Computer model helps make sense of human memory

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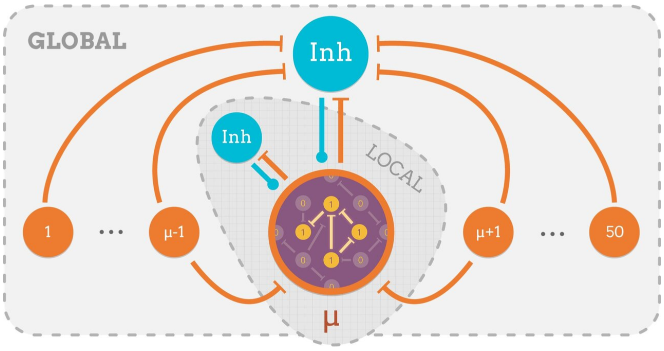

An excitatory circuit, μ, comprises a pattern of neurons that are firing (1) or not (0). Local and global inhibitory circuits acted on the excitatory circuit, allowing the circuit to remember a pattern for longer. This artificial network represents memory processes taking place in the hippocampus. Credit: Okinawa Institute of Science and Technology

Brains are a mazy network of overlapping circuits—some pathways encourage activity while others suppress it. While earlier studies focused more on excitatory circuits, inhibitory circuits are now understood to play an equally important role in brain function. Researchers at the Okinawa Institute of Science and Technology Graduate University (OIST) and the RIKEN Center for Brain Science have created an artificial network to simulate the brain, demonstrating that tinkering with inhibitory circuits leads to extended memory.

Associative memory is the ability to connect unrelated items and store them in memory—to associate co-occurring items as a single episode. In this study, published in *Physical Review Letters*, the team used sequentially arranged patterns to simulate a memory, and found that a computer is able to remember patterns spanning a longer episode when the model takes inhibitory circuits into account. They go on to explain how this finding could be applied to explain our own brains.

"This simple model of processing shows us how the brain handles the pieces of information given in a serial order," explains Professor Tomoki Fukai, head of OIST's Neural Coding and Brain Computing Unit, who led the study with RIKEN collaborator Dr. Tatsuya Haga. "By modelling neurons using computers, we can begin to understand memory processing in our own minds."

Lower Your Inhibitions

Thinking about the brain in terms of physical, non-biological phenomena is now a widely accepted approach in neuroscience—and many ideas lifted from physics have now been validated in animal studies. One such idea is understanding the brain's memory system as an attractor network, a group of connected nodes that display patterns of activity and tend towards certain states. This idea of attractor networks formed the basis of this study.

A tenet of neurobiology is that "cells that fire together wire together"—neurons that are active at the same time become synchronized, which partly explains how our brains change over time. In their model, the team created excitatory circuits—patterns of neurons firing together—to replicate the brain. The model included many excitatory circuits spread across a network.

More importantly, the team inserted inhibitory circuits into the model. Different inhibitory circuits act locally on a particular circuit, or globally across the network. The circuits block unwanted signals from interfering with the excitatory circuits, which are then better able to fire and wire together. These inhibitory circuits allowed the excitatory circuits to remember a pattern representing a longer episode.

The finding matches what is currently known about the hippocampus, a brain region involved in associative memory. It is thought that a balance of excitatory and inhibitory activity is what allows new associations to form. Inhibitory activity could be regulated by a chemical called acetylcholine, which is known to play a role in memory within the hippocampus. This model is a digital representation of these processes.

A challenge to the approach, however, is the use of random sampling. The sheer number of possible outputs, or attractor states, in the network, overworks a computer's memory capacity. The team instead had to rely on a selection of outputs, rather than a systematic review of every possible combination. This allowed them to overcome a technical difficulty without jeopardizing the model's predictions.

Overall, the study allowed for overarching inferences—inhibitory neurons have an important role in associative memory, and this maps to what we might expect in our own brains. Fukai says that biological studies will need to be completed to determine the exact validity of this computational work. Then, it will be possible to map the components of the simulation to their biological counterparts, building a more complete picture of the hippocampus and associative memory.

The team will next move beyond a simple model toward one with additional parameters that better represents the hippocampus, and look at the relative importance of local and global inhibitory circuits. The current model comprises neurons that are either off or on—zeros and ones. A future model will include dendrites, the branches that connect neurons in a complicated mesh. This more realistic simulation will be even better placed to make conclusions about biological brains.

More information: Tatsuya Haga et al. Extended Temporal Association Memory by Modulations of Inhibitory Circuits, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.078101