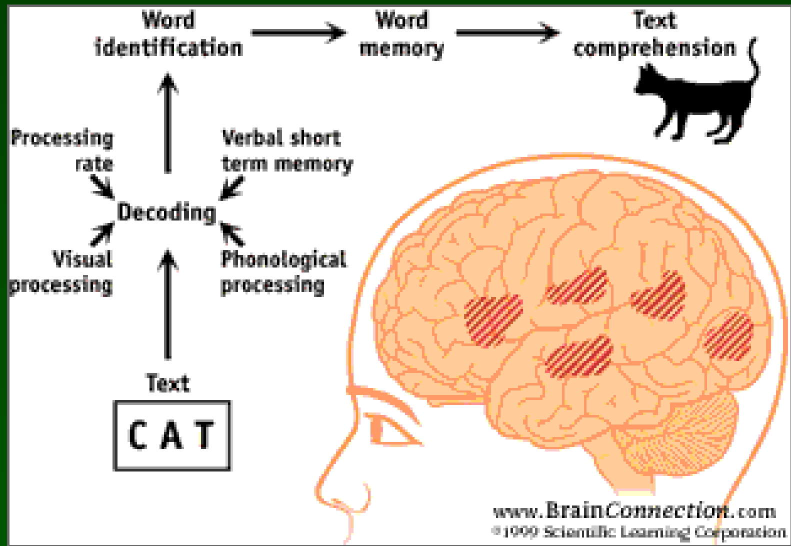
Selected topics in cognitive science & biomodeling

L12: Learning



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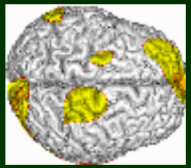
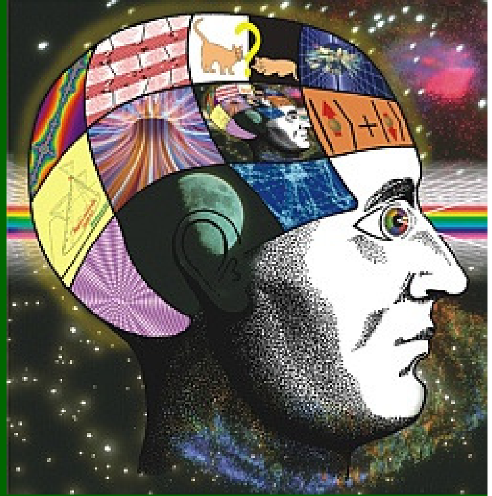
What it will be about



1. Learning, coding sensory information.
2. Topographical maps and somatosensory perception.
3. Population coding – active perception.

The problem



How do brains, using massively parallel computations, represent knowledge and perform thinking?

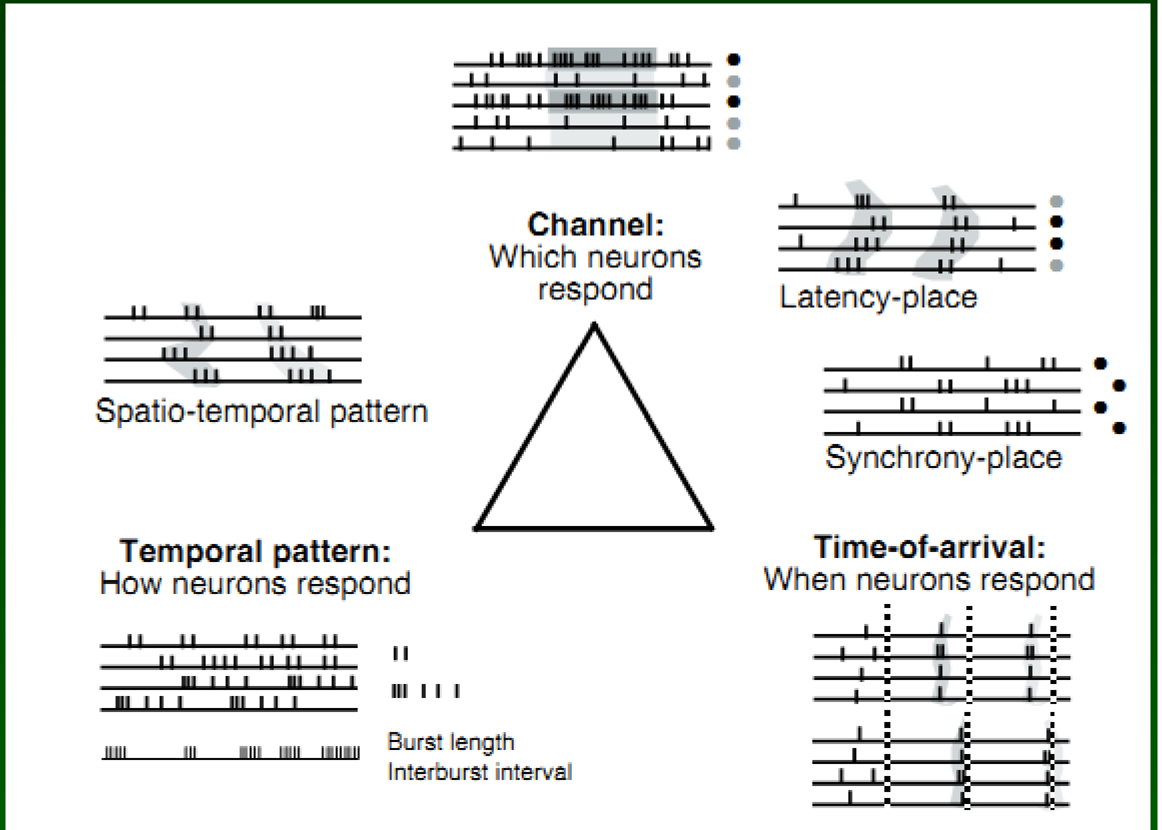
- **Ludwig Boltzmann** (1899): "All our ideas and concepts are only internal pictures or if spoken, combinations of sounds."
- **Ludwig Wittgenstein** (Tractatus 1922): thoughts are pictures of how things are in the world, propositions point to pictures.
- **Kenneth Craik** (1943): the mind constructs "small-scale models" of reality to anticipate events, to reason, and help in explanations.
- **Phillip Johnson-Laird** (1983): mental models are psychological representations of real, hypothetical or imaginary situations.
- **Jean Piaget**: humans develop a context-free deductive reasoning scheme at the level of elementary FOL.

Pictures? Logic? Both? What really happens in the brain?

Brain information code

- All brain states are just spikes – how is information encoded in spikes?

1) channel-codes (spatial activation patterns),
2) temporal spike patterns
3) spike latency (relative spike timings);
4) rate coding.

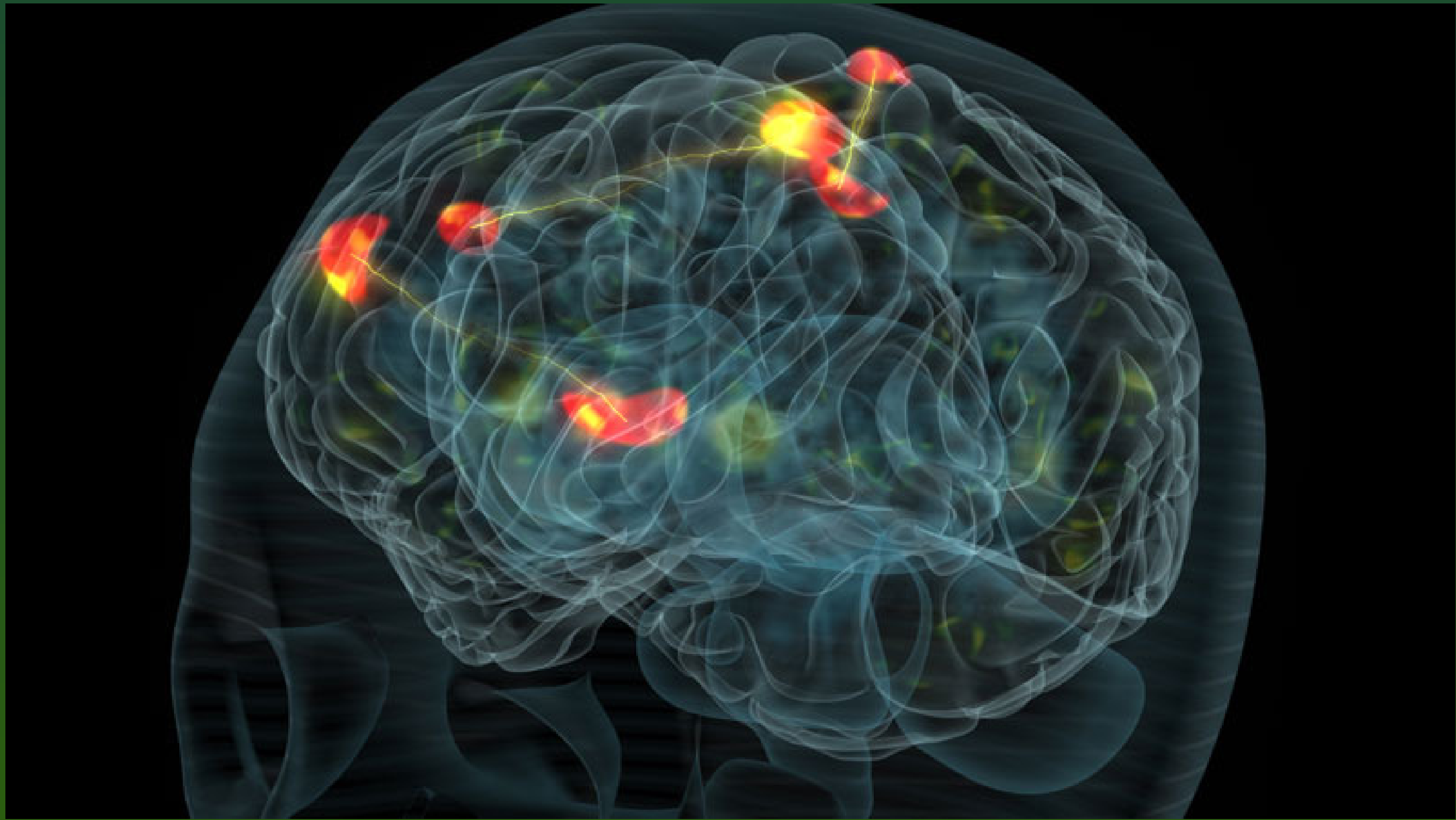


Stimulus-driven temporal correlations (phase-locking), are common in audition, vision, tactile perception.

Intrinsic temporal response structure in all sensory systems.

Particular temporal patterns of electrical stimulation elicit specific sensory experience (from Cariani, 2001); we shall used only rate coding.

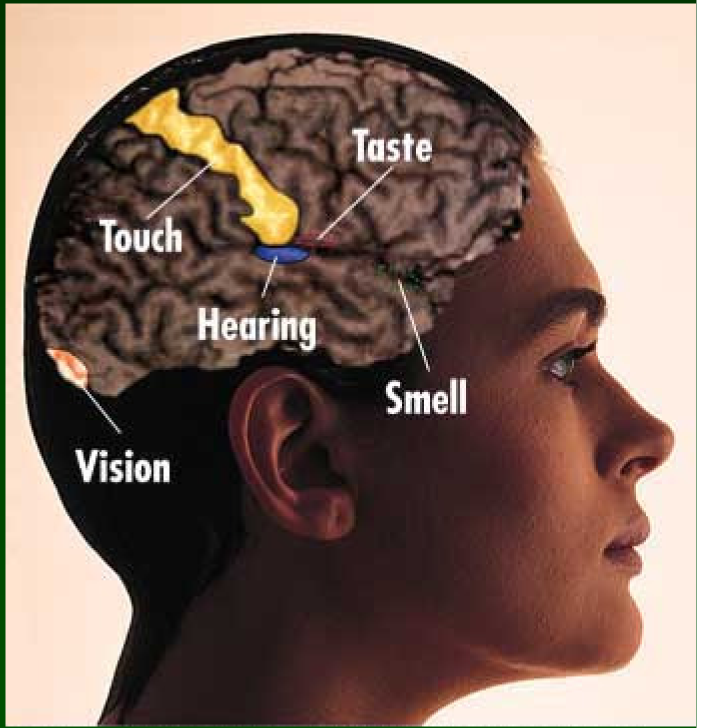
Mental state: strong coherent activation



Many processes go on in parallel, controlling homeostasis and behavior. Most are automatic, hidden from our Self. What goes on in my head?

Various subnetworks compete for access to the highest level of control - consciousness, the winner-takes-most mechanism leaves only the strongest. How to extract stable intentions from such chaos? BCI is never easy.

Cortex functions



Cortex has three major functions:

- precise analysis of sensory data;
- control of movements;
- complex cognition: association, planning, categorization of brain states (including reflection on the organism state).

All perception and action in the brain has to be coded by neural activity. Analysis is possible thanks to segregation of the data flow in thalamus and then cortex, and specific structure of inputs.

Primary sensory cortex: inputs from receptors => spinal nerve => thalamus, expects specific structure of information depending on modality.

Ex: somatosensory system reacts to touch (several mechanoreceptors and chemoreceptors), temperature, proprioception (internal body information), and nociception (pain), receiving it in BA 1-3, knowing where it comes from.

A Standard Model of the Mind

Laird JE, Lebiere C, & Rosenbloom, PS (2017). A Standard Model of the Mind: Toward a Common Computational Framework across Artificial Intelligence, Cognitive Science, Neuroscience, and Robotics. *AI Magazine*, *38*, 13–26.

Laird: A mind is a functional entity that can think.

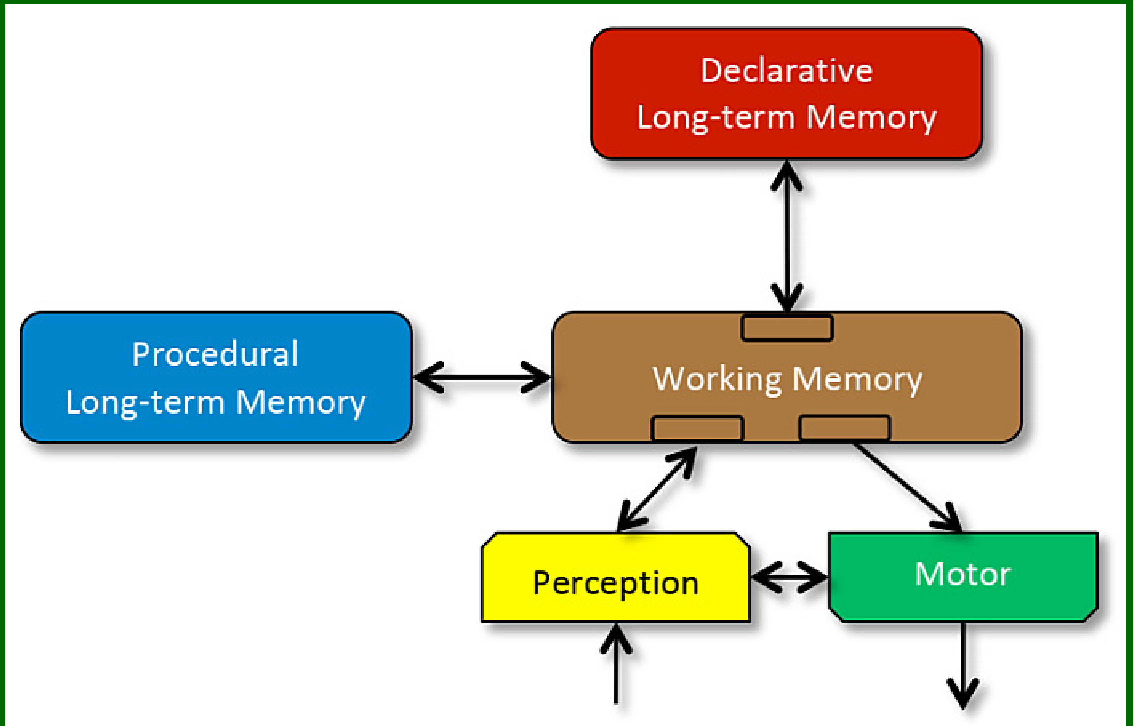
Newell: Mind is a control system that determines behavior of organism interacting with complex environment.

Cognitive informatics.
Neurocognitive Informatics.

Cognitive arhcitectures.

(Deep Mind, OpenAI).

AI-NN-ML-SC-PR communities will finally join in problem-oriented, not method oriented, large-scale projects.



Hierarchical brain structure

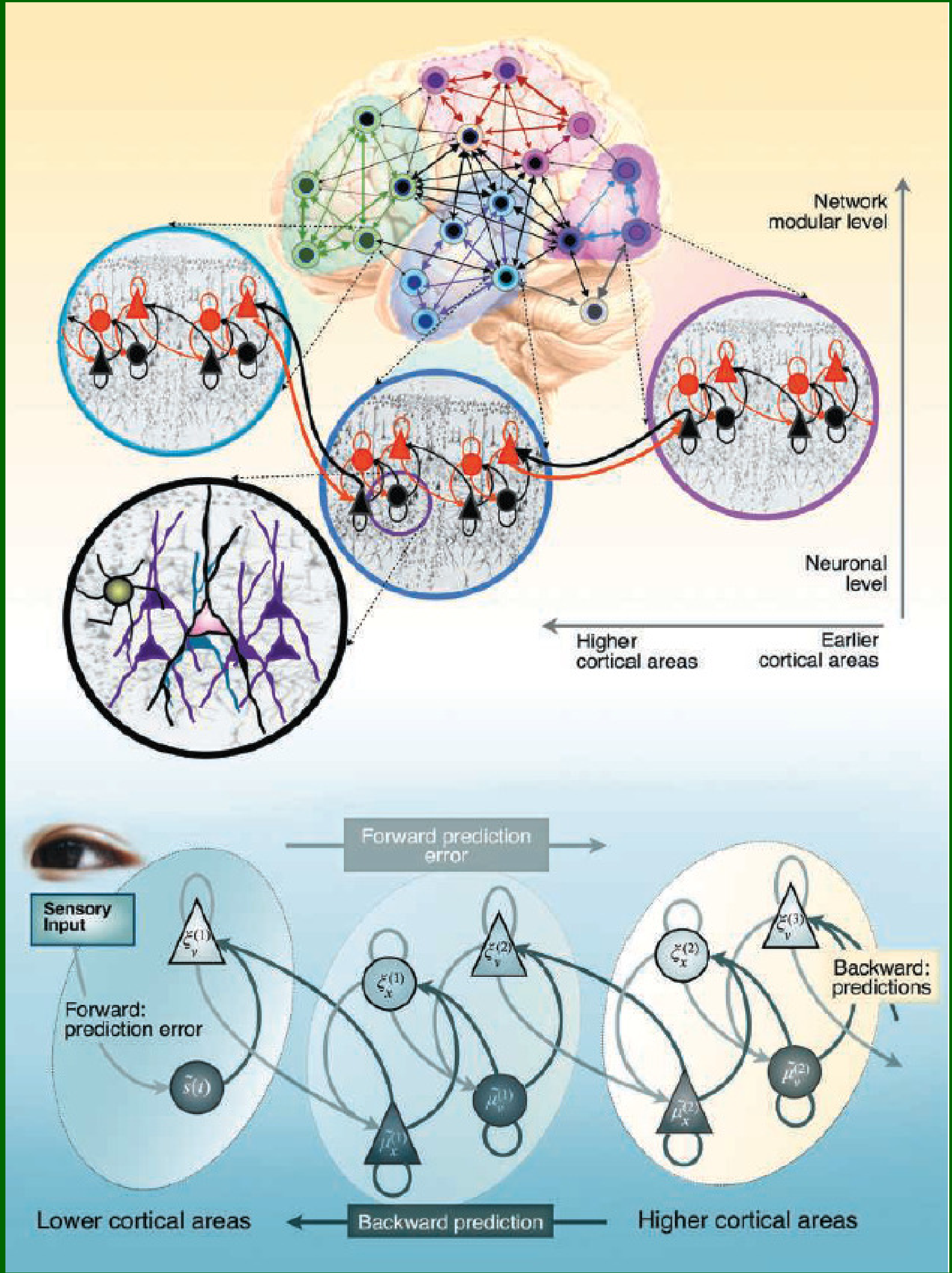
Brains try to predict and learn only when prediction fail.

Back of the brain – forward prediction error.

Front of the brain – backward predictions.

Park H-J, Friston K.

Structural and functional brain networks: from connections to cognition. Science. 2013;342

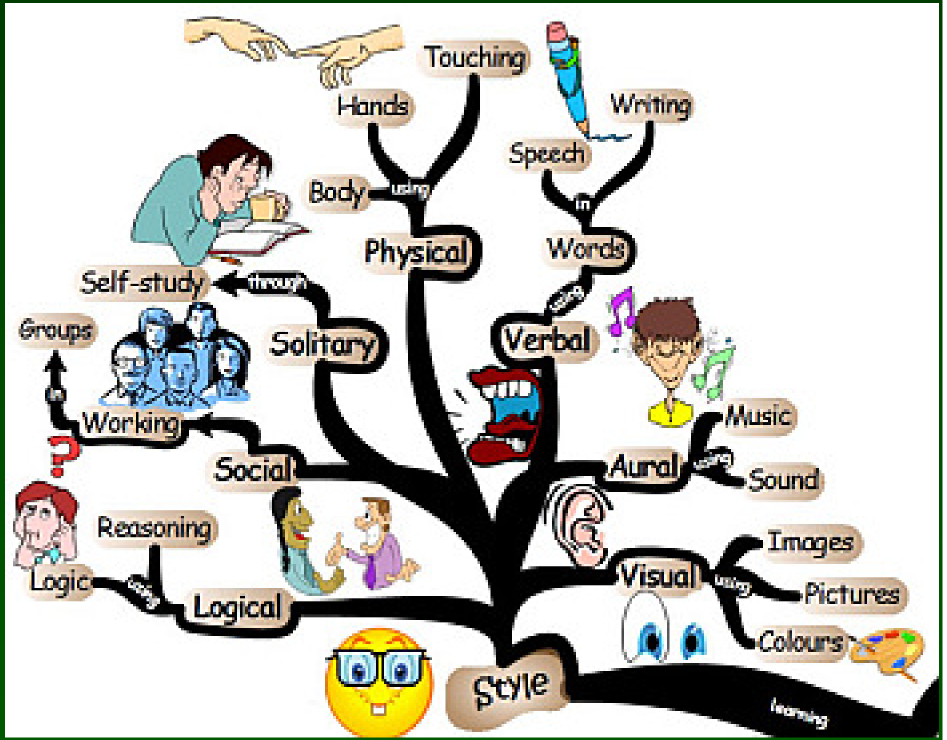


Learning: types

1. How should an ideal learning system look?
2. How does a human being learn?

Detectors (neurons) can change local parameters but we want to achieve a change in the functioning of the entire information processing network.

We will consider three types of learning, requiring different mechanisms.

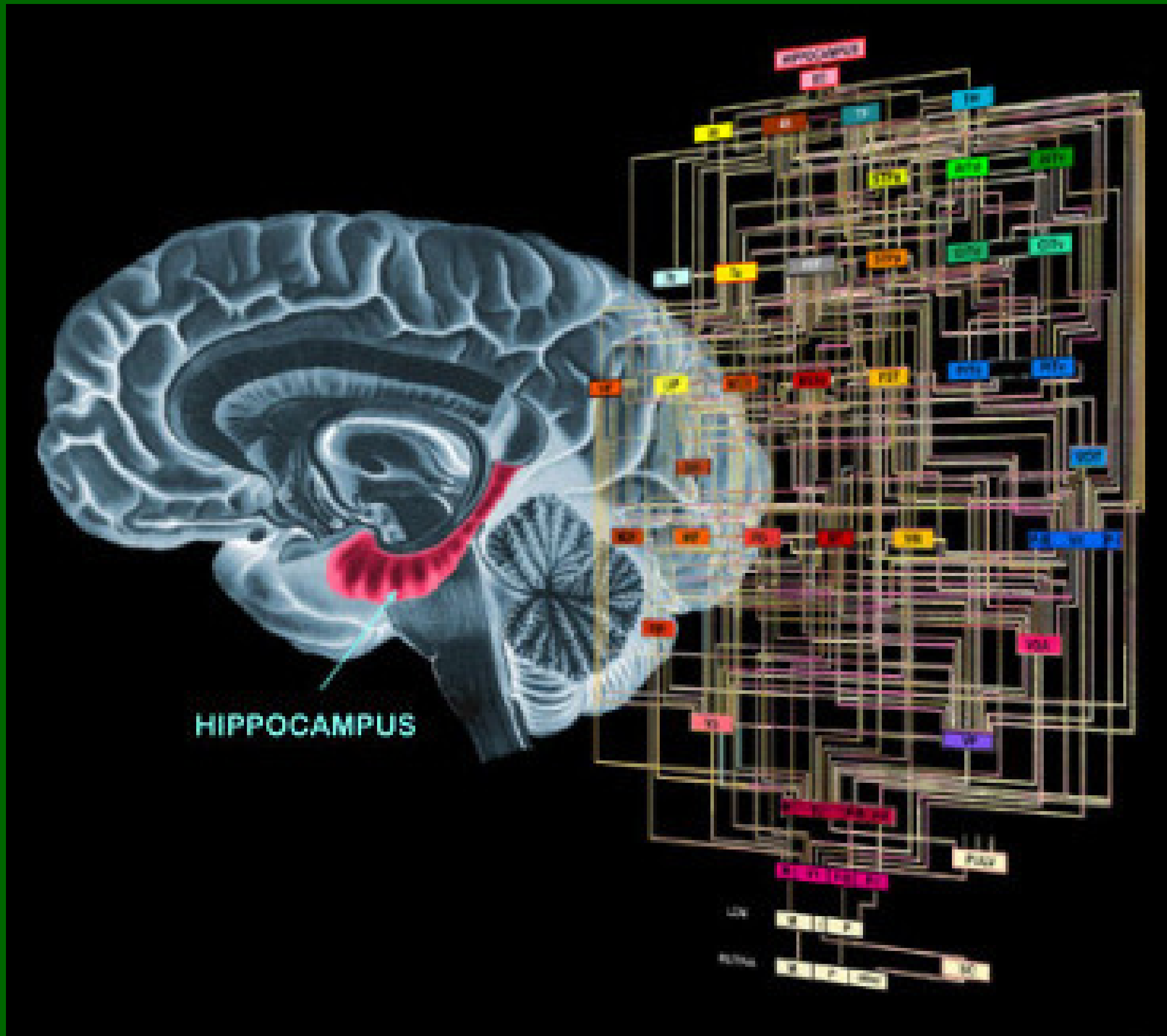


Spontaneous learning of internal models of environment.

Supervised learning of tasks (behaviors).

Goal-directed reinforcement learning.

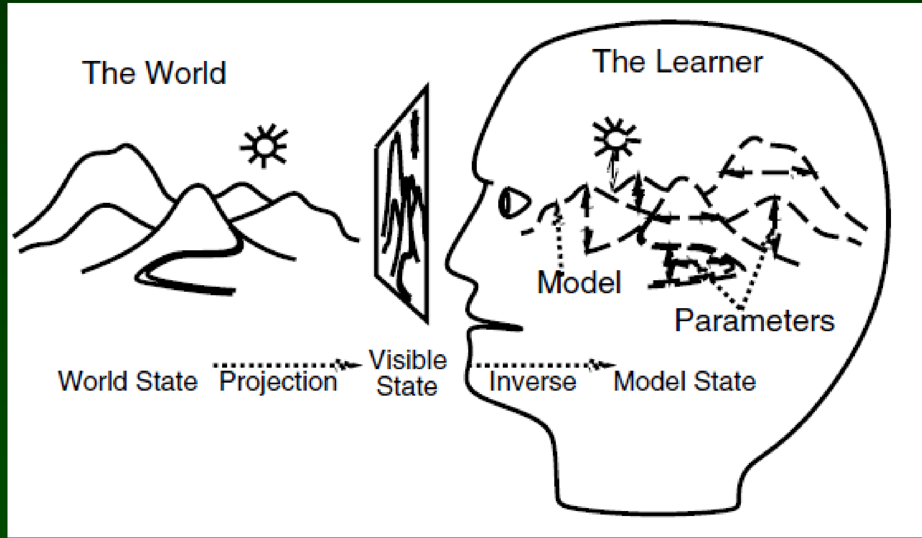
BICA, Brain-Inspired Cognitive



Understanding subtle mental processes requires a model that should show how internal states create narrative "stream of consciousness".

Primary cortex: model learning

Environment supplies a lot of information, but sensory stimuli are of poor quality and change rapidly. Without extensive knowledge of what can be expected, narrowing the interpretation of these signals, reliable identification of objects and relationships between them is not possible.



Chances of survival are greater using model of environmental states, biased for recognition of objects and stimuli, invoking correct behavior.

- Recognizing and enhancing correlations between neural activity is a necessary (but not sufficient) condition of finding causal relationships.
- Primary sensory cortex should identify useful structures for such model: phonemes, edges, basic quanta that makes perception invariant.

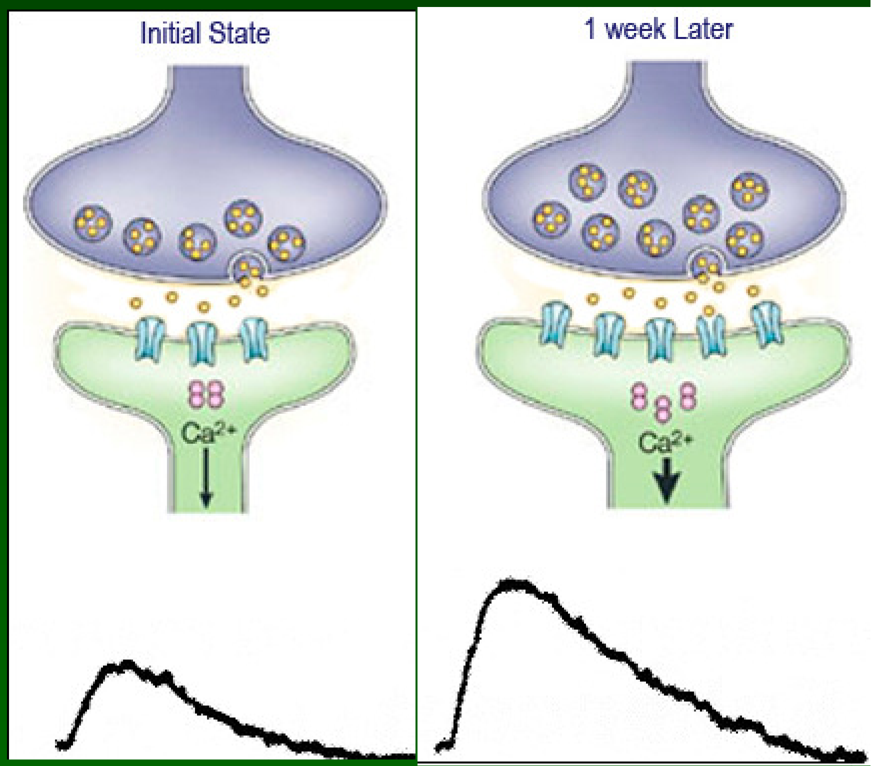
Hebbian learning in primary cortex

- Nagasena-Meander dialogue (100 BC): if it were to rain again, where will this *rain water flow*? It will *flow* in the *same* way as the first water had gone. Electrical current in the brain flows the same way (W. James, 1890).
- Donald Hebb (1949): Neurons the fire together, wire together.
- Biological mechanism: synaptic plasticity, or Long Term Potentiation (LTP) and Long Term Depression (LTD).

Synchronous stimulation enhances signal transmission between neurons, lasting from minutes to month.

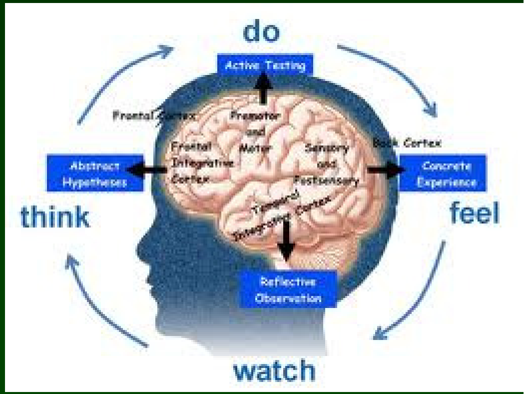
Associativity and cooperativity: weak stimulation of several pathways increases LTP effect; strong simulation of one increases other path stimulated weakly.

Memory formation (but only spatial memory demonstrated), role in addiction.



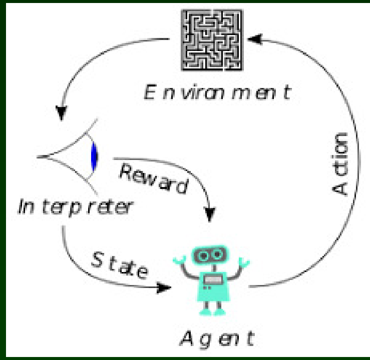
Why to learn a model?

Expectations based on previous experience can simplify adaptation to a new situation.
Example: it's easier to learn a new video game if you've already played other video games and when the designers keep similar game elements.

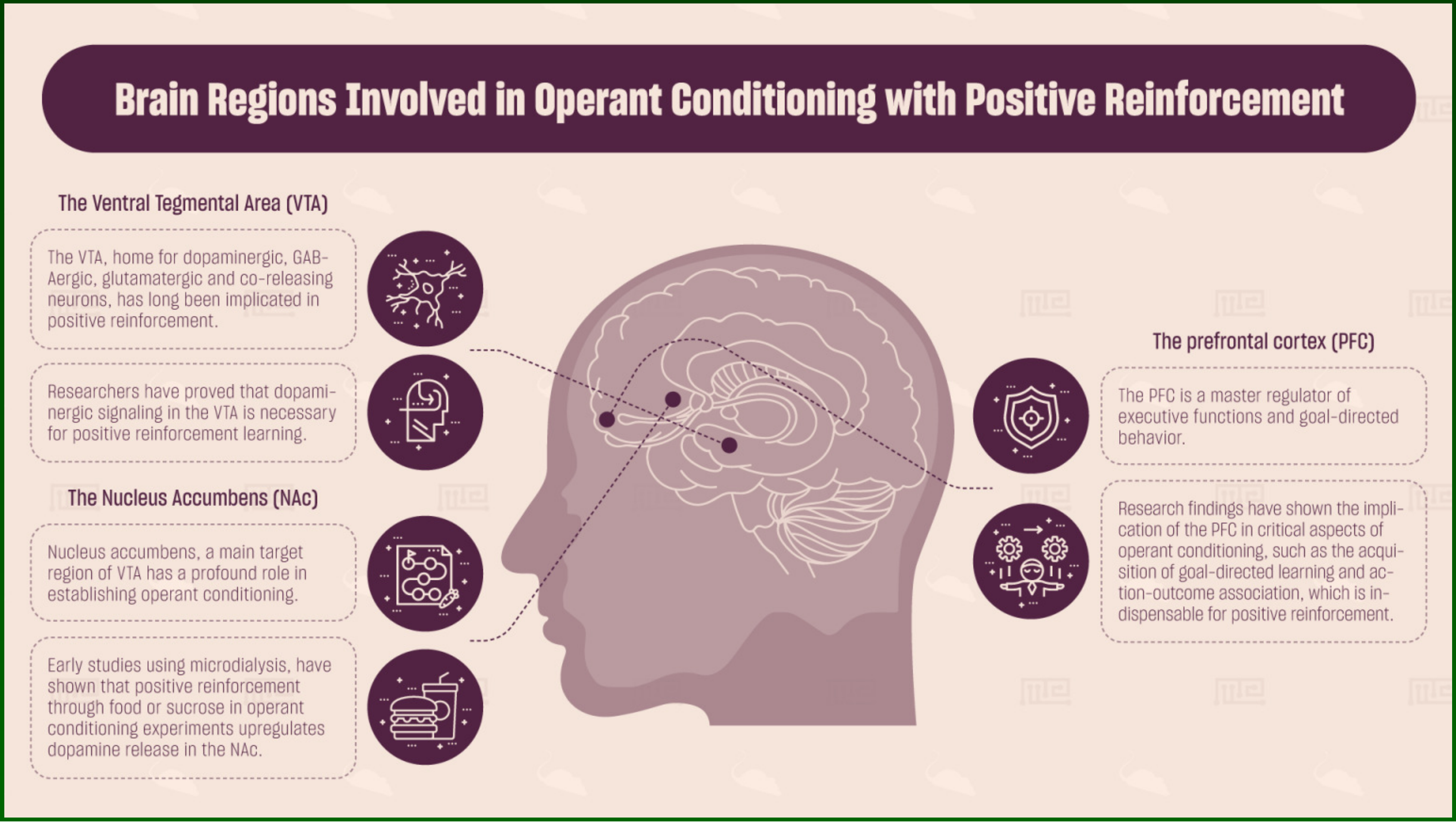


- Parametric models in science and in statistics work better than universal.
- Nativists (psychologists who stress genetic influences on behavior) assume that people are born with specified knowledge about the world.
- Rough genetic plan of brain connectivity constitutes primary behavioral repertoire: breathe, suck, move, open eyes, cry, smile …
- Genes cannot code precisely all information in the brain but can prepare brains to learn in variable environmental niche for each species, so some form of “neural Darwinism” (G. Edelman, 1978) is possible.
- Experience (bias) can also be a negative factor, limiting recognition of the need for a new approach when old solutions fail in changing environment.

Goal directed learning

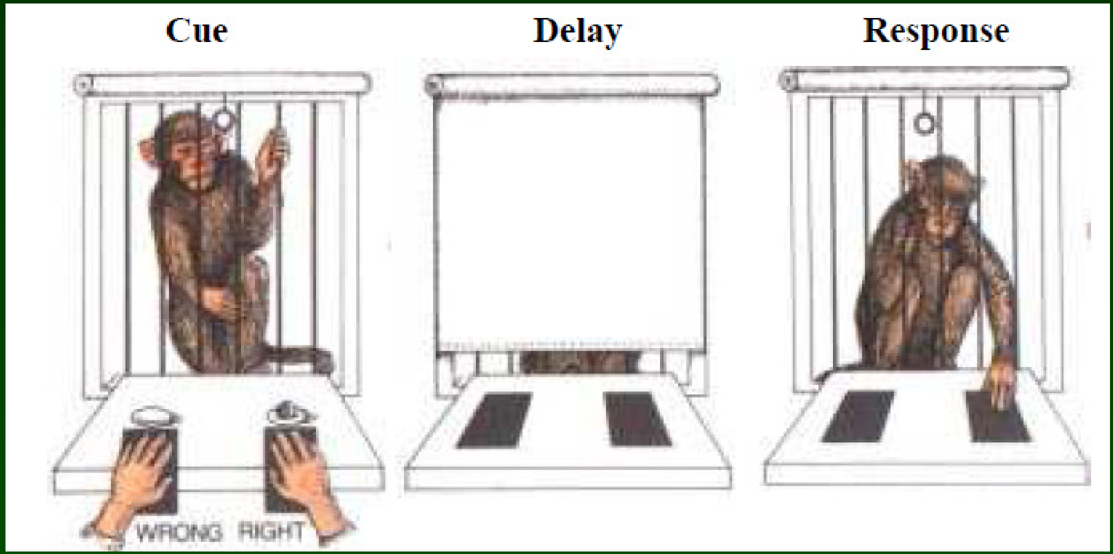


Hebbian correlation learning is good for learning features that can be used in categorization of stimuli that are frequently experienced: edges, textures, colors, sounds, tastes, smells.
Goal-directed cognition requires memory of the value of the outcome.



PFC functions

Working memory, dynamic activation that dose not dissipate.



Experiments with the delayed pattern matching.

PFC maintains information for a certain period of time by activating "working memory", this makes it possible to return to performed tasks despite the need to perform other actions, monitor errors, coordinate targeted actions, plans, generate a variety of actions.

PFC mechanisms

Dynamic working memory: PFC neurons maintain their activation allowing several functions to be performed simultaneously.

Monitoring/evaluating the results of actions, is coupled to the dopaminergic reward mechanism.

It seems that it is this information that becomes conscious, as evaluations must be available to all areas of the brain to influence correction processes.

Unconsciously teaching complex behavior through biological means based on reward and punishment mechanisms is not possible.

Consciousness must arise in any dynamic system whose physical states are subject to internal evaluation.

Building conscious robots is only a matter of time.

Automatic/Controlled actions

Dynamic working memory: PFC neurons maintain their activation, allowing several functions to be performed simultaneously, enabling multitasking.