How the brain develops: A new way to shed light on cognition

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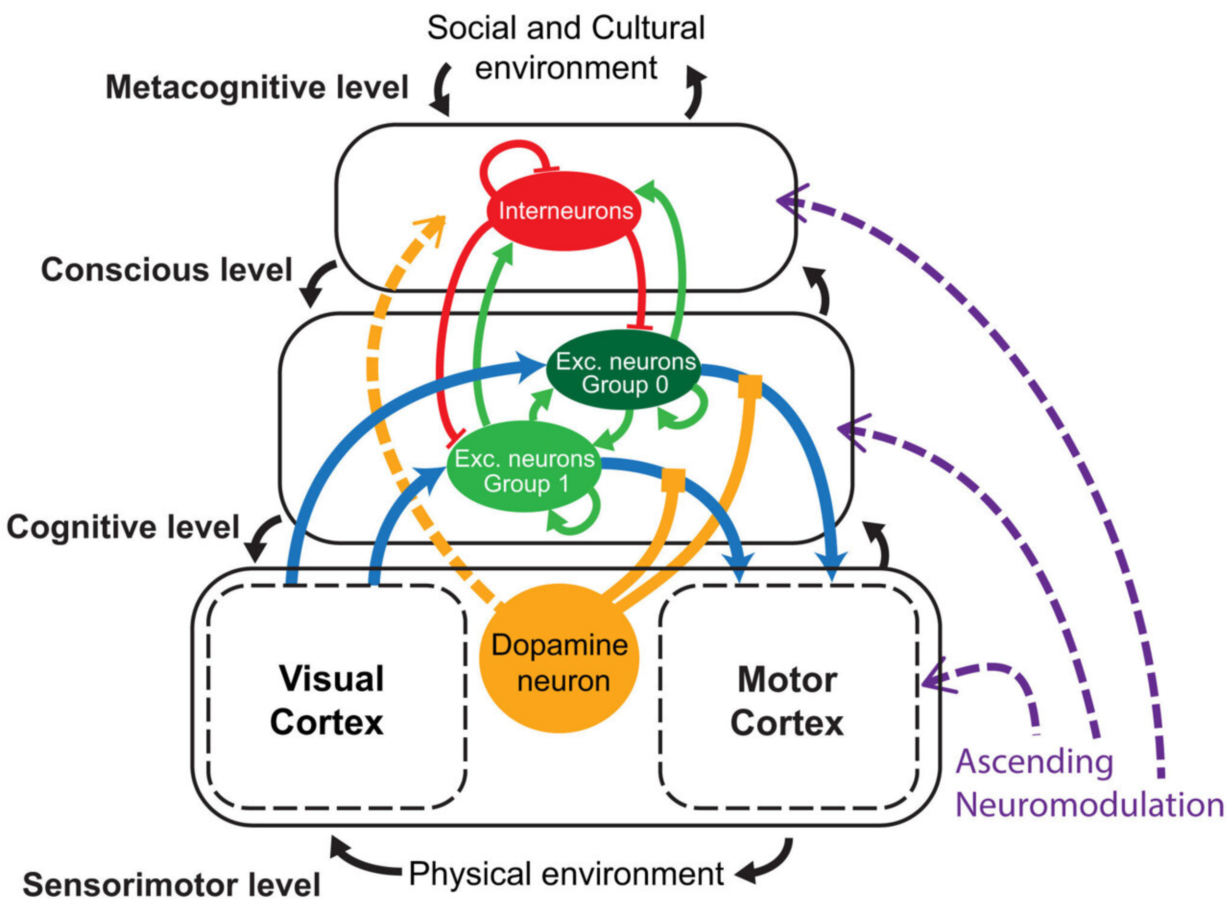

The full network architecture comprises sensorimotor, cognitive, conscious, and metacognitive levels. This is a schematic representation of the full network and its components. Colors of arrows depict different types of connections: light blue, excitatory long ranged (fixed: between VC and GNW; STDP: between GNW and motor cortex - MC); red, inhibitory (STDP); green, excitatory (STDP); yellow, extracellular dopamine modulation (affects dopamine modulated STDP). This version of the model is used to perform the trace conditioning task on the conscious level. To use the model with the delay conditioning task we do not introduce the interneurons population on the cognitive level. Credit: *Proceedings of the National Academy of Sciences* (2022). DOI: 10.1073/pnas.2201304119

A new study introduces a new neurocomputational model of the human brain that could shed light on how the brain develops complex cognitive abilities and advance neural artificial intelligence research. Published Sept. 19, the study was carried out by an international group of researchers from the Institut Pasteur and Sorbonne Université in Paris, the CHU Sainte-Justine, Mila—Quebec Artificial Intelligence Institute, and Université de Montréal.

The model, which made the cover of the journal *Proceedings of the National Academy of Sciences* (*PNAS*), describes neural development over three hierarchical levels of information processing:

- the first sensorimotor level explores how the brain's inner activity learns patterns from perception and associates them with action;
- the cognitive level examines how the brain contextually combines those patterns;
- lastly, the conscious level considers how the brain dissociates from the outside world and manipulates learned patterns (via memory) no longer accessible to perception.

The team's research gives clues into the core mechanisms underlying cognition thanks to the model's focus on the interplay between two fundamental types of learning: Hebbian learning, which is associated with statistical regularity (i.e., repetition)—or as neuropsychologist Donald Hebb has put it, "neurons that fire together, wire together"—and reinforcement learning, associated with reward and the dopamine neurotransmitter.

The model solves three tasks of increasing complexity across those levels, from visual recognition to cognitive manipulation of conscious percepts. Each time, the team introduced a new core mechanism to enable it to progress.

The results highlight two fundamental mechanisms for the multilevel development of cognitive abilities in biological neural networks:

- synaptic epigenesis, with Hebbian learning at the local scale and reinforcement learning at the global scale;
- and self-organized dynamics, through spontaneous activity and balanced excitatory/inhibitory ratio of neurons.

"Our model demonstrates how the neuro-AI convergence highlights biological mechanisms and cognitive architectures that can fuel the development of the next generation of artificial intelligence and even ultimately lead to artificial consciousness," said team member Guillaume Dumas, an assistant professor of computational psychiatry at UdeM, and a principal investigator at the CHU Sainte-Justine Research Centre.

Reaching this milestone may require integrating the social dimension of cognition, he added. The researchers are now looking at integrating biological and social dimensions at play in human cognition. The team has already pioneered the first simulation of two whole brains in interaction (published in *PLoS ONE* in 2012).

Anchoring future computational models in biological and social realities will not only continue to shed light on the core mechanisms underlying cognition, the team believes, but will also help provide a unique bridge to artificial intelligence towards the only known system with advanced social consciousness: the human brain.

More information: Konstantin Volzhenin et al, Multilevel development of cognitive abilities in an artificial neural network, *Proceedings of the National Academy of Sciences* (2022). DOI: 10.1073/pnas.2201304119

Guillaume Dumas et al, Anatomical Connectivity Influences both Intra- and Inter-Brain Synchronizations, *PLoS ONE* (2012). DOI: 10.1371/journal.pone.0036414

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