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BOOK REVIEW

Review of György Buzsáki's book rhythms of the brain

It is with a true sense of satisfaction that I write the following thoughts concerning György (Gyuri) Buzsáki's brilliant treatise on the brain and its rhythms.

While it is true that the rhythmic electrical activity of the brain has been with us in neuroscience since the discovery of the alpha rhythm by Hans Berger, it is also true that few aspects of the electrical activity of the brain have been more controversial or more misunderstood. On the one hand, to the more computationally minded neuroscientists all this issue of rhythms seems meaningless, while to those that record rhythms from the skull, rhythms seem to be all there is to brain function. Perhaps the most fundamental conceptual problem concerns the nature and meaning of such rhythmicities vis-à-vis their functional significance. Amazingly, some authors view such rhythms as "emanating" from the brain and as being the ultimate expression of brain function. This view is as absurd as to regard the extracellularly recorded electric fields the biologically significant aspect of nerve conduction. Indeed, except in cases such as the inhibitory effect of VIIIth nerve activity on Mauthner cell's axon in teleosts, or perhaps in some cases of "ephaptic modulation of nerve excitability," the *extracellular field potentials are epiphenomena.* They may report to the external observer the presence of electrical coherence of neuronal groups, but themselves are no more than shadows in a platonic cave. This very central point is indeed the "battle cry" of Gyuri's book.

The initial chapter raises the issue concerning the nature of prediction and causation as the fundamental concepts concerning brain evolution. Also, it deals with questions such as the nature of brain "smartness," its origin, and its seat in the brain. In accordance with cellular neuroscientists, the how and where of such events are rapidly translated into the properties of neurons and the circuits that they weave. The dialog between the cortical geometry and the temporality imposed by the deep central nuclei, often addressed as the "top down" and "bottom up" dynamics, is quickly raised as the scaffolding that supports the what and when of brain function. It is refreshing to note, however, that in chapter 12 the true meaning of this nomenclature is addressed as follows; "top down and bottom up processing is a mere abstraction."

The chapter that follows addresses cortical geometry viewed from the perspective of size vs. complexity. Here Gyuri's love for architecture (from L. Mies van der Rohe and Buckminster Fuller to the biological architecture so eloquently deciphered by D'Arcy Thomson) comes across clearly with his emphasis on spaces, be they real or abstract. And so, from the requirements of minimum complete (random) connectivity between neurons via Erdös/Rényi graph theory and its limits arises the realization of its inadequacy. Instead, the geometry of recurrent clusters with a small number of pivotal elements as the common thread is offered as the most sensible approach to network complexity. It allows a rational approach to the scaling problems that arise when the cortical mantle of a mouse is to be compared with that of a human.

The importance of inhibition (and the interneurons that wield it) is the subject of Chapter 3. Inhibition is considered the origin of complexity, of functional diversity and a distributed sculptor of rhythmicity into time-based functional geometry. It is difficult to overemphasize the role played by inhibition in brain function, and Gyuri is keenly aware of its crucial relevance. Indeed, he describes the inhibitory network almost as the backroom subculture that rules over the overwhelming pandemonium offered by the excitatory input which, if untamed, results in epilepsy. This functional grooming and the increased role for inhibition in CNS evolution returns to the book's central theme, i.e. the significance of temporal coherence and patterning as machine language for the brain.

In the chapter that follows, the different present day technologies capable of measuring the activity of the brain are addressed. The characterization of field potentials, their rhythmic quality and spatial distributions via EEG and MEG recordings, are elegantly treated. Other technical approaches such as functional imaging of individual neurons and neuronal ensembles, single and multiple electrode recording of groups of cells, are all considered. The admonition emerges loud and clear that even if all of these techniques could be utilized in parallel, the results must be ultimately convertible into patterns of single cell activity in the context of behavior, to be meaningful.

Chapter 5 tells all about brain rhythms as dynamic entities. It provides a description of the ways and means of understanding rhythmicity, its relation to noise (in a 1/f sense) and its effect on the robustness of the different oscillator properties. In particular it discusses rhythmicity as it relates to oscillatory memory, Weber's psychophysical law, circuit dynamics and its relation to the properties and requirements for predictive neuronal circuits.

The next chapter, "Synchronization by Oscillation," I found particularly significant as it addresses a most peculiar problem, that is, the surprising assumption arising from some corners of neuroscience that organized synchronicity can derive solely from the recurrence of neuronal circuits, and that intrinsic oscillatory properties in single neurons play no major role. The more we understand ionic channelopathies the more we will appreciate that intrinsic

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properties are the core of neuronal activity coherence, via oscillation and resonance. In particular, the role of single cell oscillation in circuit rhythmicity is exemplified here by the very elegant work of the author on hippocampal synchronicity and multicellular temporal coherence.

The following three chapters elaborate on the issue of rhythmicity and synchronicity relating to wakefulness and sleep and further support the thesis previously presented, that is, that neuronal oscillation and resonance, and their embedding into mutually interactive clusters, is the operating mode of brains across vertebrate and invertebrate forms. The very important question of cognition and gamma band activity is well treated; perhaps, some important issues concerning the role of the thalamus could have been addressed as we know that isolated cortices have little to say. And so thalamo-cortical activity should have been given the weight it deserves lest Gyuri be charged with cortical chauvinism.

Chapter 10 refers to action as state dependent "brain states." This chapter reiterates and puts very nice final touches to the view that perceptions and action are brain-state dependent. While at first approximation this may seem an overkill, given all that has been reviewed in the book so far, the point is that the duration and recurrence of massive oscillatory conditions represent one of the most salient and awesome properties of the brain's neuronal assembly. Long-term attentive states, sleep and wakefulness, "bad and good humor states" all belong to such protracted states. They can rapidly appear and vanish as exemplified by the time between being awakened and becoming cranky or being bored and falling asleep.

The antepenultimate chapter refers to the author's love and joy, the hippocampus and its relation to memory and its storage. This is a magnificent summary of one of the most complex systems in the brain. Due to its remoteness from primary sensory and motor activity, it is indeed sometimes relegated to "the other cortex." Another explanation for the remoteness with which it is associated by the non-hippocampologist, is the abstract nature of functional spaces this cortex addresses, and the fact that the functional granularity of the neocortex, measured in cortical columns, is present in this mantle with the spatial subtleness of a Stonehenge obelisk (a giant cortical module indeed). Thus, as opposed to the well-specified functional space of the neocortex, hippocampal space is affine (no geodesics); and therefore, such random space is only definable by the vectorial nature of coherent activity. In other words, it is the ultimate nightmare for those that prefer specificity wrapped up with connectivity. Theta rhythm phase modulation and its procession enacted in the hippocampus via entorhinal cortex guidance are the dynamic duo in charge of setting down our memories and thus of our psychological individuality.

The last two chapters of the book concern the dialog between systems via oscillations and, last but not least, the tough problems in neuroscience. While oscillatory coupling between systems constitutes a natural extension of the previous chapters, the last one is a compilation of those problems which keep thoughtful neuroscientists awake at night. For example, the nature of subjective experience, why some circuits feel and others do not. I for one have always felt that recurrent systems are the sine qua non for subjectivity. Gyuri states in his unflappable style, "Only structures that display persistent neuronal activity and involve large numbers of neurons support consciousness." Fortunately for the rest of neuroscience "large neuronal pools" is an arguable concept. This derives from the enchantment we all have for single cell recordings. Not that they are not absolutely crucial, but rather, that the ascribing of meaning to single element activity belonging to vast networks is folly.

Briefly, while a little on the erudite side, the book is beautifully written. It is, however, by no means a simple read. Its easy prose is at first blush, deceptive. As opposed to the many neuroscience books populating our libraries, this one demands serious and careful reading as it is a deep document indeed. It is of course possible to do a "quick scan," and the author has made this possible by following each chapter with an "in brief" summarizing chapter content. This book is seriously recommended for those who truly wonder about the brain and its function.

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