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DECODING THE NEURAL CODING PROBLEM

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In every human is a philosopher that ponders the meaning of life. Modern neuroscience seeks to provide some insight to our existential anxiety by investigating the neural basis of consciousness: how do we, as human beings, consciously perceive the world around us? This inquiry frames what neuroscientists have termed the neural coding problem. The neural coding problem investigates how the brain codes and synthesizes information to regulate an organism's behavior.

Neural coding describes how neurons in our brain and nervous system process stimuli from the environment. Neurons communicate with each other using electrical signals, called action potentials, and chemical signals, called neurotransmitters. Dramatic spikes of electrical activity characterize action potentials, and these spikes can be analyzed to understand how an organism reacts to stimuli.[9] How an organism interprets and behaves in response to stimuli can change over time. Neuroplasticity is the way in which an organism's brain changes and adapts through experience, "to learn and remember patterns in the sensory world, to refine movements, to predict and obtain reward, and to recover function after injury." Regions of the brain, like the neocortex, are centers for the assimilation of information in regards to learning.[4]

Scientists today have a variety of tools to analyze neural activity in the brain. Two of the most important methods are electrode-based techniques and functional brain imaging. Electrode-based techniques use microelectrodes to measure spikes of activity, or action potentials, in one or a few neurons at a time. An analysis of this activity determines how a neuron is tuned—how it responds to a specific stimulus—emphasizing the encoding aspect of sensation. Unlike electrode-based techniques, functional brain imaging does not require the insertion of microelectrodes into the brain and instead uses advanced technology to perform scans of the brain. Experiments typically utilize functional brain imaging to indirectly examine the activity of thousands or billions of neurons by measuring changes in blood flow.[9] Because the human nervous system is very complicated, scientists study simple organisms like the fruit fly and the rodent to understand the fundamental ways in which neurons function and to test the limits of our knowledge about this phenomenon.

Experiments with rodents illustrate the precise nature of sensory processing. For example, rodents have evolved to detect texture and roughness by analyzing the friction their whiskers feel as the whiskers drag and slip upon contact with a surface.

"These higher-level brain processes come closer to tracking our conscious thoughts—potentially allowing us to 'mind-read.'"

BY RECODING SPIKES, RESEARCHERS CAN TRACK HOW RODENTS CALCULATE FRICTION.

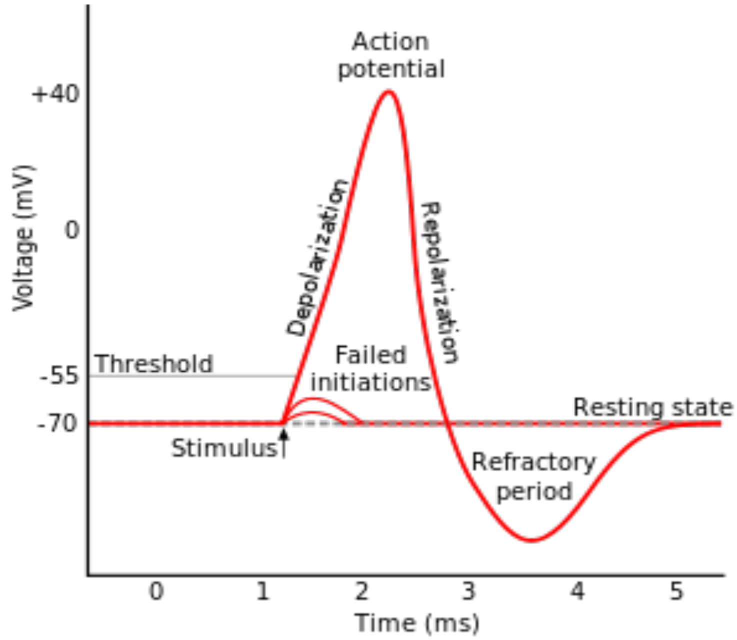


FIgure 1: A stimulus that induces electrical activity past a critical threshold launches an action potential. The peak on this graph represents an action potential as a single spike of electrical activity. Action potentials propagate across individual neurons, while neurotransmitters transmit these nerve impulses between neurons.

Rodents can use this detailed sensory information to carefully discriminate the texture of different surfaces.[8] As evidenced by even this relatively ordinary task, the nervous system is powerfully exact.

Studies of the fruit fly *Drosophila* demonstrate that such precise sensory information is used for elaborate decision-making. In order to navigate flight, *Drosophila* collects information about its surroundings using visual sensory processing. The fly also keeps track of its own motion and position in space. These cues are somehow consolidated in the brain in order to allow for decision-making about the course of its flight.[10] Though scientists can track neural responses to these stimuli, exactly how different types of information are integrated within the mind of an organism is unknown. The organization of sensory data is broadly explained by the property of neuroplasticity: the fruit fly uses neuroplasticity to make order of the overwhelming amount of sensory and motor information that it experiences during flight. The fly's decision-making process uses patterns of information to learn and respond accordingly.

The diverse ways in which organisms like humans and *Drosophila* react to the same stimuli establish scientific grounds for the subjectivity of life experience. For instance, neuroplasticity enables gustation through "taste coding." *Drosophila* organizes sensory information into different channels that are in some way desegregated to develop learned associations for particular taste molecules.[7] Research regarding gustation in *Drosophila* has also revealed that these fruit flies can taste water.[3] Interestingly, humans do not have the gustatory sensors to taste water. Because organisms have distinct ways of understanding the same stimuli, how they experience the environment also varies drastically.

The unique experiences of pain and itch also involve neuroplasticity. Whether itch and pain have separate pathways is still debated, though it is understood that both experiences are interconnected. Both pain and itch can be transient (acute) or chronic. Acute pain is usually a protective reflex in response to life-threatening conditions, while acute itch can be stimulated by a variety of sensations, including pain.[1,2] These reflexes help organisms be aware of their surroundings. On the other hand, "chronic itch, like chronic pain, can occur without injury or disease, serves no apparent biological purpose and has no recognizable endpoint," according to an article by the scientific journal Cell.[2] Mechanisms of both acute and chronic pain or itch are facilitated by neuroplasticity, but only acute pain or itch is deemed particularly beneficial.[1] The nervous system may amplify signals like that of pain or itch to enhance perception of the original stimulus. Chronic pain and itch exemplify the limits of a neuron's ability to code information and productively make sense of the environment, suggesting that perception is extremely nuanced and, perhaps, slightly imperfect. The brain produces perception—every organism's perception of its environment is unique, and therefore, every organism's reality is subjective.

Using functional brain imaging, researchers have developed methods of detecting what a human brain visually perceives about an object and its action

> *"The brain produces perception—every organism's perception of its environment is unique, and therefore, every organism's reality is subjective."*

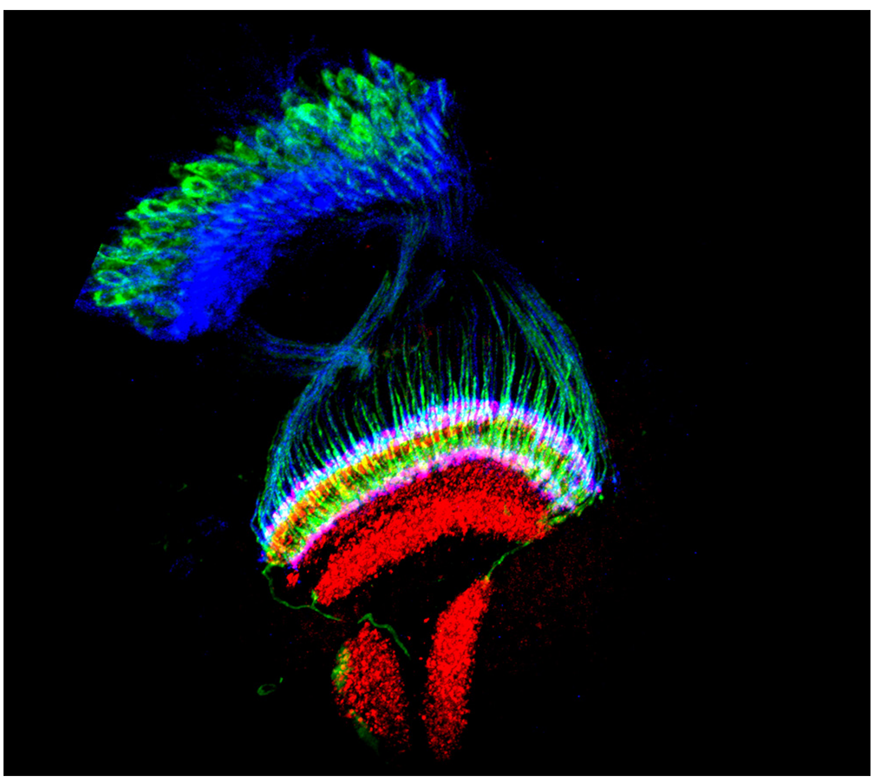
and the relationship between such objects.

DECODING THE BRAIN SHOWS HOW NEUROPLASTICITY WORKS THROUGH PATTERNS, OR IN THIS CASE, CATEGORIES.

Researchers can use this decoding technique to guess what movie a subject is watching. These higher-level brain processes come closer to tracking our conscious thoughts—potentially allowing us to 'mind-read.' For this reason, research in this field may be controversial: how will such techniques and technology be utilized if fully developed?

Scientists today certainly have a better understanding of encoding and decoding than in the past—when the brain was a complete mystery—but the middle ground of this exploration remains uncharted. How sensory information comes into awareness could very well explain consciousness. Whether humans will eventually conceive the complexity of their own consciousness is something that is left to be discovered, and how this knowledge could transform our existence is an even greater question.

Figure 2: An enhanced image of a section from the optic lobe of a *Drosophila* fruit fly.[11] A neural signal travels from the blue and green region at the top (photoreceptors in the eye that sense the stimulus) to the red region at the bottom (the brain). Neurons interpret a visual stimulus by communicating signals across the nervous system. In the brain, visual sensory information is integrated with motor information to facilitate the fly's decision-making process.



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