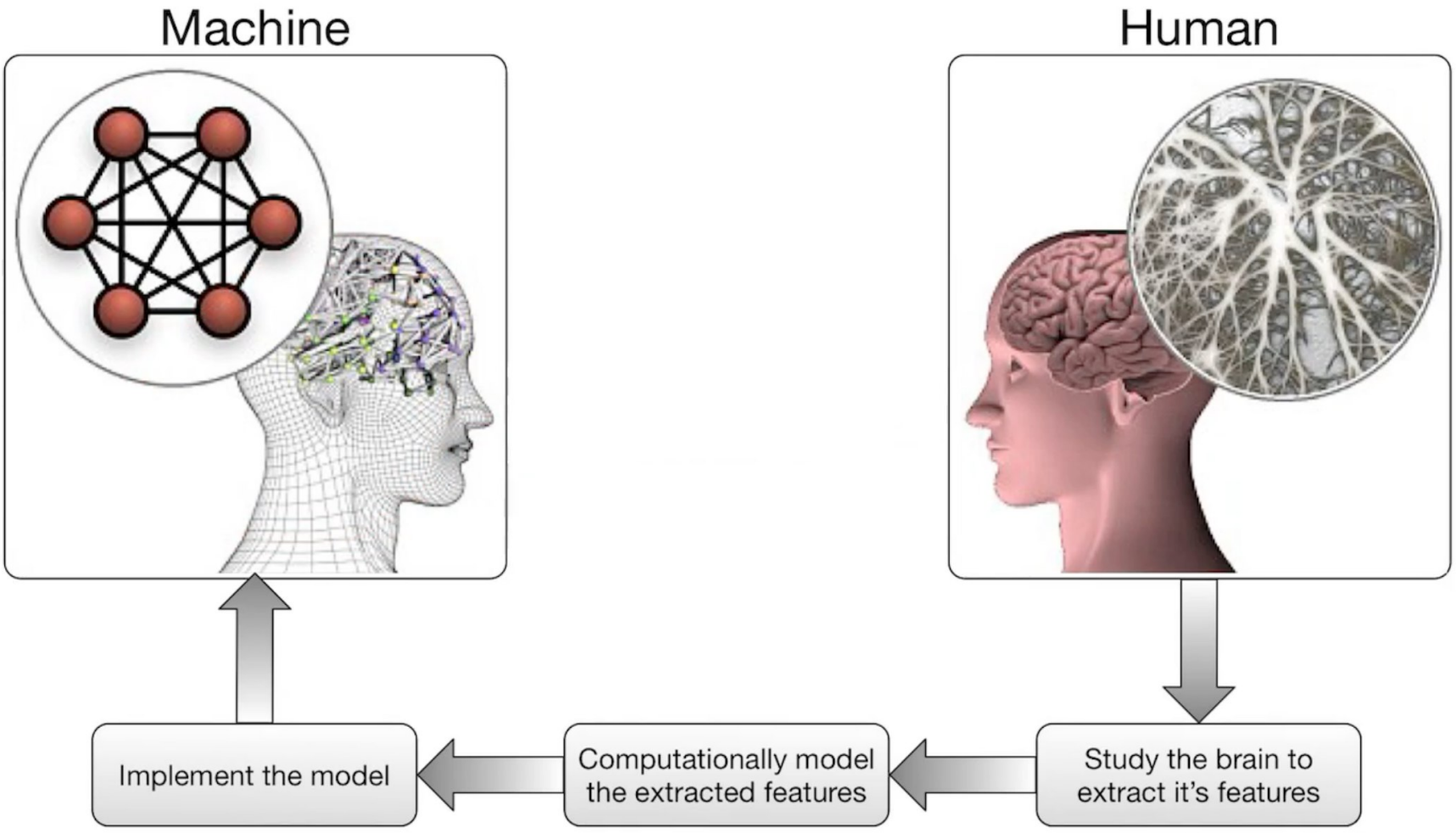
- Abstract Thinking (Terman)
- Ability of learning to adjust yourself to the environment (Colvin)
- A biological mechanism by which the effects of a complexity of stimuli are brought together and given a somewhat unified effect in behavior (Peterson).
- The capacity to acquire capacity (Woodrow).
- The capacity to learn or to profit by experience (Dearborn).

Intelligence: Commonsense notions

- Thinking and problem solving
- Learning and memory
- Language
- Intuition and creativity
- Consciousness
- Emotions
- Surviving in a complex world
- Perceptual and motor abilities
- ...

What are the underlying mechanisms to achieve these commonsense notions? We dont know fully yet!

Roadmap


Machine
Human
Implement the model
Computationally model the extracted features
Study the brain to extract it's features

Neuroscience and Computational Neuroscience

- Neuroscience is the scientific study of the nervous system.
  - It is an interdisciplinary field that incorporates biology, chemistry, computer science, engineering, mathematics, medicine, philosophy, physics, and psychology.
- The goal of computational neuroscience is to explain in computational terms how brains generate behaviors?
- Computational neuroscience provides tools and methods for
  - Characterizing what nervous systems do? (Descriptive Models)
  - Determining how they function? (Mechanistic Models)
  - Understanding why they operate in particular ways? (Interpretive Models)

Neuroscience and Computational Neuroscience

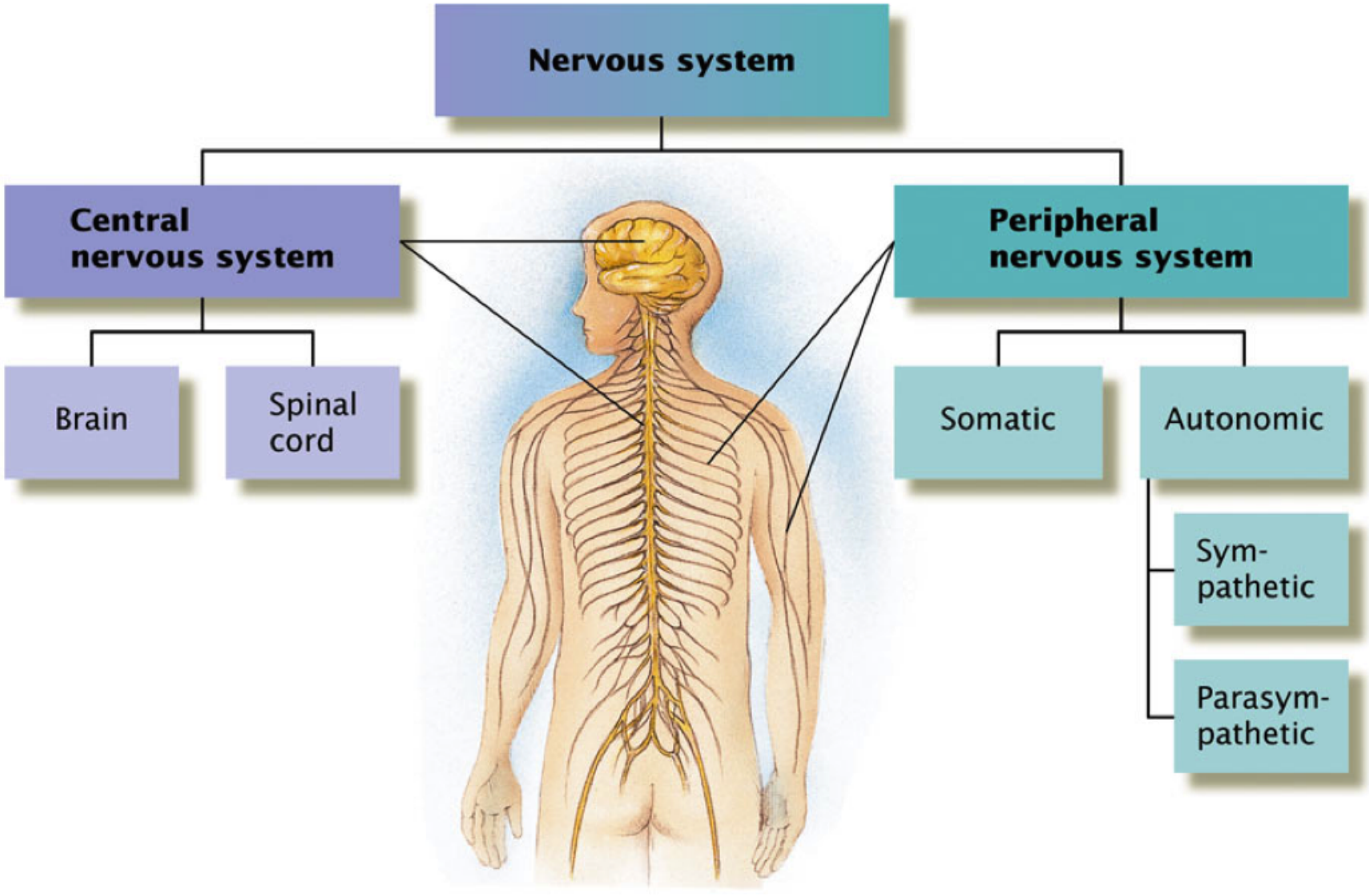
Computational neuroscience employs theoretical tools to explain, predict, or interpret experimental data and the complex mechanisms that underlie it.

- Advanced data analysis: Developing tools to extract more understanding and information from neural data.
- Dynamical and statistical modeling: Using data to construct models that test the role of specific neural mechanisms.
- Theory:
  - Developing novel conceptual models that explain or bring together disparate observations and make new predictions and suggest new analyses.
  - Identifying minimal structure or dynamics that explain a key neural phenomenon.
  - Identifying computational/algorithmic motifs and design principles that optimize and explain neural function.

Levels of Modeling

- Descriptive Models:
  - How do neurons respond to external stimuli and how do we describe this quantitatively with a neural encoding model?
  - How can we extract information from neurons (decoding)?
- Mechanistic Models:
  - How can we simulate the behavior of a single neuron on a computer?
  - How do we simulate a network of neurons?
- Interpretive (or Normative) Models:
  - Why do brain circuits operate the way they do?
  - What are the computational principles underlying their operation?

Organization and Function of the Nervous System



Peripheral Nervous System (PNS)

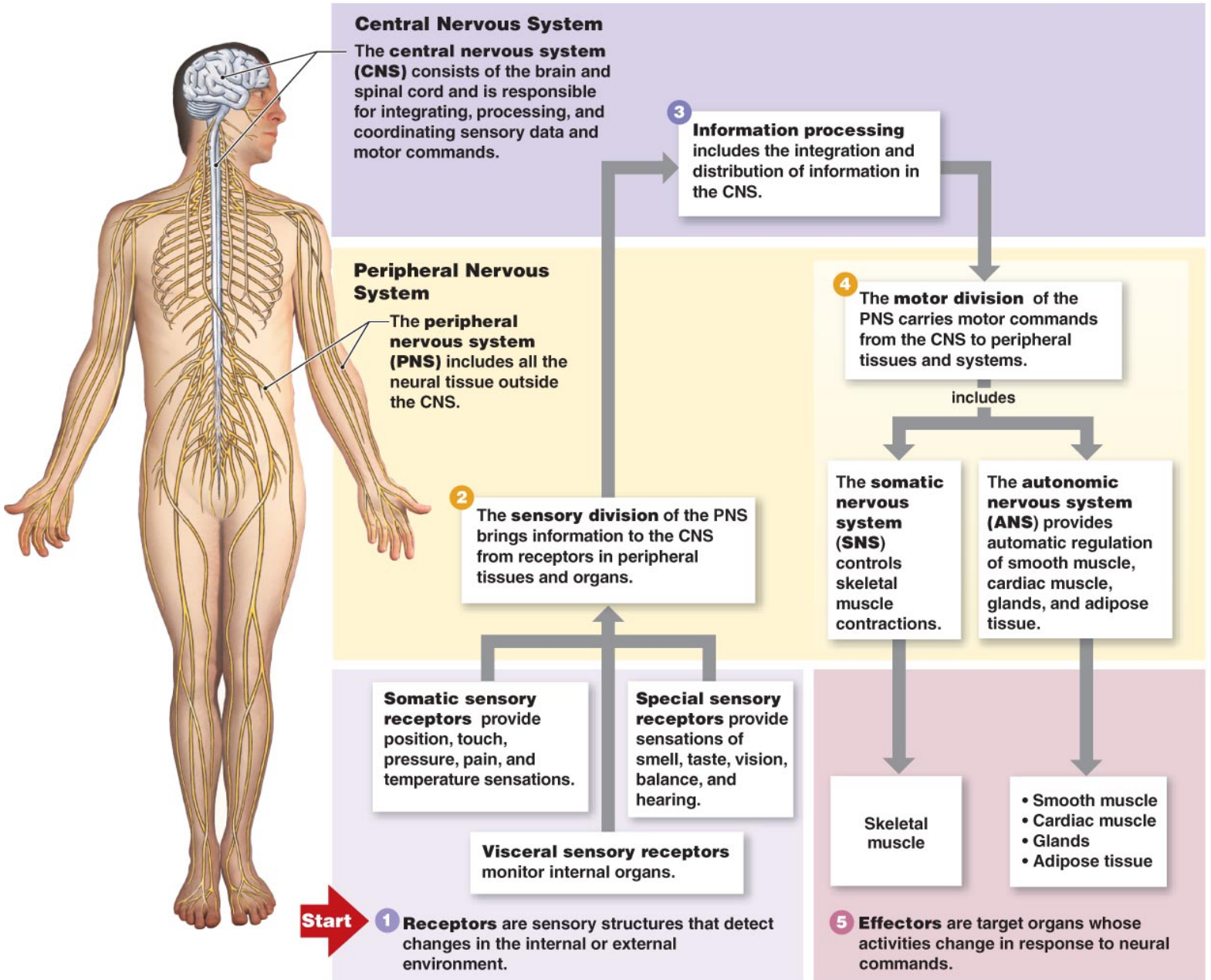
- Somatic: Nerves connecting to voluntary skeletal muscles and sensory receptors.
    - Afferent Nerve Fibers (incoming): Axons that carry info away from the periphery to the CNS.
    - Efferent Nerve Fibers (outgoing): Axons that carry info from the CNS outward to the periphery.
- Autonomic: Nerves that connect to the heart, blood vessels, smooth muscles, and glands.

Central Nervous System (CNS)

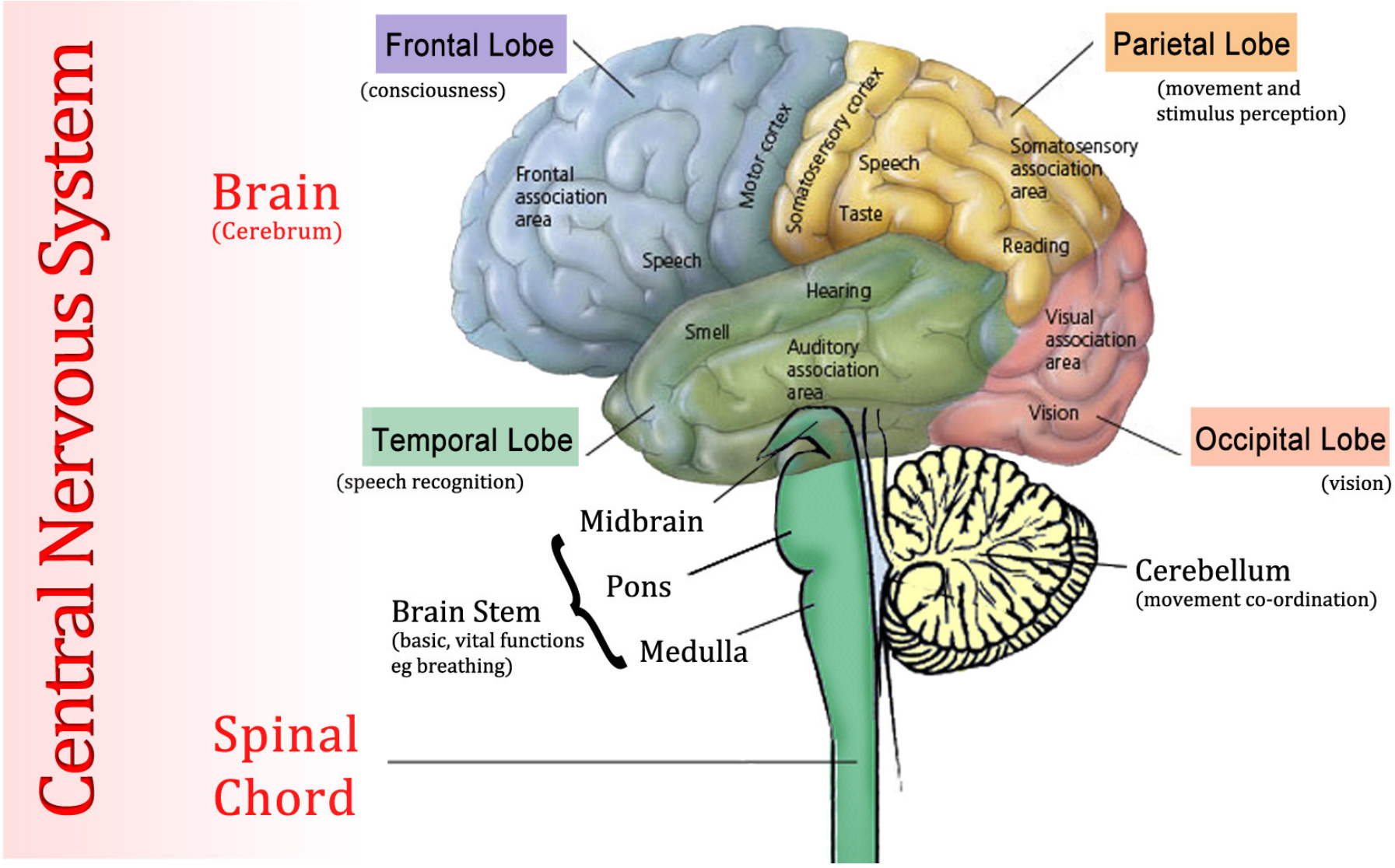
CNS = Spinal Cord + Brain

- Spinal Cord:
  - Local feedback loops (control reflexes)
  - Descending motor control signals (from the brain activate spinal motor neurons)
  - Ascending sensory axons (convey sensory information from muscles and skin back to the brain)
- Brain: Performs many function and composed of different regions.

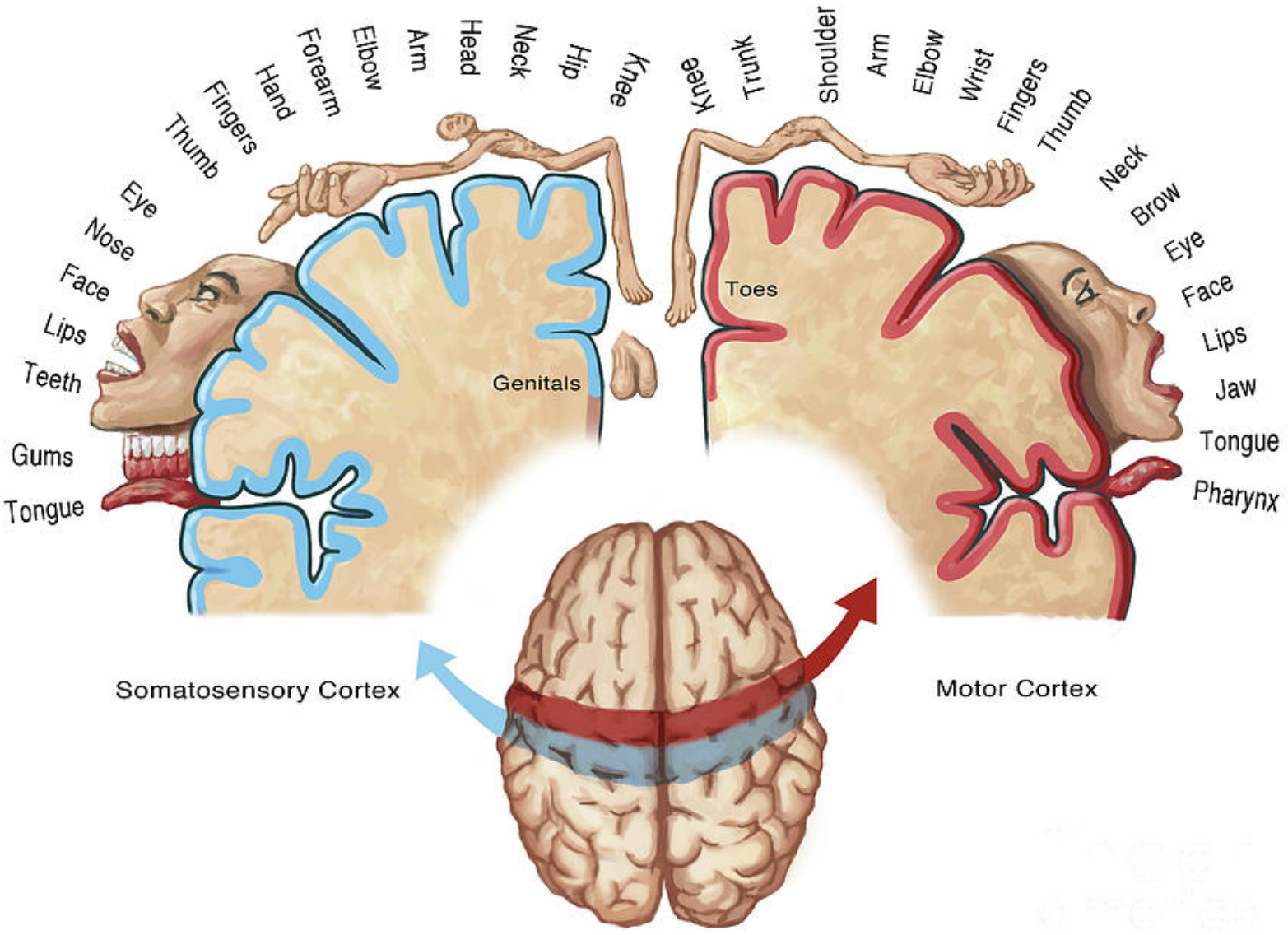
Organization and Function of the Nervous System



Organization and Function of the CNS

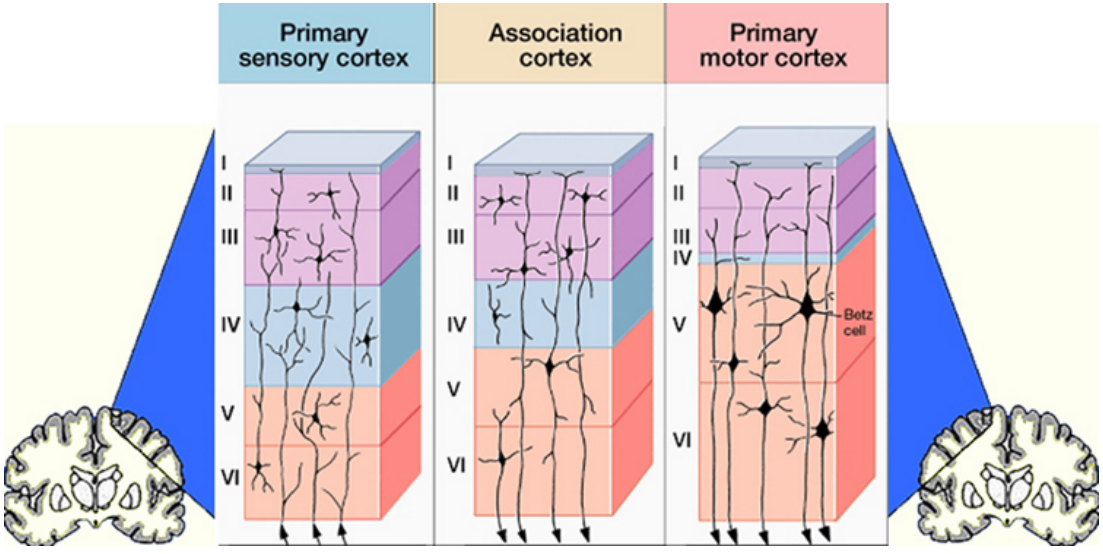


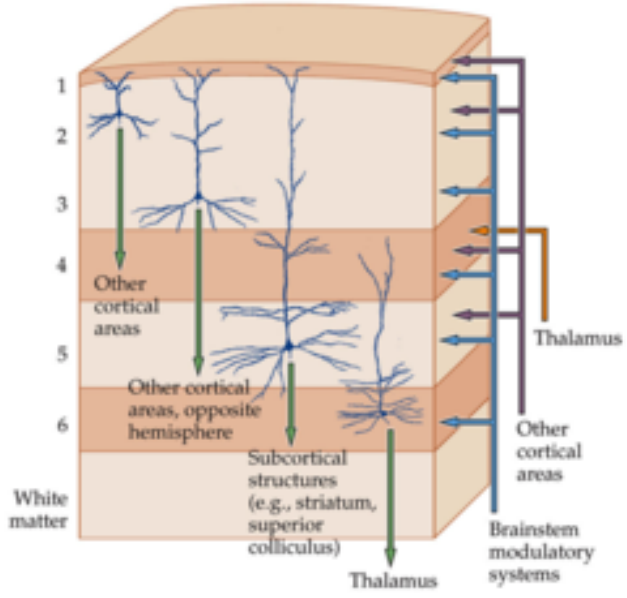
Cortical homunculus



Cerebral Cortex: A Layered Sheet of Neurons

- Cerebral Cortex: Convoluted surface of cerebrum, about 1/8 of an inch thick
  - Approximately 30 billion neurons.
  - Each neuron makes about 10000 synapses, approximately 300 trillion connections in total.
- Six layers of neurons
  - Relatively uniform in structure.
  - Is there a common computational principle operating across cortex? We dont know fully yet!





Neural versus Digital Computing

- Device count:
  - Human Brain: 10^{11} neurons, each neuron has 10^4 connections
  - Silicon Chip: 10^{10} transistors with sparse connectivity
- Device speed:
  - Biology has $100\mu s$ temporal resolution
  - Digital circuits are approaching a $10GHz$ clock
- Computing paradigm:
  - Brain: Massively parallel computation and adaptive connectivity
  - Digital Computers: sequential information processing via CPUs with fixed connectivity
- Capabilities:
  - Brains: Better at solving ill-posed problems (speech, vision)
  - Digital computers excel in math and symbol processing ...

From Eye to the Visual Cortex