Editorial: Can There Be a Physics of the Brain?

The recently launched brain initiatives [1] have thrown financial support behind one of the greatest intellectual challenges of our time: to develop an understanding of "how the brain works." Physicists are expected to play a vital role in this research, and already have an impressive record of developing new tools for neuroscience. From two-photon microscopy [2] to magnetoencephalography [3], we can now record activity from individual synapses to entire brains in unprecedented detail. But physicists can do more than simply provide tools for data collection.

One of the great successes of physics is universality—the idea that at larger scales, some small-scale details can be ignored. For neuroscience, this is where physics could have its biggest impact, providing general principles of brain function. Ideally, these principles should come in the form of equations. However, there is skepticism from both sides (biology and physics) that this could really be achieved. The brain is a highly complex structure with tens of distinct neurotransmitters and receptors [4,5], a menagerie of cell types, and precise wiring patterns [6]. Can these small-scale details really be ignored? The answer looks like it might be yes, with glimmers of universality beginning to appear in neuroscience.

Sethna and colleagues argue that systems biology models are governed by only a few "stiff" parameters. The values of all the other "sloppy" parameters vary without strongly influencing the state of the system [7,8]. Recent experiments on networks of cultured neurons support this view [9], while computational models of the simple nervous systems of crabs and worms show that many different combinations of parameters can be used to produce essentially the same circuit function [10,11]. Biological experiments show that while the values of many parameters constantly change, neural functions remain remarkably stable [12]. In all these cases, diverse arrangements of microscopic variables produce the same macroscopic invariant.

Universality is also central to the hypothesis that the cerebral cortex is poised near a critical point, where only one variable, a control parameter, would govern the macroscopic phase of the system [13]. Near the critical point, correlations between neurons would occur across all scales, leading to optimized communication [14]. In addition, susceptibility would be greatest there, making the cortex most responsive to external stimuli [15]. Experimental evidence for this hypothesis has accumulated over the last ten years: power laws and scaling relationships have been found in neuronal cultures [16], and in the cortices of monkeys [17] and humans [18–20]. Despite the evidence and the appeal of this idea, there are some doubts [21].

The current deluge of neural data has opened up many pathways to explore, and there is a healthy debate about competing ideas. Many years from now, as physicists seek to contribute to neuroscience, it is likely their biggest challenges will no longer be in developing new tools for collecting data. Rather, they will be in determining how large numbers of neurons collectively interact to produce emergent properties like cognition and consciousness. This will be a frontier for interesting new physics, unlike anything we have seen before.

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