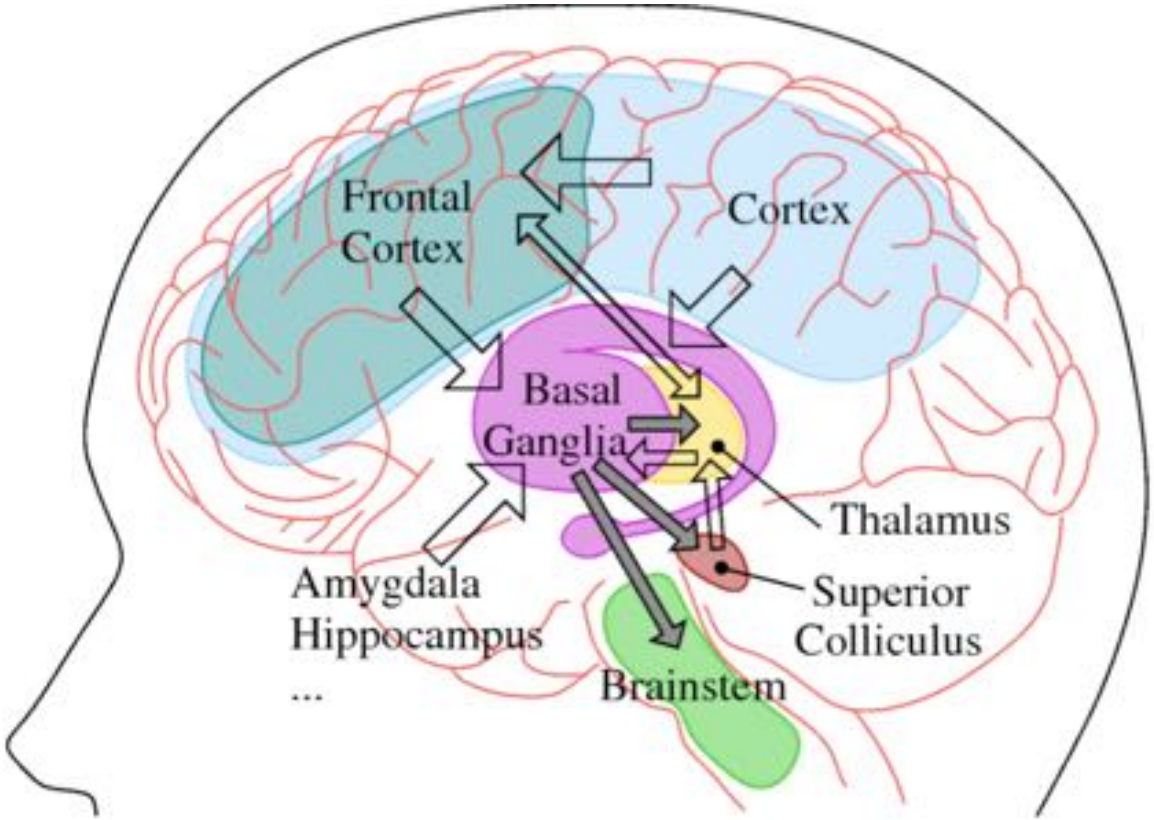
Approche systémique : simuler moins pour modéliser plus

Computational Neuroscience
Cognition
Memory
Brain & Body
Complex systems

Mnemosyne



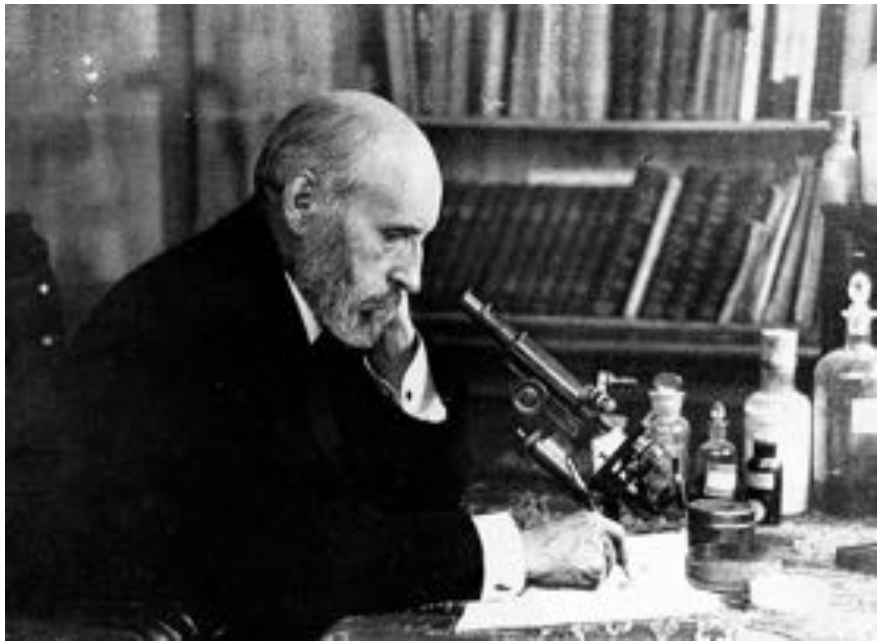
institut des maladies neurodégénératives

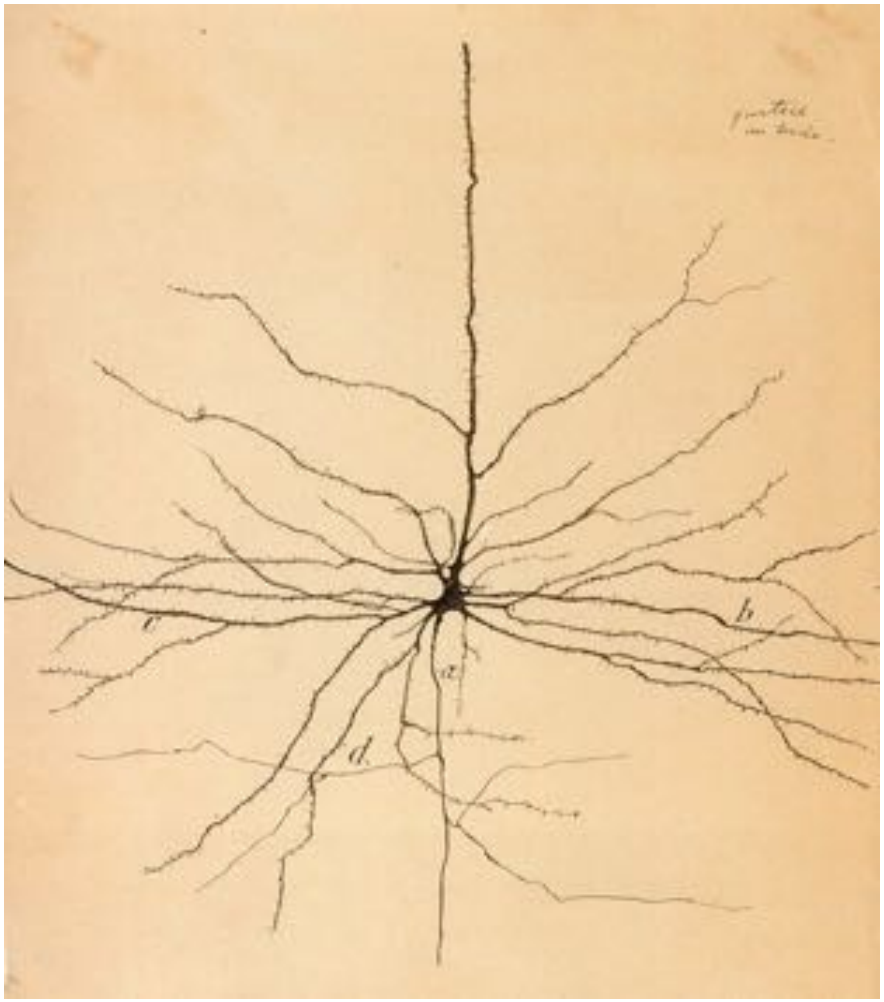
Frédéric ALEXANDRE

Approaches in Science

- Descriptive science (observation, experimentation, data: describe reality)
- Normative science (how it should be, under a certain formalism)
  - Theoretical (explanations, knowledge, relations between variables)
  - Modeling (simplifying to answer a question)

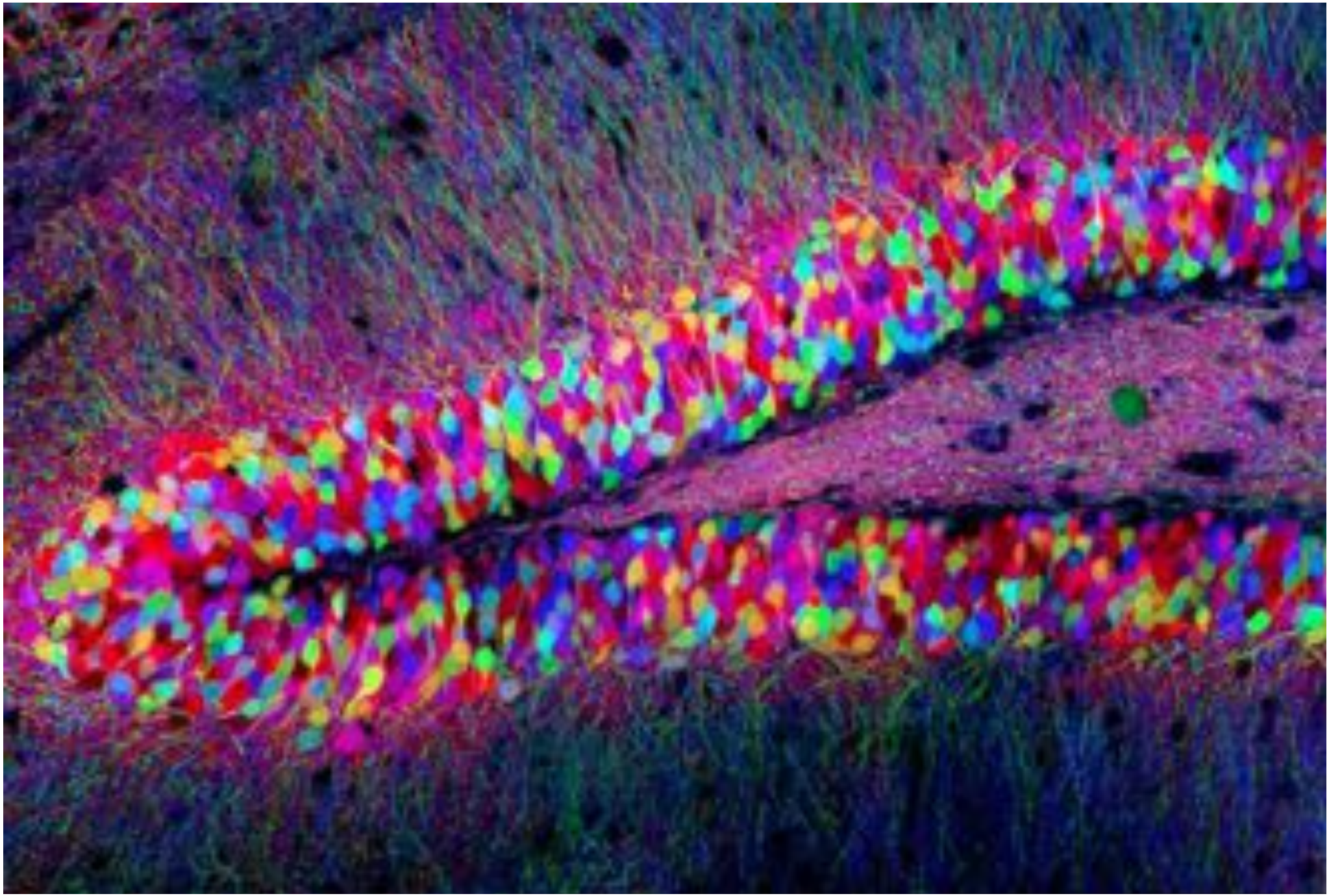
Neuroscience
Observing the brain





(Ramon y Cajal, 1906)

2007: Brainbow technique



Different kinds of models

- Knowledge models (from equations in Physics, often using algebra and dynamical systems)
- Representation models or phenomenological (often using statistics)

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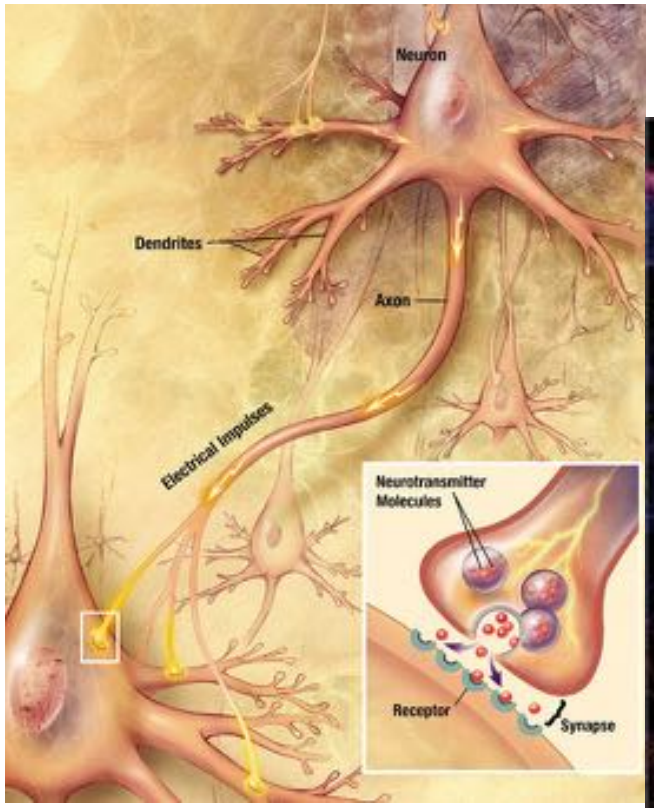
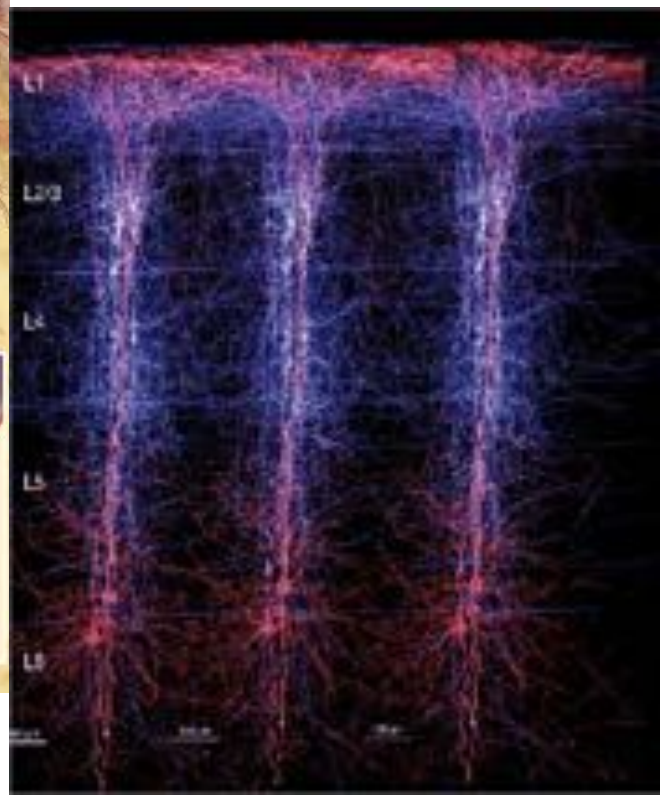
- Representation models or phenomenological (often using statistics)

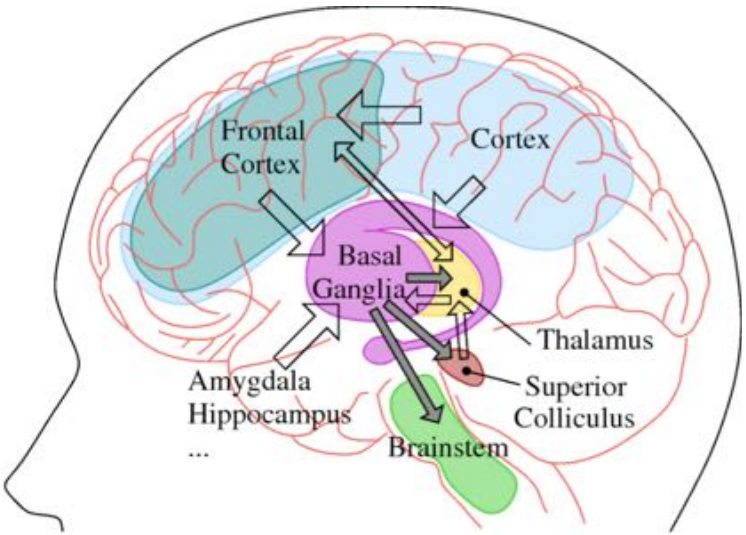
Important steps in model design:

1. Choose the question, select the important variables and their relations, define the system (structure and initial state);
2. Run the simulation until needed; observe and interpret the resulting behavior; make predictions
3. Compare to reality and modify the model

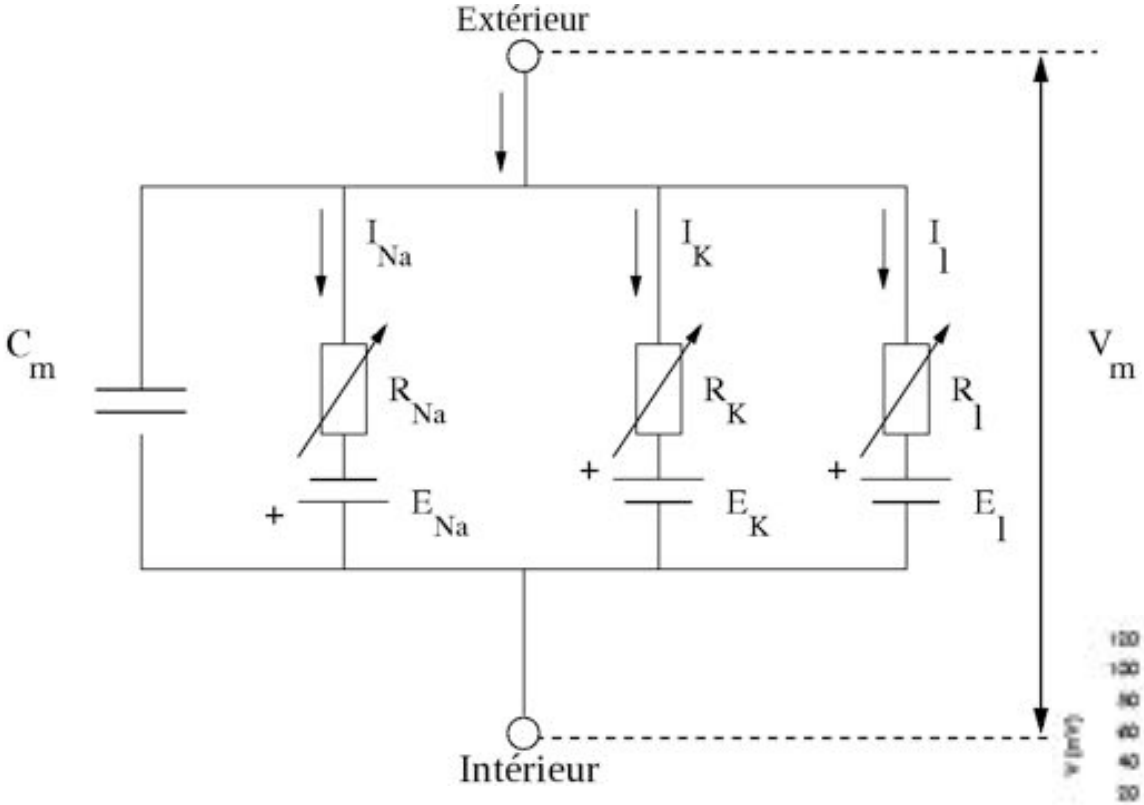
Three scales of description: neurons, populations, structures



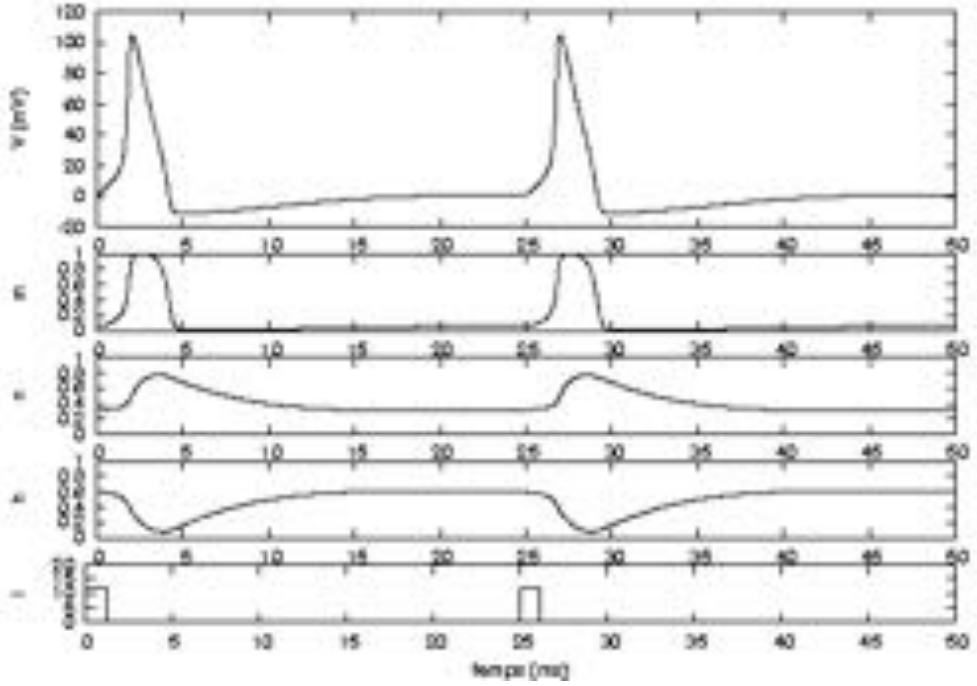




The neuron level **The circuit level** **The function level**



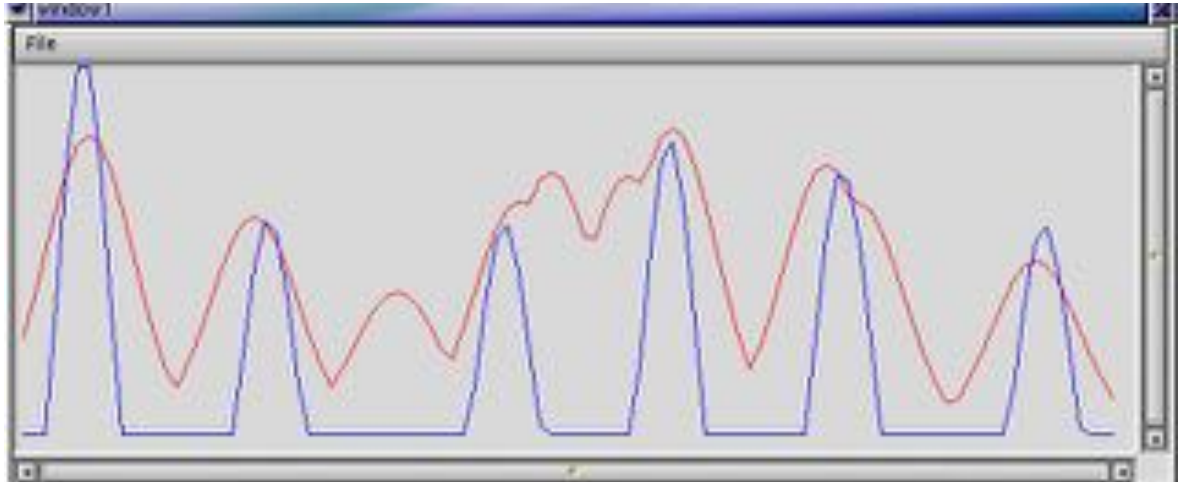
Hodgkin-Huxley Model (1952)



$$C_M \frac{dV_M}{dt} = -g_{Na} m^3 h (V_M - E_{Na}) - g_K n^4 (V_M - E_K) - g_l (V_M - E_l) + I$$

Functioning rules

$$\tau \frac{\partial u(x,t)}{\partial t} = -u(x,t) + \int_M w_M(x-x') f\left[u(x',t)\right] dx' + \int_{M'} s(x,y) I(y,t) dy + h$$



Feedforward input

$$s(x,y) = Ce^{-\frac{|x-y|^2}{c^2}}, C, c \in \Re^{*+}$$

Lateral input

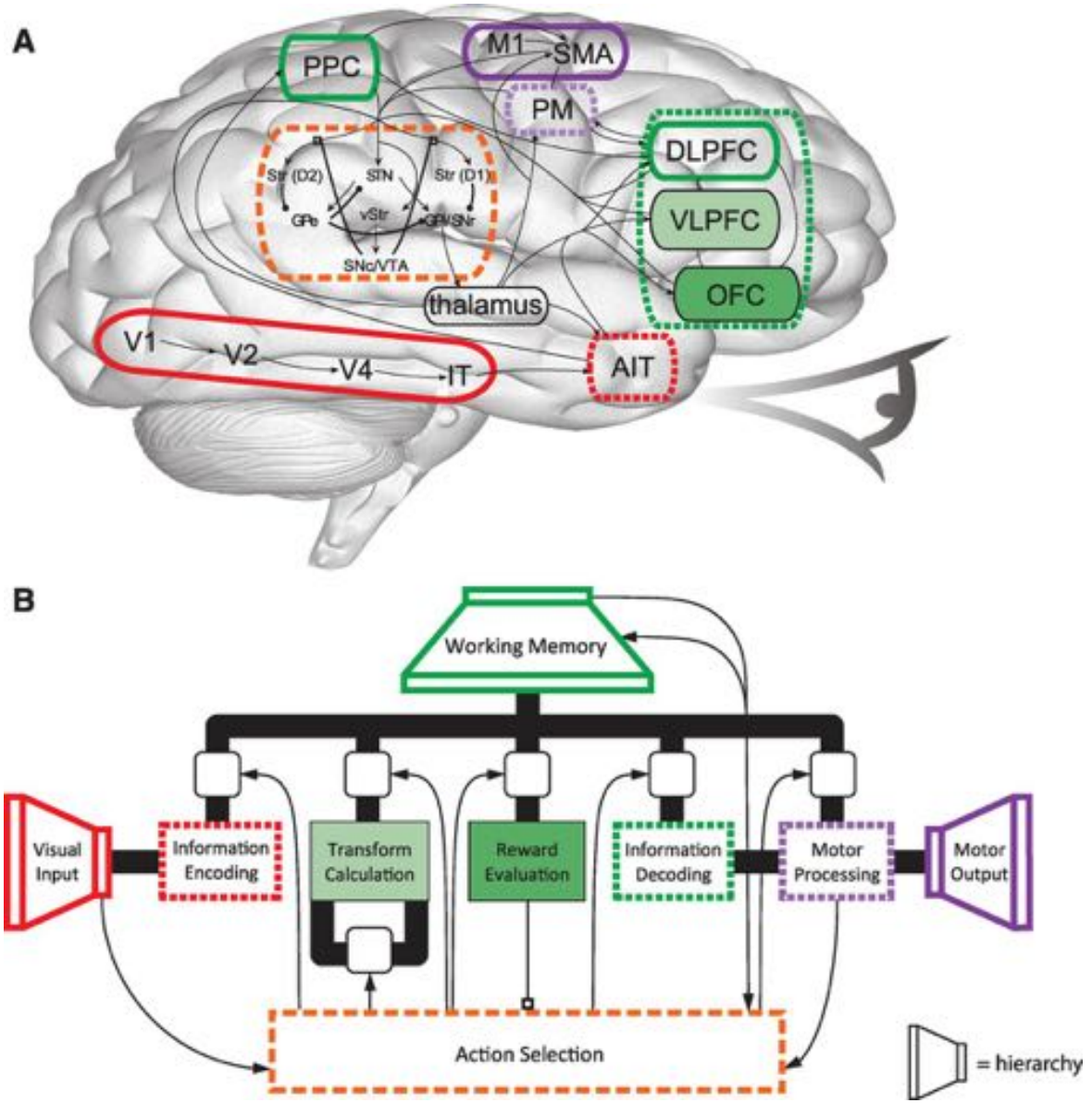
$$w_M(x-x') = Ae^{-\frac{|x-x'|^2}{a^2}} - Be^{-\frac{|x-x'|^2}{b^2}}, A, B, a, b \in \Re^{*+}$$

Learning rules

In a graph of neural units, connection strengths vary as a function of units coactivation

The Spaun project

(functional brain simulation, 2012)



How does the brain work ?

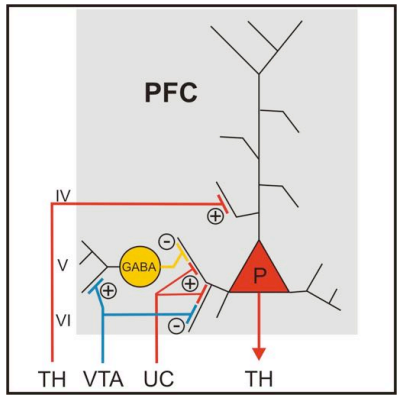
Why does the brain work ?

Positivist or Systemic view of the Brain ?

- The brain is an open system
  - Interaction with the body
  - Interaction with the environment
- The brain is an adaptive (changing) system
  - Cognition results from interacting memories
  - Autonomous lifelong learning
- The brain is a multimodal multilevel system
  - Sensing pain and pleasure as well as light and sounds
  - From hormones to language

Cognition= interacting memories

Prefrontal cortex

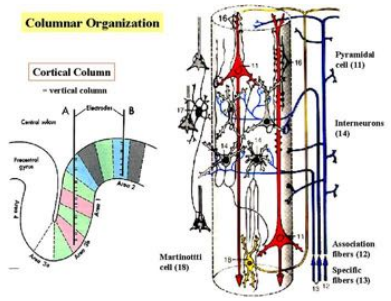


Working memory

Hippocampus

Episodic memory

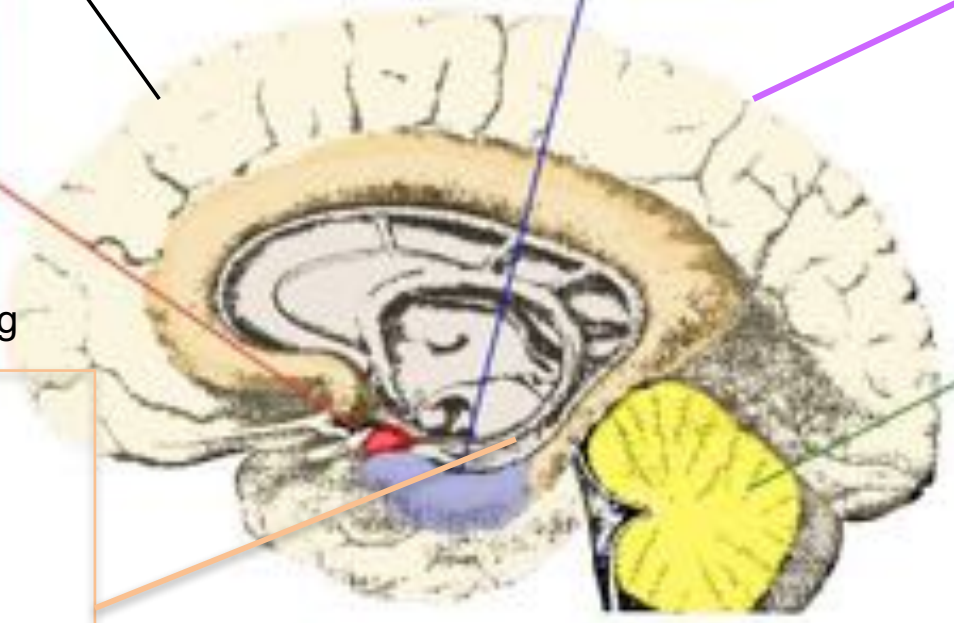
Posterior Cortex



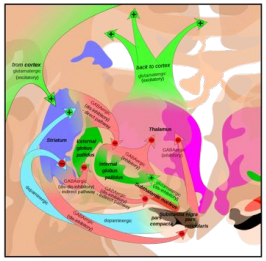
Semantic memory

Amygdala

Respondent conditioning



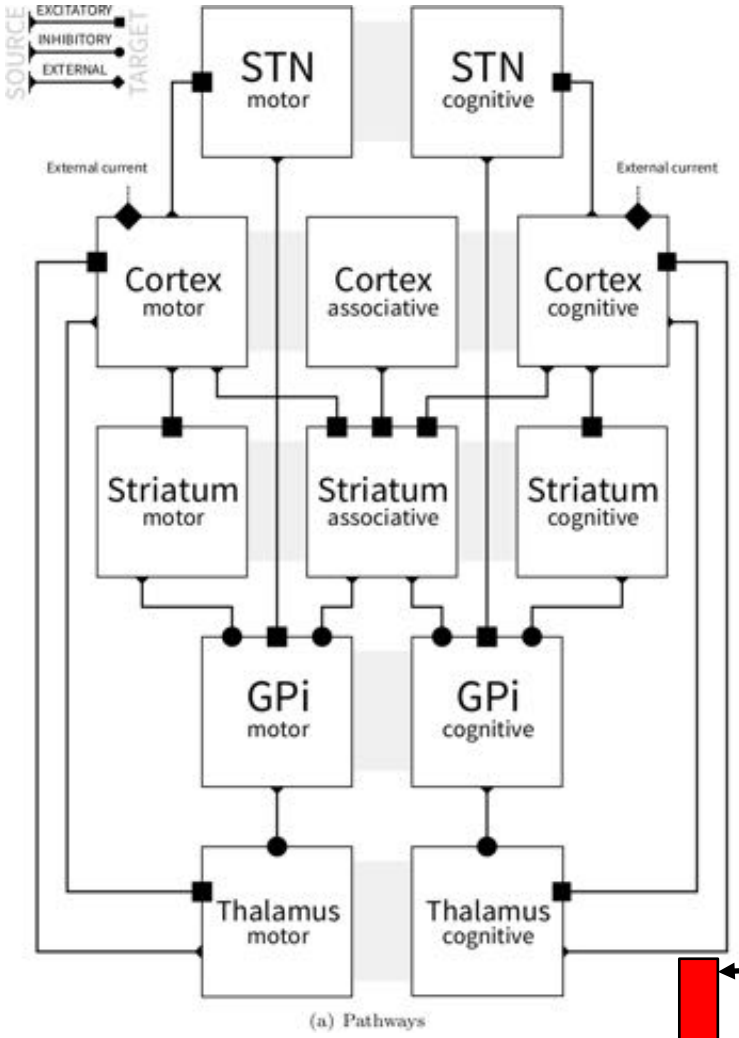
Basal Ganglia



Instrumental conditioning

Cerebellum

Procedural memory



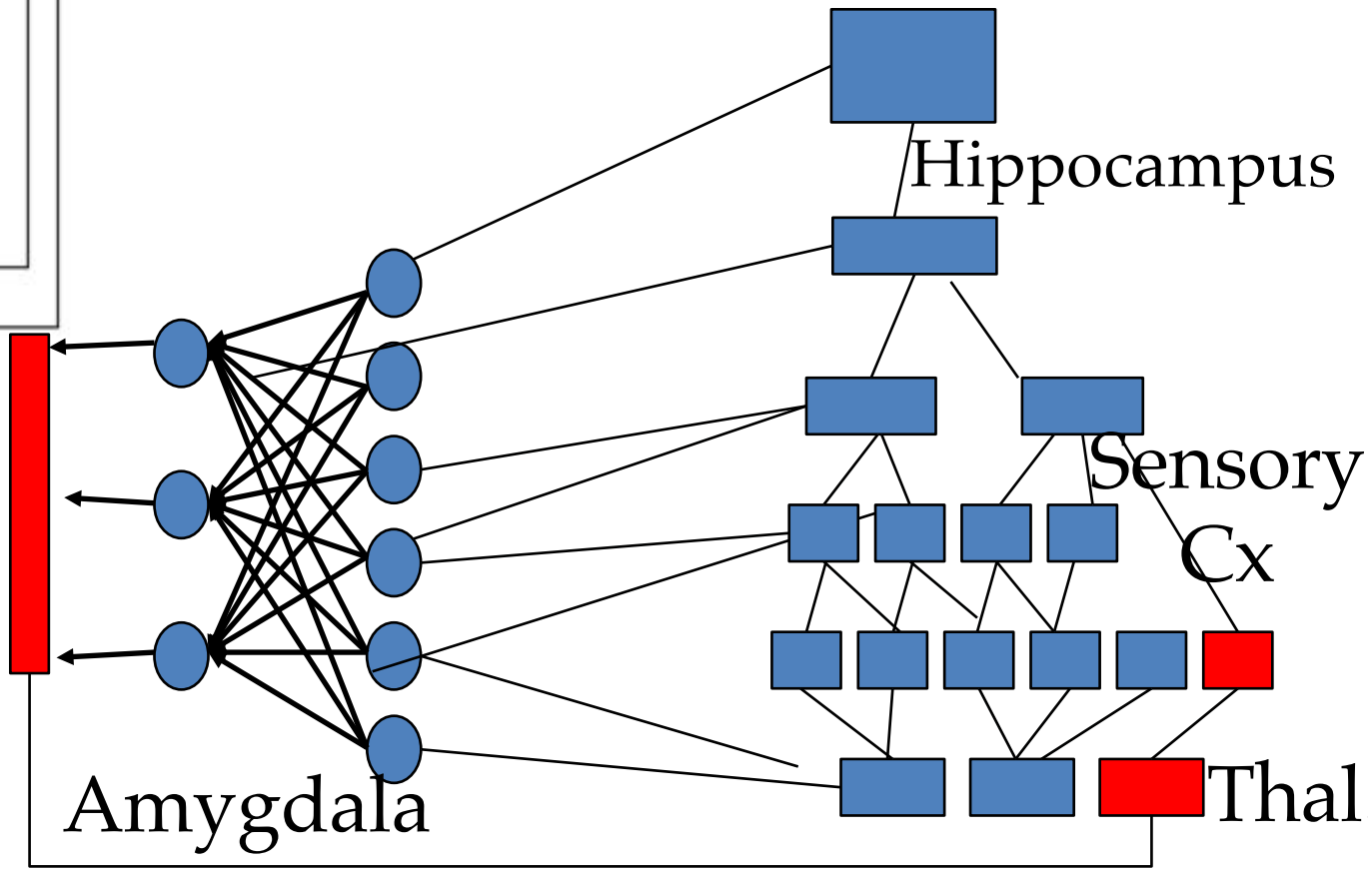
(a) Pathways

Errors of prediction to memorize episodes or categories ?

(Carrere, 2013)

Goal-Directed or Habitual ?

(Topalidou, 2016)



Embodiment, needs, pleasure

Toward autonomous learning…

All the models are wrong but some of them are useful (Georges Box)

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