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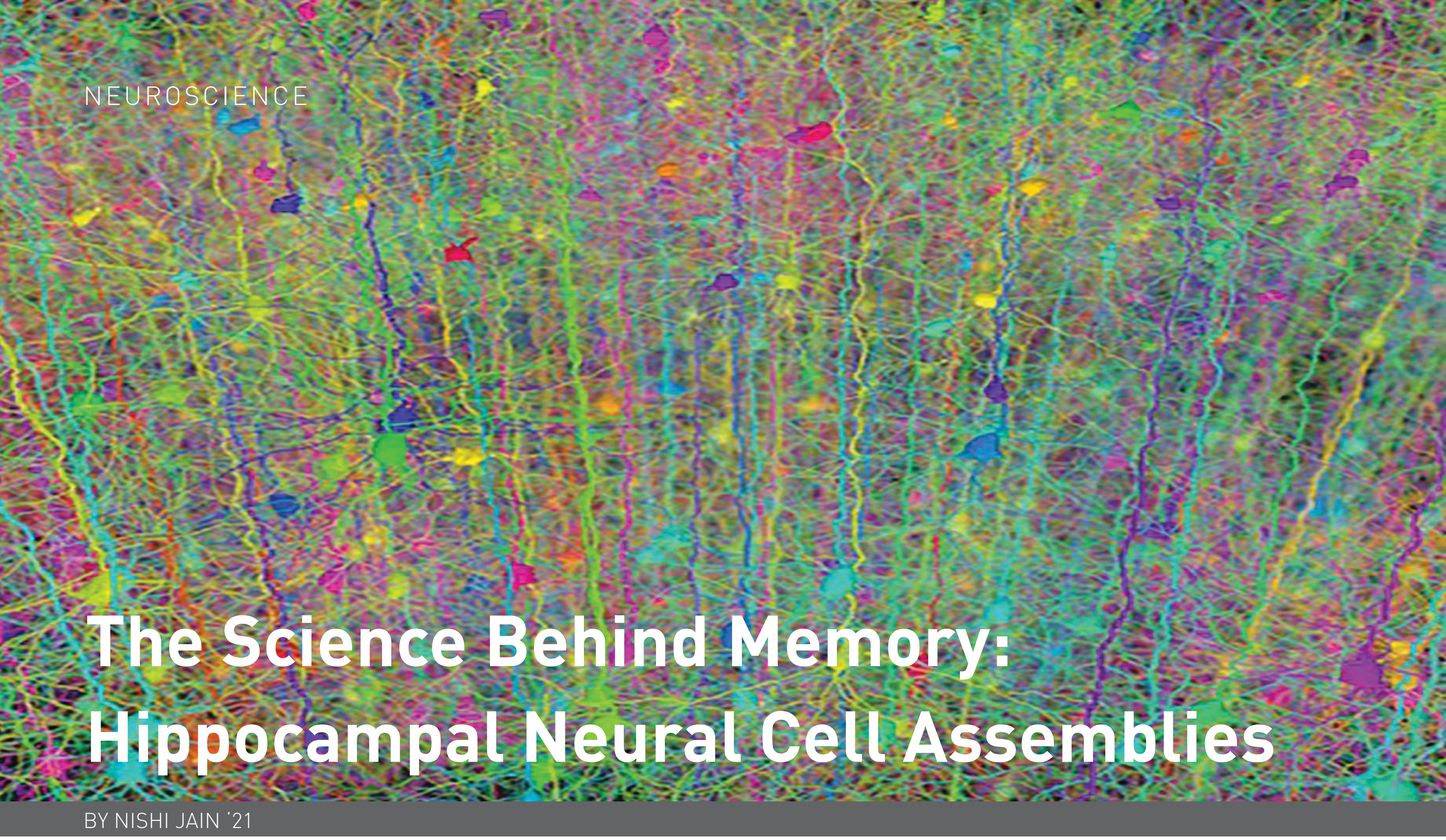

The Science Behind Memory: Hippocampal Neural Cell Assemblies

BY NISHI JAIN '21

Figure 1: This image depicts one of many neural networks.

Source: Wikimedia Commons (Credit: Hermann Cuntz)

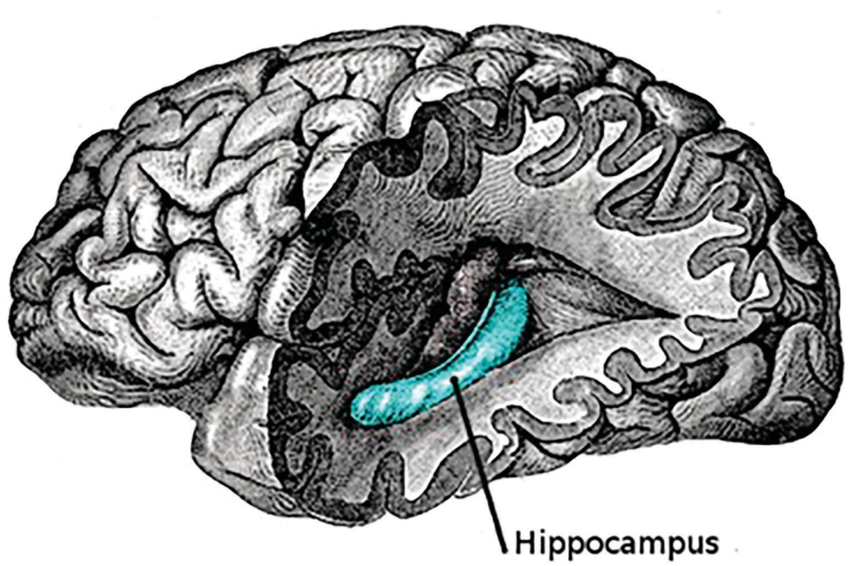

Figure 2: The hippocampus is located under the cerebral cortex and in the medial temporal lobe.

Source: Wikimedia Commons (Credit: Henry VanDyke Carter)

Theories Behind Cell Assemblies

The hippocampus, located under the cerebral cortex and in the medial temporal lobe, is known to play a quintessential role in the acquisition and consolidation of our memories (Shirvalkar, P. R., 2008). Through the twentieth century, there was significant debate regarding the nature of this acquisition and memory consolidation in the hippocampal region of the brain; this debate eventually lent itself to two distinct schools of thought—the single neuron coding hypothesis and population coding hypothesis (Barlow, 1972).

The single neuron coding hypothesis—discussing the idea that behavior and memory is individually coded in specific neurons—was later overlooked in favor of the latter, the population coding hypothesis. The population coding hypothesis looked at neurons not individually, but rather as groups of neurons, and used the theory of "cell assemblies" as its basis (Hebb, 1949). Cell assemblies was proposed to be subnetwork of cells within the larger structure of the network connections by Canadian psychologist Donald Hebb; in later years his work was applied to the aforementioned study of the hippocampal implications of the population coding hypothesis (Palm 1982).

It was theorized that there is primarily one set of active neurons that is involved in the recall of many different memories, along with the idea that one cell assembly can overlap with other cell assemblies—leading to the idea that one neuron can be a part of multiple assemblies with multiple functions (Palm 1982). This theory was cemented with a study done by Dr. Yoshio Sakurai, one of the leading researchers in the Department of Psychology at the Toyoma Medical and Pharmaceutical University in Japan, who showed that the pairs of task-related hippocampal neurons showed correlation through mutual coactivation and overlapping in common tasks (Sakurai, 1996).

Thus, the general consensus was formed that the acquisition and the memory consolidation in the hippocampal region of the brain was not based on the single neuron doctrine, as previously proposed, but rather in the population-coding hypothesis that proposed a more group based function for neurons involved in memory.

Breaking it Down: Neural Cell Assemblies

In the decades following Sakurai's study, significant research was done into the nature of these neural assemblies as they pertained to the development and recollection of episodic memories, or our personal events and experiences. Investigation into the nature of these neural assemblies helped determine that the sequential activation of neurons may be the key to understanding the conscious retrieval of episodic memories (Gelbard-Sagiv et al. 2008, Pastalkova et al. 2008). Episodic memories are based upon three individual things: 1) the spatiotemporal organization of episodic memories in hippocampal region of the brain, 2) multiple representations of past associations in the form of different modes or occurrences of the particular event subject to recall, and 3) the binding of multiple perceptions or incidences of the memory into one constructed memory (Eichenbaum 2004).

On an electrophysical level this was proven through the observation that the hippocampal neurons active during the acquisition of the memories were then reactivated during the free recall of the experiences, part of the consolidation of the memory (Gelbard-Sagiv et al. 2008). Providing more detail to this hypothesis was the development that sequential activity of hippocampal neurons in the recollection of episodic memory can be generated freely, or without the presence of an external input or stimulus (Pastalkova et al. 2008). Collectively, these concepts formed a probable theory for the recall of individual episodic memories—that they were based on free activation of one of a series of neurons that were in an assembly.

Expanding on Sequential Activation: The Implications of Neural Networks

A neural cell assembly can be thought of as a coalition of network nodes that correspond to episodic memories. Hippocampal neural nodes and networks are then arranged in groups, and as per the "cell assembly" theory, the activation of one of these neurons can increase the predictability of other neurons in the network or group significantly (Harris et al. 2003). Furthermore, networks that support similarly related memories share common nodes that code for common elements among multiple memories—thus showing that one neuron can participate in multiple assemblies. This plays into the aforementioned theory regarding the free recollection of an episodic memory—since there are common nodes that connect multiple memories within a network, the neural network can be internally reassembled, with many different activation points (Shirvalkar, P. R., 2008).

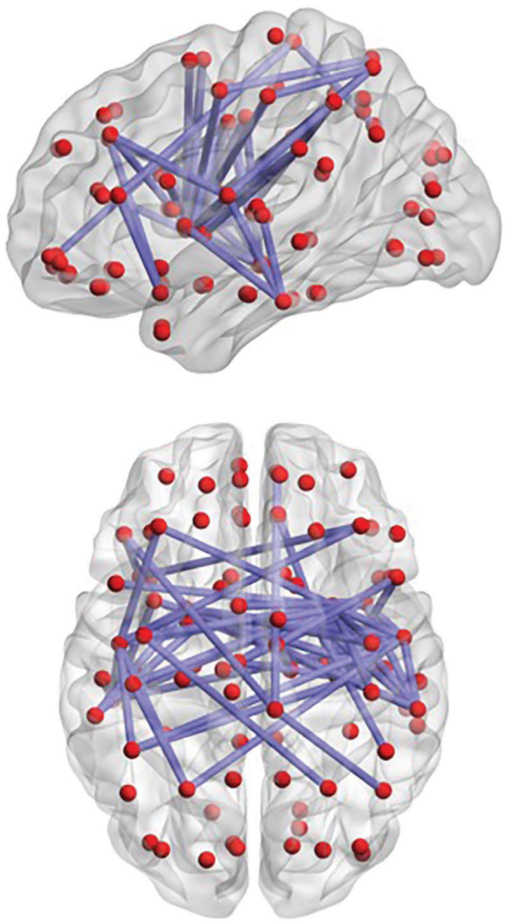

Figure 3: An example of a neural network in the brain.

Source: Wikimedia Commons (Credit: Soon-Beom Hong)

In addition, another hypothesis has arisen regarding the nature of neural activation. With the common understanding that neurons have similar activation patterns during the acquisition as the recollection of episodic memories, it is possible that following the activation of one of the nodes, that the subjective recall of one of the episodic memories activates the same coalition of neurons that was activated during the first acquisition of the memory and thus the same network and the same neural assembly is activated during the stimulus-free recollection of the memory (Gelbard-Sagiv et al. 2008). This theory is consistent with the Hebbian network assembly, which discussed the idea that the repeated recollection of episodic memories depends on repeated activation of neurons in the assembly. (Hebb 1949).

Alongside this, a theory emerged regarding the prominence of individual neural networks and assembly in the transition between thoughts

"Since there are common nodes that connect multiple memories within a network, the neural network can be internally reassembled, with many different activation points. "

into conscious awareness and episodic memory recollection. Inevitably, there are multiple different neural networks and assemblies that characterize our episodic memories; but one specific theory, known as Neuronal Group Selection, looks at each experience that could code for an episodic memory as supported by a singular core of active neurons. This core of active neurons is chosen through a process that is none too different from Darwinian evolution—the larger group evolves through varied experiences and is narrowed down to the core through environmental stimuli and interactions (Edelman 2004). Similarly, another theory looked at the elements of consciousness as a singular coalition of neurons in "high level" areas of the brain, one of them being the hippocampal region, that operates as the primary core of activity (Shirvalkar, P. R. 2008).

Short Term vs. Long Term Memory

On the personal level, long term memory can be viewed as similar to short term memory, except potentially with less clarity and with the experience happening typically a longer time ago. Speaking on a neurobiological level, the experience of the brain in the development and recollection of episodic memories is similar as well. In the hippocampus, this can happen in one of two ways: 1) the hippocampus may choose to preserve the mapping neural network that coded for the experience exactly as it was initially erected when the memory was acquired, or 2) it could change the initial mapping of the neural network by internally restructuring the network by assigning new network paths and mappings to the neurons that have been largely unused and previously coded for other episodic memories and events (Debiec et al. 2002). Though further research is to be conducted on this topic, there is a relative consensus that the latter is more prominent due to the fact that it allows a much larger capacity for long term and short term episodic memories (Shirvalkar, P. R., 2008).

An Alternative Theory: Goal Representation in Task-Related Recollection

Though the discussion up until this point has been largely focused on the concept of episodic memory recollection, it is important to note that there is a large discussion on the

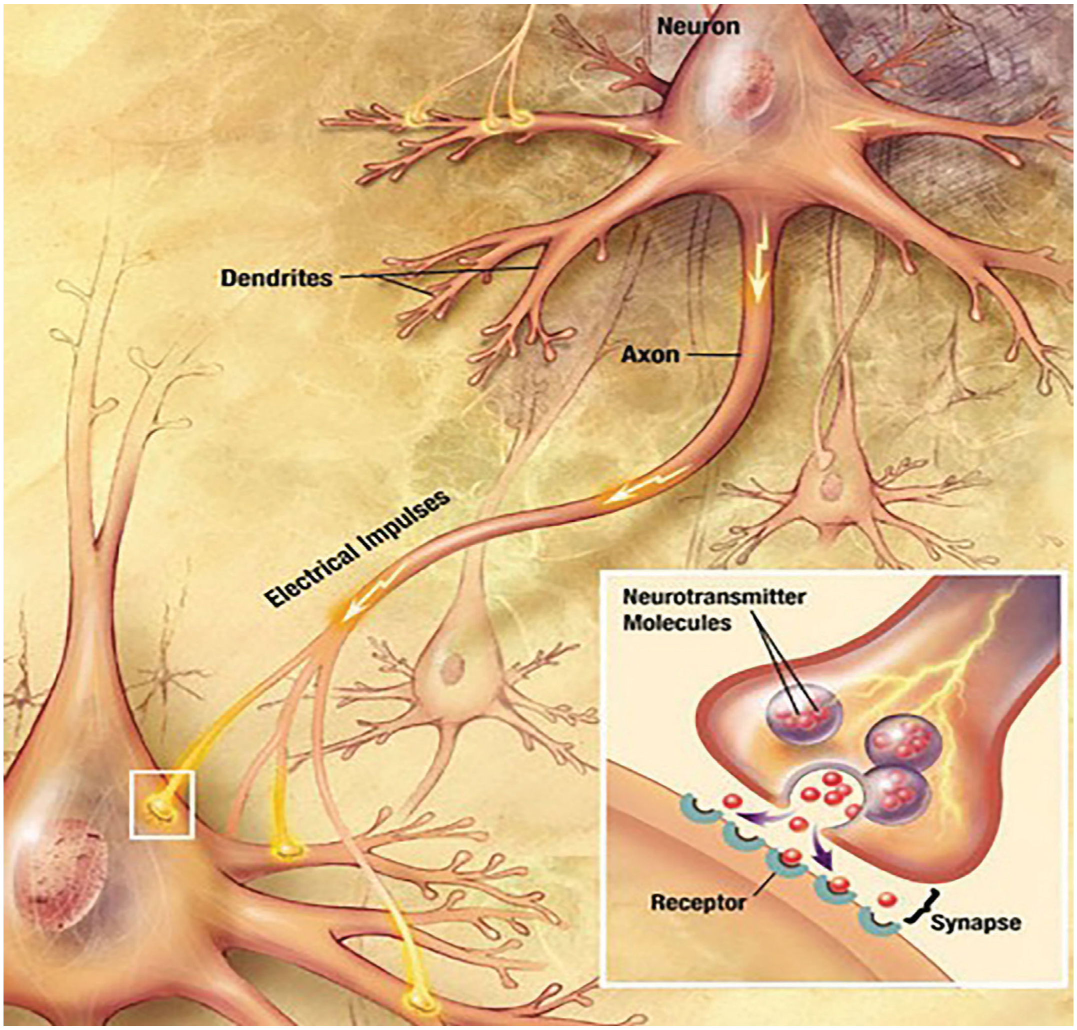

Figure 4: An example of neural coding and electrical impulses being sent between neurons.

Source: Wikimedia Commons

implications of neural assemblies on task-related recollection and behavior. There are two different schools of thought regarding the action-related application of neural networks, one of which states that neurons can be "time-encoding," or that neurons may be used primarily for the basis of the chronological order of the memory. This theory was constructed from the prior discussion of the sequential nature of the activation of hippocampal neurons in a neural assembly—something that is applied not only to the recollection of episodic memories, but additionally to task-related memories (Okatan, 2010). This theory is taken alongside one that is largely more favored, the theory of goal representation, which essentially states neural codes at the end of neural assemblies are principally goal representations, and the neural assemblies to attain those serve as reward-predictive values (Okatan, 2010).

During the phase following the initial establishment of the memory, during the reinforcement learning phase, the hippocampal neurons in the assembly receive reward positive or reward negative inputs from the prefrontal goal representations, and then accordingly project that information to mediate the progression of the assembly (Okatan 2007a, Okatan 2007b). This progression suggests that the communication between the prefrontal cortex and the hippocampus as a result of the reward system causes different cell assemblies to be activated through the process of the reinforcement learning phase of potentially just one task, due to trips taken to different goals with positive and negative reward feedback given (Okatan, 2009).

This reward-based theory presents two distinct propositions. One, if presented with two different objects that have an associated task, then the hippocampal region of the brain can automatically begin activating the sequential neural assemblies that is associated with each task, and thus each item. Two, after choosing one of the two objects and following the activation of the neural assembly, the particular path that is rewarded the most through the course of the task is inevitably strengthened in the hippocampal region, and thus can win competitive interactions with other cells assemblies with the same goals—something that relates to the aforementioned Darwinian theory of the development of the primary neural network in episodic memory recollection (Kesner et al. 2005). This second proposition can then be taken a step farther in saying that the "winner" of the competitive interactions have object selectivity, and thus can influence upcoming responses to the same stimuli; or, in other words, the response to stimuli and the specific neural assembly that is used is managed by the magnitude of past rewards that resulted from past communication between the hippocampal and prefrontal cortex regions of the brain (MacDonald and Eichenbaum, 2009).

> "The theory of goal representation [...] essentially states neural codes at the end of neural assemblies are principally goal representations, and the neural assemblies to attain those serve as reward-predictive values."

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