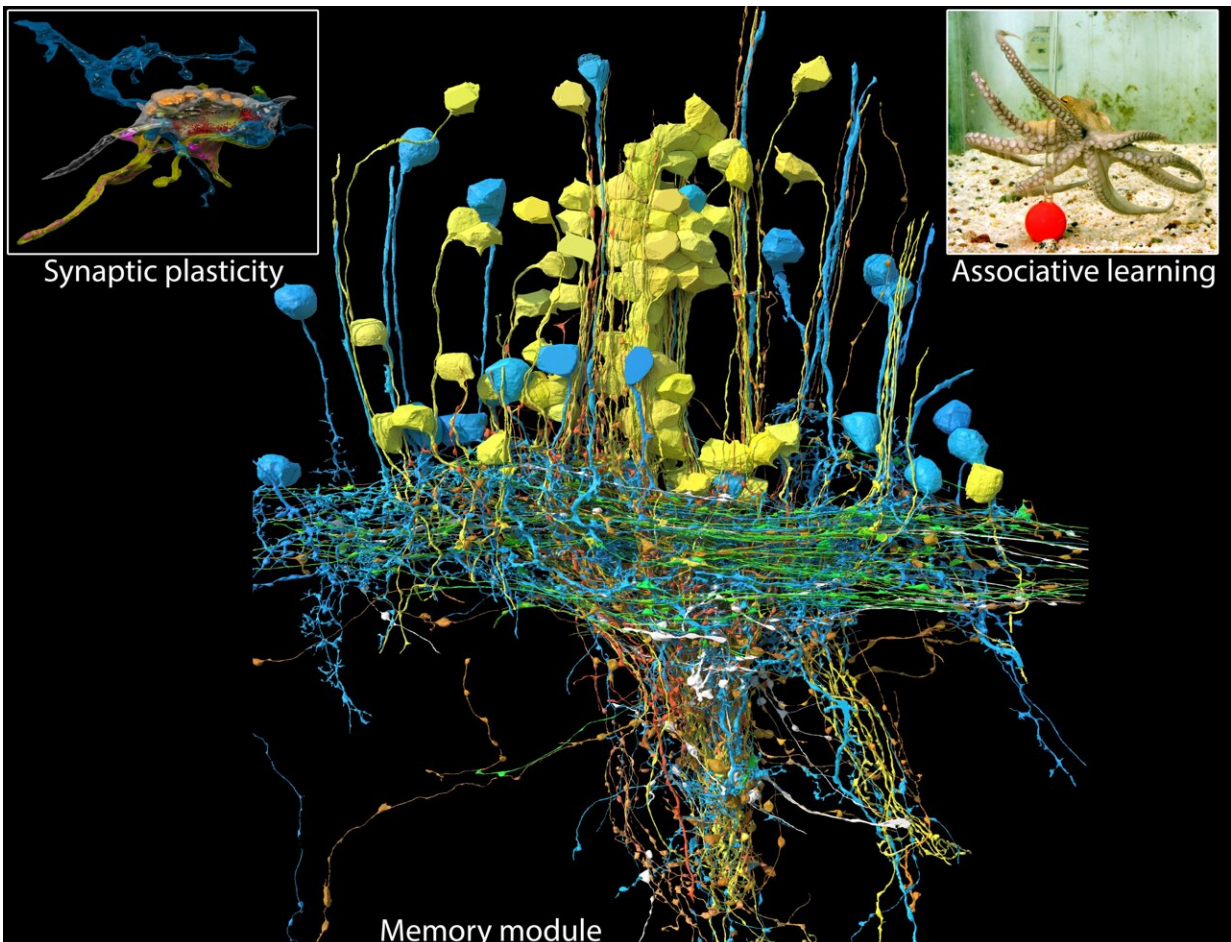# Unlocking mysteries of octopus cognition: Paving the way for memory research

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The neural network where the octopus learns not to attack the red ball. Credit: Hebrew University, Harvard University

New study by Prof. Benny Hochner from the Alexander Silberman Institute of Life Sciences at The Hebrew University and Prof. Jeff Lichtman from Harvard University has unveiled the intricate neural architecture governing the enigmatic learning processes of Octopus vulgaris.

This research introduces a promising model for delving into [memory](#) networks, with implications for both cephalopods cognition, considered the most intelligent invertebrates, and broader insights into memory processes, including those in humans. The findings are published in the journal *eLife*.

The octopus, separated from us by 700 million years of evolution, showcases [cognitive abilities](#) rivaling higher vertebrates. Prof. Hochner's team at Hebrew University focused on the octopus's central nervous system's vertical lobe, crucial for learning and memory. They aimed to compare [neural networks](#) and mechanisms across species.

Collaboration with Prof. Jeff Lichtman's laboratory at Harvard University, leveraged innovative automated tissue preparation and new machine learning reconstruction algorithms. This cutting-edge technology enabled the cutting and sorting of ultra-thin sections, each a mere 30 millionths of a millimeter thick, constructing a three-dimensional representation of the structural elements comprising the network.

Prof. Hochner remarked, "Our previous studies revealed a fascinating phenomenon of long-term synaptic strengthening (Long-Term Potentiation—LTP) even within the vertical lobe of the octopus. This phenomenon, recognized as a universal synaptic process essential for learning and memory, caught our attention."

"We meticulously charted the connectivity of the vertical lobe using the

precision of an electron microscope, achieving a resolution on the order of about 4 millionths of a millimeter. Together with Prof. Jeff Lichtman's team at Harvard University, we engineered a robotic system alongside a sophisticated computational algorithm, uniquely capable of organizing hundreds of ultra-thin sections (each only 30 millionths of a millimeter thick) into a comprehensive 3D structure. This innovative approach enabled us to trace the connectome—namely the intricate synaptic connections among the neural elements composing the network."

Under the leadership of postdoctoral researchers Dr. Flavie Bidel from Hebrew University and Dr. Yaron Meirovitch from Harvard University, a minute tissue volume representing the vertical lobe was meticulously reconstructed to unveil the connectome. Through the application of advanced machine learning algorithms and precise annotation, the researchers charted the wiring of the vertical lobe within octopus brains.

This challenged established notions of neural network functionality in the context of learning and memory. Unlike typical models, the vertical lobe's network operates in a feed-forward configuration, like a one-way street, with information only from the input neurons to output neurons that control octopus behavior.

Central to this simplicity is the organizational structure of approximately 25 million interneurons, divided into two distinct groups: simple [amacrine cells](link) (SAMs) and complex amacrine cells (CAMs). The SAMs, numbering around 23 million, specialize in learning visual characteristics through synaptic reinforcement. In contrast, the CAMs, totaling approximately 400,000, play a pivotal role in consolidating activity levels.

The two types of cells send their axonal branches to connect with bigger cells in the output layer. Simple cells, that transmit "learned"

information, make the big cells active, while complex cells make them less active, controlling how the brain works efficiently.

This evolutionary adaptation underscores the octopus's unique cognitive prowess, contributing to our understanding of neural mechanisms important for cognitive functions. The research reveals Octopus vulgaris as an invaluable model organism for in-depth exploration of memory acquisition networks and opens doors to further unraveling the intricacies of cephalopod cognitive processes, enriching our understanding of memory across various species.

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