Neither the Neuron nor the Synapse:

An Unsustainable Solution to a Big Problem

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Is the brain a mess of biological material? Do thoughts and other mental phenomena arise from this mess? If yes, what framework should we adopt to conceptualize this mess? What components should constitute this framework? Are the components once chosen by neuroscientists outdated by current research? Rosa Cao argues for a paradigm shift. Her reasoning is twofold: the synapse is a more apt functional unit than the neuron, which is an even less suitable functional unit than previously thought. This essay will summarize Cao's major points, offer qualifications, and argue that the oversimplification of the neuron within the synaptic functional unit framework uproots the support for the framework itself.

Before diving into Cao's criticisms of the neuron as the functional unit in favor of the synapse, I will introduce a definition of the functional unit. These definitions are Cao's, not my own, and will make up the givens which I will use to identify an instability within the synaptic functional unit framework (SFUF). In its naked form, the model is as follows: there exists senders, receivers, and signals; these signals represent some aspect of the external world; and when the receiver acts based on the signal received, both the sender and receiver benefit. It can be inferred that the most suitable functional unit is the one that satisfies these criteria the most completely and elegantly. My criticism of Cao's argument is built off one of the implications of this model.

An implicit stipulation to this this sender/receiver/signal model is that there is no other agent interfering with the signal between sender and receiver. For explanation's sake, it's helpful to imagine a medium between sender and receiver. This word medium is used in its most abstract sense—it does not have to refer to any physical correlate—rather, its existence is justified only by the possibility that the signal *could* be interfered with on its path from sender to receiver, and,

crucially, that this interference is *independent* of the actions of the sender and receiver. I will refer to a medium which interferes with a signal as a bad medium.

It will be useful to imagine these concepts as a concrete scenario. Imagine that a boy in suburbia is in love with the girl who lives five houses down from him. Every day, he places a love letter in her mailbox, but on some days the neighborhood troublemaker invades everyone's mailboxes. If the troublemaker sees the boy's love letter, he will erase certain sentences and add his own. These additions are unpredictable; sometimes they are even more pleasant than the original (the troublemaker is a gifted poet, after all), but other times, the troublemaker writes rude things which causes the girl to second guess her budding romance. In this analogy, the boy is the sender, the girl is the receiver, the letter is the signal, and the troublemaker is a bad medium. Note that the troublemaker does not always tamper with the letter, and sometimes his tampering even enhances the original sentiment of the sender. Regardless of the valence of the interference, tampering is tampering, and the troublemaker is a bad medium—these nuances will come into relevance shortly.

If a bad medium like the one described exists between functional units, then that calls into question the integrity of that functional unit framework. In the SFUF, Cao characterizes the neuron as a "supply route," a "cellular highway," to connect synapse to synapse, implying that the neurons act as media which cannot independently manipulate signals, the tunnels facilitating the movement of subway trains, if you will. This simplification undermines the reality of the situation that the neuron *can* act independently of the synapse to completely transform the signal, making it an example of a bad medium.

The neuron itself can respond to a synaptic input in an inhibitory or excitatory fashion through manipulation of its ion channels. Take dopamine, for example; postsynaptic dopamine

receptors can be excitatory or inhibitory through the activity of ion channels. The mechanisms by which those channels open and close are determined by processes *within* the neuron. Additionally, the configuration of the neuron as excitatory or inhibitory is *dynamic*, constantly changing based on the inner workings of protein synthesis within the cell. And finally, these inner workings occur independently of the synapse. For these reasons, the neuron is a bad medium, rendering the SFUF far less tenable.

Reducing Cao's critique of the neuronal functional unit to a flaw in the SFUF paradigm, however, would be a disservice to the broader goal of her essay: a criticism of the neuron as the functional unit. She introduces the compelling idea that neuroscience may have shortsightedly privileged the neuron as the functional unit due to its unique ability to propagate an action potential. Although the action potential has interesting implications in regard to rapid long-distance physical change throughout the brain, a functional quirk like an action potential alone is unable to logically elevate neurons to the elite status of functional unit, especially in light of the more recent research on the influence of glia and astrocytes on learning and extracellular signaling.

Cao poses a question that, although bordering on an appeal to nature fallacy, is exciting and productive nonetheless: in the NFUF, the synapse is portrayed as a "glitch" in the propagation of action potentials from neuron to neuron. Isn't it counterintuitive to think that the brain evolved "stopgaps" which hinder the rapid flow of action potential signaling? Why do these sluggish, chemically modulated regions which interrupt the lightning quick "information transferring" of action potentials even *exist*? Wouldn't an entirely electrically modulated network of brain material be massively preferable to the archaic hardware that we have? These questions beg for a paradigm shift away from the NFUF.

If both NFUF and SFUF are faulty, then what is the functional unit of the brain? The most compelling framework lies within one of Cao's concessions—that the brain is a mess of tangled biological material, and really *all* parts comprise its functional units—indeed, the perfect map is that which is being mapped. How can we privilege the neuron when it's outnumbered by billions of other cells which could also be implicated in signaling? Although the synapse as the functional unit might be an improvement, this new paradigm brings with a host of other difficulties as well.

This essay aimed to relay Cao's argument of a shift from a neuron-centric view of the brain to a synapse-centric one while articulating why although the need to shift from a neuron-centric view is valid, the shift to a synapse-centric view is also unsound. Although it is helpful to explain phenomena by abstracting the brain into functional units—defining senders, receivers, and signals—ultimately these frameworks are just that: frameworks—built off reductivist assumptions. Although a criticism of both the old and new model may be an unsatisfying response, the destruction of previous frameworks and the instantiation of new ones advances knowledge—an endeavor undoubtedly worth our time and thought.

REFERENCES

Cao, Rosa. 2014. “Signaling in the Brain: In Search of Functional Units.” *Philosophy of Science* 81 (5): 891-901.