Review of "Oscillations in Neural Systems", D. Levine, Ed.

M. Kon, Boston University and A. Przybyszewski, University of Massachusetts

Oscillations in Neural Systems, edited Daniel S. Levine, Vincent R. Brown, and V. Timothy Shirey; Lawrence Erlbaum Associates, Mahwah, New Jersey, 2000, hardbound, ISBN 0-8058-2066-3, US$ 99.95

A nice, solid cover containing different shapes arising from oscillatory waves symbolizes the subject of this book about the meaning of oscillations in the brain. Its articles approach this subject from experimental and as well from theoretical and modeling points of view.

Many experimentalists are still skeptical about the role of oscillations in the brain. They believe that in most cases the averaging of activations triggered by a stimulus yields most of the required information and processing.

To prove that oscillations are central to brain functioning (a thesis of many of the authors in this compilation), a wide range of experimental examples and theoretical analyses are needed. This book is a good source for both of these basic aspects of the discussion.

Oscillations are currently among the most studied aspects of neural networks, given that there is lots of experimental evidence that they appear almost universally in neural functioning. In the past few years it has become more commonly accepted that oscillations must play a central role in many closely studied aspects of the nervous system. This book was the result of a 1994 conference on oscillatory phenomena in neural networks held in the Dallas-Fort Worth area. Though the date of the conference is a number of years back, the articles have been more recently updated.

The study of oscillatory neural networks has had a number of distinct and complementary aspects over the past few years. On the level of individual neurons, there has been work on the driving forces for oscillations, both within and between individual neurons. This work has ranged from physiological studies in laboratories, to mathematical models involving detailed analysis using partial differential equations and dynamical systems. The oscillations of neural systems are collective in nature, and indeed have been known for so long because the coordinated actions of cells have been easily identifiable through EEG measurements. Models involving such collective oscillation have been used to describe and study operations of various circuits in the brain. Macroscopic properties of the various circuits have been characterized and classified over the years, and specific modeling and measurement has been done of various rhythms, including the well-known alpha, gamma, and delta rhythms.

Further, oscillations are speculated to be involved in the basic dynamics of cognitive functioning, including in attention and the segmentation of perceptual tasks. They are also being harnessed in the construction of artificial neural architectures involving perceptual and memory-related tasks.

This book is divided into several sections, based on the natural categories defining areas of study of oscillatory neural systems. It starts in the first half with single neuron properties, network properties, and results of subcortical and cortical experiments analyzing oscillations. The second half of the book is more theoretical and describes the meaning of oscillations in perception, attention, cognition, symbolic knowledge, as well as analyzing the role of the chaos.

One can be excited or skeptical about the significance of oscillations in the CNS. It is clear, however, that there is still much which needs to be explained about the brain. It has a very complex structure because many cells multiply their individual complexities through high connectivities, and also because there are significant non-linearities in the properties of cells' membranes, synapses, single ion channels, and hence their communication mechanisms.

It is amazing that this mass of interactions and variability consistently (though on different levels) obeys linear, logarithmic, and other regular rules and relationships. To find such regularities in the brain's structure and behavior, we need to resort to both experiments and modeling. This book gives many examples of new experiments and new perspectives on data analysis. A number of contributions contain data from novel experiments, analyzed from an "oscillatory" perspective. From the modeling point of view, there are many hypotheses on how oscillations may play roles in the complexities of brain function.

We now look at the book in more detail. The first section involves several chapters on individual neural or isolated network oscillations and how they are modeled from experimental and theoretical points of view. This includes a chapter on oscillations of cultured neural networks, which involves experimental results on spontaneous versus electrically and chemically stimulated oscillations. Another chapter describes a method to detect oscillations in a pair of firing neurons, showing that dynamics of individual neurons emerge from interactions among multistage nonlinear processes at the molecular, cellular, synaptic and network levels. A characteristic effect is bistability of networks, which involves both bursting and beating effects.

Although many models are promising, experimentalists are sometimes naturally skeptical about their component assumptions. A common approach of modelers is to assume simplifications in their simulations. Therefore, verification of such models with experiments is crucial. For example, properties of local field potential oscillations in the visual cortex are analyzed in one of the chapters. The model shows how recurrent inhibitions in the cortex and how varying input rates can modify oscillation frequencies. Even in simpler two-cell networks, complex dynamics can be observed in the relationship between output spike trains and temporal input structures.

The second section involves modeling and the experimental study of oscillatory cortical and subcortical systems. This involves in one chapter a description of a model of the thalamocortical system based on detailed computer modeling of chemical interactions among neurons. Low frequency oscillations (LFO) in the thalamocortical (Th-Ctx) and cortico-hippocampal (Ctx-Hi) circuits were recorded. It is shown that these two systems have different mechanisms responsible for the LFO. In the Th-Ctx circuit intrinsic synaptic connections are responsible for pattern activity. This is in contrast to the Ctx-Hi circuit, were the input primarily generates oscillatory patterns. Another chapter explains how the reticular-thalamic layer plays the role of a pacemaker in LFO of the Th-Ctx network.

Another contribution shows that a pair of excitatory-inhibitory neurons connected through long-range-cortical connections can lead to fractal spike patterns (but only over long counting times). Generalizations of such fractal behavior to chaos in the field potentials is however not evident in other experiments. A simulated 8x8 array of coupled nonlinear oscillators predicts chaotic spontaneous activity in the cortex model; however, such behavior has not been sufficiently verified experimentally.

Response synchronization as a mechanism for binding in the motor system has been proposed before, but it is not always consistent with observed muscle activity. One author proposes an adjustable pattern generator theory (APGT), which would identify movement commands as burst discharges associated with synchronous cortical activity.

The next section of the book involves chapters on oscillatory models in perception, memory, and cognition. One chapter studies the ability of the brain to identify asynchronously processed data (e.g., from visual information) arising from a given single percept (perceptual framing). Another gives a globally coupled return maps model of depth gestalts, involving an explanation of phenomena such as perception of the Necker cube. There are also chapters which give a general model of how oscillations function in the brain in their relationship to attention. It is hypothesized in one chapter that oscillations in pre-attentive circuits are self-organized, while those in post-attentive circuits are driven by special brain structures (central generators); mathematical and computer modeling is used to analyze neural circuits based on this idea. It is suggested that oscillators in the frequency range around 40Hz are related to attention.

Finally, the last section covers applications of the theory of oscillatory circuits in structures such as artificial neural networks. One contribution proposes a searching strategy for sparsely distributed resources which can be based on chaotic oscillations. Another studies a generalization of an adaptive mechanism related to negative feedback, leading to an oscillatory structure which could explain how associative memory works. There is a study of phase-locked oscillations which lead to correlations that are reinforced using a Hebbian learning rule. Another chapter presents an inference and knowledge encoding mechanism based on synchronous activities between neuron elements.

Oscillatory Hopfield networks are also analyzed in this section, which studies possible uses of such networks. A notion of "chaotic annealing", in which the oscillation is adiabatically quenched, is introduced - this allows a network to cycle through large numbers of states, and to stabilize as ordinary Hopfield nets do, once oscillation has been turned off. VLSI implementations of model neurons are presented in another chapter -- their behaviors have been used to study and characterize oscillatory biological networks.

Given the current excitement being generated by the notions of how oscillations determine and enhance functionality of networks, this book has come at an excellent time. The span of topics enhances the view that there is a lot of depth, and probably a great future for the modeling of networks using the paradigm of oscillatory structures. This is a good book for obtaining an overview of the broad branches this area has grown. Detailed experimental results, as well as theories and speculations, provide a deeper view of the issues and potential explanations of the role of oscillations. This book is recommended to anyone interested in neural networks in their recent (and possibly future) incarnations.

Henri Poincare inspired the physical and mathematical world when he addressed the question of stability of our planetary system using a newly developed dynamical systems theory, leading to the study of oscillatory dynamics. We might wish to parallel these developments by asking whether and to what extent the brain's oscillations tell us about its stability and other properties. As a caveat to our analyses, however, we should be aware, as Poincare suggested, that "experience is judged according to a theory." Our expectations of what we will find may to a large extent determine our understanding and interpretation of experimental data.