Rhythms of the brain.


The term “brain rhythm” refers to the rhythmic changes in brain activity typically recorded using an electro-encephalogram (EEG). Different brain rhythms are distinguished on the basis of their frequency, morphology of their waveforms, and location. The study of brain rhythms is of great practical importance. For example, neurologists study changes in brain rhythms in order to characterize different states of consciousness and stages of sleep and to diagnose the epilepsies. On the other hand, neuroscientists have long been fascinated by the association between gamma-frequency oscillations in the EEG and the temporal binding of sensory stimuli by the cerebral cortex and the relation between hippocampal theta-frequency oscillations and spatial orientation in rodents. In this entertaining monograph the author addresses issues related to the genesis of brain rhythms and their contribution to the “invisible operations of the brain”. Although the author makes no attempt to put his ideas into a mathematical formulation, it can be anticipated that many of his observations will heavily impact the attempts of future modelers.

The textbook is organized into thirteen chapters which, for reasons unknown to this reviewer, the author has referred to as Cycles. At the end of each Cycle there is a section entitled “Briefly” that summarizes the main points of the chapter. Roughly speaking, in the first 174 pages the author manages to apply almost every buzz word in modern complex systems science to the study of the interrelationships between brain structure and function (small world connectivity and power laws (Cycle 2), self-organized criticality (Cycle 3), synchrony and stochastic resonance (Cycles 5 and 6)). During the next 182 pages the author discusses many of the brain rhythms that he has spent his life working on: sleep (Cycles 7 and 8), sensory binding (Cycle 9), attention (Cycle 10), the role of the hippocampus in spatial memory (Cycle 11), and coupling of cortex with hippocampus (Cycle 12). Unfortunately, very few concrete connections are drawn between the two halves of the book. The problem of reconciliation is recognized by the author in the final Cycle, which has appropriately been entitled “Tough Problems”. These difficulties may, in part, be related to the author’s decision not to discuss areas of neuroscience, such as motor control and epilepsy, for which there is already mathematical and experimental support for this author’s insights concerning the relevance of topics such as “small world connectivity” [e.g. T. I. Netoff et al., J. Neurosci. 24 (2004), no. 37, 8075–8083] and “edge of stability” [e.g. L. Moreau and E. D. Sontag, Phys. Rev. E (3) 68 (2003), no. 2, 020901, 4 pp.; MR2010067 (2004h:92002)] for understanding brain function.

This is a book that is guaranteed to provide its readers food for thought. The mathematically oriented reader will immediately sense the difficulty that the author has in defining the kind of mathematical entity that best describes a brain rhythm. This difficulty becomes more understandable if the reader sneaks a peak at pages 358–360. The problem comes from the observation that although individual neuron pacemakers share many of the properties of limit cycle or weakly chaotic oscillators, it is unclear whether the same can be said about brain rhythms (p. 173). Finally
in Cycle 13 the author makes an exciting jump: brain rhythms are to be regarded as an emergent property of neuronal networks composed of non-oscillatory elements. Hence the author’s rule of thumb: if it is broken into pieces and does not oscillate, then it is an oscillator (rhythm). This concept of emergent oscillations is necessitated by the fact that pacemakers corresponding to the known brain rhythms have not yet been identified despite extensive searches. It is unfortunate that the author only briefly dismisses issues concerning the generation of the EEG (Cycle 4); a more careful discussion of the EEG would have supported the notion of a population level phenomenon at the basis of brain rhythms (for an elementary introduction see [J. S. Ebersole and J. Milton, in Epilepsy as a dynamic disease, 51–68, Springer, Berlin, 2003; see MR2001934 (2004g:92017)]). Consequently I found the author’s discussions much easier to follow if I mentally substituted the word “rhythm” for “oscillator”. The difficulty defining a brain rhythm becomes compounded when the author discusses synchrony. The basis of this discussion is the well-known concept of synchrony in populations of oscillators [A. S. Pikovsky, M. G. Rozenblyum and J. Kurths, Synchronization, Cambridge Univ. Press, Cambridge, 2001; MR1869044 (2002m:37001)], not the properties of synchrony of emergent rhythms. Unfortunately very little is known about the mechanisms that produce population-level rhythms from non-oscillatory elements (for a very speculative exception see [J. G. Milton and M. C. Mackey, J. Physiology-Paris 94 (2000), no. 5-6, 489–503]). Although the author chooses not to pursue this line of reasoning, it might be an interesting topic for a talented reader.

On the other hand, computational neuroscientists will likely take issue with the way that a major theme of this monograph has been presented: in order to understand brain computation it is necessary to understand brain connectivity. This has certainly been the goal of neuroanatomists for over a hundred years. The author argues that on a global scale, brain connectivity must ultimately reflect a compromise between two organizational principles: (1) the degree of local clustering; and (2) the degree of separation between distant parts of the brain. This observation is used to motivate a discussion of “small world networks”, from which the author eventually concludes that the brain is a “scalable and robust spherical structure”. Completely missing from this discussion is the wealth of solid experimental and mathematical work on the relation between brain structure and function. For example, fifty years ago a neuroanatomist suggested that at the local level of cortical neurons, the probability that two neurons are interconnected decreases exponentially as the distance between them increases [D. A. Sholl, The organization of the cerebral cortex, Methuen, London, 1956]. This is the connection rule that was incorporated into the now famous mathematical models of H. R. Wilson and J. D. Cowan [Biophysical J. 12 (1972), no. 1, 1–24] and which ultimately provided an elegant mathematical description of the relationship between neuronal connectivity in the visual cortex and functions, including the generation of migraine and hallucinogenic visual auras [P. C. Bressloff et al., Philos. Trans. Roy. Soc. London Ser. B 356 (2001), no. 1407, 299–330]. Thus I suspect that many neuroscientists will be upset to read that the study of brain function can be reduced to the mathematical equivalent of the “spherical cow” problem. However, all said and done, experimental evidence does support the notion of “small world connectivity” in primate cortex [e.g. K. E. Stephan et al., Philos. Trans. Roy. Soc. London Ser. B 355 (2000), no. 1393, 111–126].

Ultimately, nit picking aside, the importance of a book derives from the discussion that it
generates between its readers. While reading the Cycles I was reminded of the following advice from Sir Isaac Newton (1642–1727): “I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seaside, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.” This author is to be congratulated that he has had the courage to put this issue on the table top: in order to understand how the brain works should we look at the trees or the forest? He has done this by writing one of the most thought provoking and fun books in neuroscience that I have read in some time.

Reviewed by John G. Milton

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