

Brain Representation

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Despite the current inability to thoroughly describe how organisms depict the internal and external stimuli they interact with, informed introspection establishes this phenomenon's existence and its critical role in all behavior. Self-evidently we possess knowledge structures, whether in the brain or the mind, that compose our conceptual framework of nouns and the verbs they perform. Although referred to differently throughout history, the perceptive-interpretive portion of this process is now called representation. The title of Churchland's seventh chapter in *Brain-Wise* is "How Do Brains Represent?" (2002, pp. 270-274). From these four words, the author establishes her position that brains are in the business of representing and hence outlines the chapters' intention to provide proof for this stance.

Notably, while the author believes a representational brain theory is likely to be correct, she also states that this theory is "provisional," as contemporary evidence at the time is insufficient for or against this claim. An uncertainty that, in her opinion, generates two questions. Is a biological embedded representative model necessary or sufficient for explaining an entity's interactions? Then if it is, how is this representation achieved? She also denotes two opposing camps tackling these questions, characterized by their proclivity to accept neuroscientific research: the brain-friendly and brain-adverse approaches. The following paper will address Churchland's brain-friendly approach regarding external representation, starting by analyzing the opening quote, then summarizing key neuroscientific evidence, such as rodent representational neuron types, primate equivalents, and the concept of vector coding, pairing each with new observations from recent literature.

This chapter begins with the quote, “We have to remember that what we observe is not nature herself but nature exposed to our method of questioning,” attributed to the theoretical physicist Werner Heisenberg. A quote that is currently understood to mean that everything, including humans, is part of the universe’s wavefunction. A claim supported by the theoretical physicist David Bohm through his saying, “If the quantum theory is to be able to provide a complete description of everything that can happen in the world... in principle, it ought to be able to describe the human investigator as he looks at the observing apparatus...” (Brown & Wallace, 2004). Before perception or its representation occurs, there is the world, which acts counterintuitively at the smallest measurable scales, and by recent accounts, constrains our perceptions due to a fundamental lack of understanding. A conundrum coined the measurement problem (Carroll, 2019, 19:00-20:02).

In a neoteric debate about this dilemma between theoretical physicist Sean Carroll and foundations of physics philosopher David Albert, the pair lay out the history and the platter of reputable explanatory theories (2019, 23:07-41:43). The debate’s crux is nicely summarized when Carroll, backing the Everettian many-worlds view, claims we simply do not feel like we exist in a state of superpositions, rebutted by Albert saying it is evident that we are not (2019, 20:02-22:22). No matter which stance ends up winning the day, the objective world and the brain’s electrical activity performing the representation both abide by the unsettled physical laws outlined by the standard model. Therefore, while neuroscience, particularly representation research for this paper’s context, shows acceleratory growth, a theory of brain representation will be incomplete until this prerequisite issue of what we represent is understood.

This underlying limitation aside, the author proposes two neuroethological studies correlating hippocampal neuron activation with organismal spatial perceptions, laying the representational brain theory groundwork (Churchland, 2002, pp. 275-279). The results of these two experiments performed nearly three decades apart are as follows. First, O'Keefe and Dostrovsky, in 1971 using in-vivo single-cell recording technologies, found that neurons referred to as place cells preferentially fired depending on the rodent's position in a figure-eight maze. Second, Packard and Teather in 1998 observed that rodents with a lesioned hippocampus, when placed in a novel arm of a T maze, fell back to a conditioned response strategy for finding a food reward, while the rats with intact brains showed adaptability in their navigation. Together, these experiments suggest that rodents do not merely operate via conditioned responses but instead have some form of neuronally correlated spatial mapping capabilities located within their hippocampus, a medial temporal lobe structure. This evidence alone was not enough to say that brains represent, but as there were in Churchland's words no other "plausible options" available at the time of writing, the representation assumption was considered the premiere theory.

Now jumping forward the two decades to the present, the rodent representational brain theory has become even more established as laboratory neuroethological research has put forward seven more representational neuron types and over twenty new brain regions considered to have a representative function (Grieves & Jeffery, 2017). This review reports the relevant literature of the last century, including Churchland's two cited rodent studies. However, the group's primary focus is on the breadth of novel research, introducing, alongside place cells, two now similarly established representational cell types, head-direction and grid cells. Single neuron electrophysiology investigations

suggest that head direction cells are a collection of neurons, each of which has a “preferred direction,” meaning they differentially fire depending on the head’s orientation relating to a landmark in 360-degree 2D space. Grid cells also evaluated using similar methodologies are neurons arranged in a triangular tessellated grid, which fire in synchronization and maintain a stable firing relationship even during external stimuli alterations, thought to be useful for understanding self-motion. Collectively, painting a picture that the process of rodent spatial representation is a product of many layers of type-specific representation utilizing many cell types.

Foreseeing the limitation that her primary brain-friendly evidence is species-specific, Churchland includes a section about primate representative capacity, in which she asserts the posterior parietal cortex as a representational hub but fails to make a direct connection between the cellular features underpinning the two species’ representational systems (2002, pp. 309-316). Interestingly, a more recent comparative review by Rolls and Wirth affirms Churchland’s parietal lobe interest, suggesting that this hub, in conjunction with a more developed fovea and temporal cortex, altogether associated with enhanced image processing, creates the existence of place cell equivalents in primates called view cells (2018). These structural differences turn rodents’ one-dimensional point representation into a two-dimensional representational tether between organism and object, facilitating a scene-like representation by similar hippocampal neurons in primates. A sentiment further supported by an include experiment evaluating the neuronal firing patterns of macaques exploring large-scale virtual mazes, in totality showing that individual cells in primate brains’ correlate with aspects of representation similar to the well-established rodent model.

Further adding to this already complex picture, Churchland also notes other qualities of neurons and collections of neurons that likely enable representation, such as “tuning,” “receptive fields,” and the likely capacity to “vector code” (2002, pp. 285-293). The last, vector coding, is touched on heavily as it aims to replace another paradigm, local coding. Although the author has a personal stake in this idea, this updated concept offers more explanatory power as its proposed redundancy and space-saving nature mesh with experimental observations and skull size constraints. The local coding paradigm suggests that cells only represent one thing, like a person’s face or the smell of fire. In contrast, the vector coding hypothesis suggests that the same face or smell generates a particular activity pattern (varying latency, collectivity, and amplitudes) across a cell population. Churchland includes a “face space cube” diagram to conceptualize vector coding, where the three axes represent facial characteristics like eye width and brow size. While this diagram is a cube for pictorial purposes, her actual conceptualization is that of a larger “vector/parameter-space,” which is the combination of thousands of perpendicular dimensions that could create nearly infinite representational capabilities with a limited number of cells.

Although the name vector coding has been reappropriated in recent spatial representational research to mean the allocentric/egocentric coding of vectors between objects or in an object’s direction, respectively, Churchland’s brain-friendly vector coding conceptualization has again survived (Bicanski & Burgess, 2020). There is now work showing that the in-vitro activation of distinct rodent hippocampal interneuron types will produce nine different quantitative firing patterns determined by response inequalities (Komendantov et al., 2019). The group further separates these nine into five transient

firing patterns, classified as the activity before steady-state activity and four steady-state patterns. Although this primary literature only evaluates the hippocampal neuronal firing pattern variability, it is likely consistent across other brain regions. Therefore, given this evidence about firing variety, the vector coding hypothesis is a feasible candidate for representation when paired alongside the historically established brain connectivity and neuron count.

In conclusion, representation is how organisms with brains might perceive and begin to interrupt the internal and external environment. Given the explosion of experimentally sound neuroscientific results, it appears to correlate strongly with brain activity. That said, there is still the unresolved measurement problem imposed by quantum mechanics, limiting our knowledge of how the world acts right at the beginning of representation. However, spatial representation research in rodents is paving the way forward by implicating many cell types and brain regions in this faculty, and translation of these findings into primate models is close to its heels. Alongside these findings of what stimulates individual neuronal activity, work in the firing patterns or “vector coding” lays another plank on the bridge between atomic structures and representational capability by explaining how complex information might transfer throughout the neural circuitry. Only time will tell whether the brain-friendly approach will offer a complete explanation of representation, but in the two decades since writing this book, Churchland appears to have been correct in fighting for the incorporation of neuroscience into the philosophical debate on if and how the brain represents.

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