

BOOK REVIEW

***The Computational Neurobiology of Reaching and Pointing — A Foundation for Motor Learning* by Reza Shadmehr and Steven P. Wise**

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Over the last three decades, computational neuroscience has become an increasingly important component in neurobiological research. Modern multi-electrode and multi-site recording techniques, brain imaging, brain-machine interfaces, data from chronically implanted electrodes, etc., together with the abundance recordings of behavioral data generate a wealth of information that can hardly be interpreted anymore without computational models of the underlying (usually nonlinear) processes. Computational neuroscience comes in various flavors, depending on which level of detail a nervous system is to be understood, and which particular information-processing problem is in focus. David Marr's (Marr 1982) seminal work on computational neuroscience for vision made the useful distinction between the levels of *theory*, *algorithms*, and *implementation* in computational neuroscience. Theory addresses in a rather abstract manner how a particular problem can be solved at all, irrespective of whether it needs to be solved by a biological or an artificial system. Algorithms are concerned with how a particular theoretical approach can be put into working algorithmic procedures, and the implementation level addresses the realization of an algorithm in a particular medium, e.g., a computer or the neural architecture of a living being. Of course, these three levels are not mutually independent, e.g., the requirement of implementing a process with biological neurons may demand special algorithms, or even a special theory, but it is often useful to approach computational neuroscience with these three levels in mind in order to avoid getting lost in the overwhelming number of details of a nervous system.

In terms of different specializations in computational neuroscience, one can at least distinguish between two areas, low-level computational neuroscience and systems-level computational neuroscience. Low-level computational neuroscience is primarily concerned with models of single neurons, channel dynamics, computational abilities of individual neurons and smaller neural networks, etc. Systems-level

computational neuroscience looks more into how the nervous system accomplishes actual behaviors, like object recognition, visual attention, decision making, reinforcement learning of reflexes, etc. System-level computational neuroscience is usually also specialized on the different major tasks that a nervous system has to fulfill, including visual perception, auditory perception, memory, learning, sensory-motor control, etc. (e.g., Dayan and Abbott 2001).

With these classifications in mind, the book *The Computational Neurobiology of Reaching and Pointing — A Foundation for Motor Learning* by Reza Shadmehr and Steven P. Wise (Shadmehr and Wise 2005) falls in the category of systems-level computational neuroscience that addresses the topic of sensory-motor control on all three of Marr's levels, i.e., theory, algorithms, and implementation. It actually adds one more level of analysis, the level of *evolution*, which helps the reader understanding how various systems of the central nervous system came into being as a patchwork of ever more complex organisms. The book fills an important gap among textbooks in computational neuroscience and motor control, as the last published textbooks on related topics are by now more than 10 years old (e.g., Schmidt 1988; Latash 1993).

The authors chose to focus the book on a topic of neuro-motor control that has received the most attention from the computational community over the last decades, i.e., reaching and pointing movements with arms. This “restricted” (“just” 500 page-long) view of sensory-motor control is very useful, as it complements other books that emphasized periodic motion and pattern generation by self-organization in other motor systems (Kelso 1995), and as it allows connecting to a rather solid foundation of engineering control theory that was developed in the context of manipulator robotics (e.g., Sciavicco and Siciliano 2000). And it is really this continuous interplay between solid theory and neurobiological experiments that makes Shadmehr and Wise's book a truly modern computational neuroscience book in the spirit of Marr.

The reader of this book will discover an enormous amount of breadth and depth, which make its study largely self-contained. The first chapter and sections discuss the neuroanatomy of the vertebrate central nervous system and its evolutionary origins. All major brain structures that contribute to motor control are covered and their functional contributions to motor control are explained. Very early, the book starts emphasizing one of the key components of motor control, i.e., the computation in closed loop information systems and the associated problems of stability, feedback delays, controlled variables, and noise. After these introductory chapters, which cover about one third of the text, a methodological progression is made from more elementary components of motor control, like the computation of target locations and displacements, to more complex functions, like motor skills, learning, predictions, and decisions.

Before executing a reaching or pointing movement, the CNS needs to determine the position of its own limbs and that of the target, which is the topic of Chapter II. The authors chose to center the discussion of this topic on the need to compute a difference vector between target and the current limb position. This view allows a very useful and modern discussion of frames of reference for such computations, possible theoretical approaches, and finally summaries of experimental results from behavioral and neurophysiological studies. In a similar combination of theory and experiment, Chapter III focuses on a more advanced topic, the formation of

movement trajectories that connect the current and desired position of a limb, and some of the adaptive processes that subserve such a behavior. Topics addressed include the alignment of different sensory modalities like vision and proprioception, how learning can modify these alignments, and how simple and complex movement trajectories can be generated from the knowledge of the difference vector discussed in Chapter II.

Chapter IV finally addresses computational approaches to how the motor system can achieve accurate control while taking into account the complex nonlinear dynamics of an arm, what role predictive processes and learning play in this context, motor memory, and decision making and complex movement sequences. Motor control with internal models, the learning of such internal models, how they generalize to novel situations, and how they can be memorized play a predominant role in this chapter. The concluding sections involve the rather complex and unexplored topics of how to decide on which target to pursue and how to accomplish action sequences.

Studying this book by Shadmehr and Wise is a delight for both the uninitiated and the advanced reader interested in computational motor control. The book covers essentially all seminal papers in this field from the last 20-30 years and puts them into a modern context. Despite its emphasis on computational modeling, the authors managed to keep to technical content easy to digest, and they offer a lot of knowledge and insights for a large spectrum of possible readers, ranging from neurobiologists to biologically inspired roboticists. I am convinced that this textbook will be the most outstanding text for computational motor control for the years to come.

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