The Medium-Independence of Computation, Neural Computing, and Neurotransmitters

A common view in philosophy of mind and cognitive science is that, if the brain computes, then all its computations must be medium-independent procedures. This is because all physical computations are essentially medium-independent, since computation is an abstract, formally defined procedure, which can be physically implemented (or realized) in many different media. It follows that all neural computations must be medium-independent (Anderson & Piccinini 2024; Drayson 2025; Garson 2003; Haugeland 1985; Piccinini & Shagrir 2014; Piccinini 2020; Piccinini & Bahar 2012).

The operations performed by my gastrointestinal tract to digest what I eat are instead medium-dependent. This is because the operations constitutive of digestion "are defined in terms of specific physical alterations of specific substances," such as specific chemical reactions involving specific molecules (Piccinini 2015, 122; Shagrir 2022, Ch. 5). So, digestion, unlike computation, cannot be physically implemented in many physical media, and so, it is not a medium-independent procedure.

Digital computation is the paradigmatic example of medium-independent computation, whereby "[t]he rules defining digital computations are defined in terms of strings of digits and internal states of the system, which are simply states that the physical system can distinguish from one another. No further physical properties of a physical medium are relevant to whether they implement digital computations. Thus, digital computations can be implemented by any physical medium with the right degrees of freedom" (Piccinini 2015, 123).

Candidate vehicles of computation in the brain—what computational neuroscientists call the neural code (Rieke et al. 1997; deCharms & Zador 2000; Brette 2015; Cao 2018)—include the rate and timing of neural action potentials (or spikes). These would be medium-independent vehicles for neural computation, because "[t]he functionally relevant aspects of spike trains, such as spike rates and spike timing, are similar throughout the nervous system regardless of the physical properties of the stimuli (i.e., auditory, visual, and somatosensory) and may be implemented either by neural tissue or by some other physical medium, such as a silicon-based circuit" (Piccinini & Bahar 2013, 462). The problem with this suggestion is that we do not know whether all and only properties that define the neural code are properties of action potentials.

The nervous system has electrical properties. But it also possesses biochemical, molecular, morphological, and historical properties (Striedter 2005; Sterling & Laughlin 2015; Sporns 2016; Zeng & Sanes 2017; Cao 2022; Chirimuuta 2022). Although we do know that neural transmission can be electrical or chemical (Pereda 2014; Valenstein 2005), nobody has yet demonstrated that neurotransmitters cannot be vehicles of computation in the brain. If certain neurotransmitters constitute vehicles of neural computation or are directly involved in specific neurocognitive operations, then it will follow that some neurocognitive operations are not neural computations, which narrows the scope of the computational theory of mind. Or, it follows that the brain does not literally implement the sort of computations formalized by existing mathematical theories, which supports the idea that the brain should not be understood as a computing system. Or, it follows that not all neural computations are essentially medium-independent, which calls into question the fruitfulness of the notion of medium-independence in computational neuroscience.

My aim in this paper is to provide evidence that certain neurotransmitters do constitute, at least partly, vehicles of computation in the brain.