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Comments on Aur's "From Neuroelectrodynamics to Thinking Machines"

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In [1] Dorian Aur heatedly criticizes what he calls the "current neurophysiological doctrine," which relies on the measurement of neural events on a millisecond time scale, that is, spikes or action potential. Aur's intention is no other than to terminate one of the most fundamental ideas in neuroscience since the pioneering work of Edgard Adrian in the 20's, the functional relevance of these nerve impulses as carriers of information.

In Aur's view, the spike timing and other related forms of neural coding expressed in terms of temporal observables are no more than epiphenomena. The principles of neural computation must be found in the spatial distribution of electrical processes that occur during the action potential. Thus, "current mainstream provides a weak understanding of computations performed in the brain," because it ignores the "hidden information" embedded in the complex microscopic interactions inside the cell, during the millisecond time frame of a spike.

Thus, "intrinsic computational processes" are decided at a much slower time scale and smaller space scale than is commonly assumed in neurophysiology. Neuroelectrodynamics (NED), a new theoretical framework that borrows from Hamiltonian mechanics, Thermodynamics, Quantum Physics and non-Turing computation, is surmised as the "change in paradigm required" to understand "brain language."

This review highlights the methodological pitfalls and conceptual errors introduced in the model suggested by Aur. First, it is shown that the mathematical equations proposed are not adequate for the studied system, that is, the brain, and second, a discussion on the aftermath of the dismissal of spike trains as carriers of relevant information, as stated by Aur, is sketched.

First, with regard to the methodological aspects, Aur makes a claim for "adequate techniques" in order to understand "the neuron's language." For Aur, the diversity found in actual recording of action potential propagation in nerve cells needs to be explained in terms of the spatial distribution of electrical charges inside the neuron. The spike directivity vector is presented as the tool put on place to reveal the hidden information laying in the intracellular interactions inside the cell. Thus, while mainstream neurophysiology assumes that it is the timing of the spike that matters, Aur announces a new approach to understand neural computation, up to now unperceived by neurophysiologists, in which meaningful patterns are built upon spike directivity vectors that quantify transient charge density taking place during action potential.

The methodological implications of Aur's approach are of a devastating complexity, owing to the stratospheric dimensionality of the neuron models needed to capture the dynamics of ions, molecules and proteins inside every single cell. It is hard to imagine how one may come to grips with the dynamics of such a gargantuan system. There are millions of proteins inside each neuron! Surprisingly enough, Aur's bet is Hamiltonian mechanics, which is mainly geometry in phase space [2].

Although Aur's modeling choice is entirely legitimate, the actual model proposed does not apply neither aims at the physical reality for which claims to be conceived, the brain.

It goes without saying that a model is always a simplified description of some features of a system, for example point neuron models are simplifications unable to simulate

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a number of phenomena, those related with the cell's morphology. For a recent review, see [3].

The problem is that for Aur's model to work, at least a two-fold scenario has to hold, and none of the two is true. On the one hand, following Aur formulation of the brain dynamics using Hamiltonian mechanics, the brain needs to be a non-dissipative system, and on the other hand, in order to understand the behavior of the system, we need to be able to find the solutions of the equations.

The equations that Aur formulates are for non-dissipative Hamiltonian systems, while the brain is a dissipative system.

A dissipative system has bounded free supply (energy, matter), that is to say, the amount of energy or matter that flows out of the system to the environment cannot be arbitrarily large. From a thermodynamic setting, all systems are dissipative because subjected to the second law of thermodynamics, so a dissipative system necessarily absorbs a fraction of its supplied energy and transforms it (losses it), for example, into heat [4, 5].

Thus, dissipativity is a property of open systems, and only under the unrealistic assumption that the brain is closed or isolated, are Aur's equations applicable.

Aur is half right when he states that "chaos can naturally develop in Hamiltonian systems with many degrees of freedom." Hamiltonian systems, with only 2 (or more) degrees of freedom and non-integrable, may exhibit chaos [6]. The integrability is, therefore, critical in Hamiltonian systems with chaotic regimes; however, this is never mentioned.

Needless to say the equations need to have solution, and Aur never says which method we may use to solve the phenomenal number of nonlinear equations, very vaguely described in the paper (the reader is left to his or her own imagination to fill up parameters like I, w, Θ, ε in equations (1) and (2)).

Thus, one may easily see why Aur defends the view that "Turing framework is limited," something radically different, indeed, must be conceived in order to compute the $6M10^{10}$ equations in the model of the brain suggested by Aur (M is the number of relevant intracellular entities such as proteins or ions, and 610^{10} are the number of equations for the momentum and position of each of the 10^{10} neurons in the human brain). It is worth noting how far the three equations in Lorenz model of chaos [7], or the four-dimensional Hodgkin-Huxley neural model, and its simplified versions, for example, Morris-Lecar or FitzHugh-Nagumo [8], are from this.

Second, with regard to the conceptual and experimental aspects, we must admit that in neuroscience, terms like "information processing" or "neural code" are used in a rather general and vague way. This is an indicator that researchers have not been able to provide a formal theory that makes unnecessary use of these and other concepts in a metaphorical sense.

Spikes are temporal events, used to study neural processes in a given coding framework, for example, coincidence detection [9], STDP [10] or oscillations [11].

Using the distinction made by the philosopher C. S. Peirce [12] between symbol, token and type, a spike is a symbol realized in a physical entity (symbol as a token) that may have a semantic content (symbol as type).

In this view, spikes are symbols, that is, measurement values that provide information of the system, but spikes are not necessarily the unique relevant tokens; other events may happen to be functionally relevant for the system, for example, bursts, local action potential or even the velocity of electrical charges inside the cell, as Aur (and only him) suggests.

Temporal coding is realized in the neural system; this is a fact supported by numerous experiments [13, 14, 15] just to cite a few. Thus, it is uncontroversial that neurons or assemblies of neurons are able to transmit the temporal structure (spike pattern) of a given stimulus.

A different issue is whether a spike pattern carries information that allows us to understand the message being encoded. It is unreasonable to assume that all the relevant information processed in a neural system is encapsulated in time spikes. Thus, the point made by Aur that, "the temporal coding framework approximates only a small part of weak interactions and ignores strong interactions that occur in the cell" must be considered very attentively. Patterns of molecular processes with slower temporal scale of spikes might be relevant for neural coding.

The intracellular perspective has been suggested by systems biologists like Dennis Bray [16, 17, 18] who claims a functional role for proteins, that is, biochemical circuits of proteins may perform computational tasks like information storage, or Uri Alon's hint "the cognitive problem of the cell" on how special proteins called transcription factors produce an internal representation of the environment [19]. While it is perfectly possible to have a neuron that represents some external feature without any observable change in its firing rate [20], the overwhelming evidence for the existence of timing patterns of spikes, which mediate in neural information processing, disproves Aur's statement "temporal features carry little information about object categories, behavior, or semantics" [21]. A number of studies relating timing pattern and neural information processing exist for the visual system [22], olfactory system [23, 24], auditory system [25] or the hippocampus [26, 27, 28], just to cite a few cases.

What is being questioned here is which spatio-temporal scale we are considering as relevant. Whether patterns of spikes have a functional role or not, it is strictly an empirical issue. In this regard, to study neural systems within an internal perspective, rather than the external view, which relies on averaging neural responses, for example, spikes elicited from extracellular events, may provide important insights on the actual mechanisms underlying information processing in the brain.

The organistic or internal perspective is conducive to think in inferential terms of what new information can be inferred from a single given observation. It is here where Aur's shift toward the characterization in mathematical terms of intracellular components, which may be relevant to explain the informational processing capabilities of the cell, acquires some value.

Nevertheless, NED itself is riddled with methodological and conceptual pitfalls, in addition to a lack of empirical support. This, in effect, invalidates it as a serious candidate to come grips with the neural coding problem, that is, the understanding of those entities and physical processes in the brain, which convey relevant information for the behavior and adaptation of the organism in a certain milieu.

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