elsewhere. Schema theory seeks to characterize the functional (indeed, often representational) role of mental (ultimately neural) resources. But unlike (some) classical approaches, schema theory does not require that there exist inner, static, textlike symbol structures ready to be operated upon by a single kind of "central processing." Instead, a schema is tied to the execution of a type of task in an environment and incorporates both knowledge and procedures for applying the knowledge. It is not invoked by top-down control but by a process of cooperative computation, and is thus designed to function as part of a larger distributed network of such functional elements. Much of *Neural organization* concerns itself with basic schemas used for perceptual and motor tasks. Note that a schema, thus understood, is a functional unit and may be anatomically distributed throughout different structural brain regions.

But the big issue rapidly looms. How can schema theory, which seems so well-suited to understanding basic, often preprogrammed behaviors (e.g., the famous work on frog visuomotor coordination and more generally on what Arbib et al. call "instinctive schemas"), deal with the higher reaches of human thought and reason? The second part of the Arbib et al. story offers a sketch of a mechanism. The idea is that instinctive (basic, special-purpose, perceptuo-motor) schemas are joined by somewhat more abstract (learned) schemas and that these two types of resources then interact in flexible ways to support intelligent human behavior. It is in the interaction that much of the real work, it seems, gets done. Thus, commenting on Milner and Goodale's proposal with its quite severe dissociation of vision-for-thought and vision-for-action, Arbib et al. comment that "it is not enough to dissect more carefully a variety of specialized subsystems. In general, the various aspects of our visual recognition of, and motor interaction with, an object are joined seamlessly" (p. 244). Drawing on Jeannerod (1994), it is suggested (and see Clark 1999 for a similar account) that a rather more complex web of interactions unites the two streams, and (in Ch. 8) that the effective connectivity patterns between component schemas may often be dynamic and malleable.

The trick to high-level cognition, if I understand the authors correctly, lies largely in this kind of seamless joining and dynamic reconfigurability (accomplished perhaps by neural gating mechanisms and/or various binding and unbinding techniques). Hence, in section 8.6, with the alluring title of "From action-oriented perception to cognition," we are told that the instinctive schemas (basic perceptuo-action routines) provide "a basis for, and are intertwined with" (p. 260) rational behavior. The final picture is one in which a variety of basic ("embodied, action-oriented") resources are combined with some more abstract learned schemas and the whole caboodle orchestrated (not top-down but by cooperative computation) into temporary ensembles according to the demands of a current task: one that may call, for example, for the fine interweaving of planning and action, recruiting ventral and dorsal resources in some complex, task-dependent mixture.

As a broad story about the nature of the continuities and more important, the discontinuities that make human cognition the flexible tool that it is, this is an appealing model. But it leaves one crucial element unexplained: how does the process of cooperative computation actually solve the recruitment problem? How are the RIGHT schemas assembled into the *right* temporary wholes at the right times? With the right "coordinated control program" (p. 250) in place, some very complex problems (see e.g., the VISIONS example in sect. 8.6.1) can be solved. But how do we learn these control programs and how is that learning neurally implemented? Must the right control program be in place in advance or can we generate it "on the fly"? Regarding "how the various assemblages that exercise . . . restructuring are themselves acquired and updated through experience," we are told only that all this "remains to be discovered" (p. 250). The trouble is that as long as that is so the big issue remains unresolved. For what really counts is the unknown process by which the right stuff (schemas) gets recruited at the right time so as to meet higher-level demands. But that is, in essence, a version of the notorious frame problem itself! The question about cognitive incrementalism then becomes simply the question whether the fundamental principles that lie behind nature's solution to the "flexible schema recruitment" version of the frame problem are functionally continuous with those developed to subserve embodied, embedded cognition. And since we don't know the answer to the recruitment problem yet, we cannot really say one way or the other. But it looks (and here I must agree with Fodor 1983) increasingly unlikely.

I don't wish this to sound too negative. The basic picture that Arbib et al. paint is one I find deeply attractive (see, e.g., Clark 1997). But I do think that deep questions about cognitive incrementalism remain unresolved, and that the final value of the embodied, action-oriented approach, as an approach to *cognition,* depends almost entirely on the outcome.

Let me end, however, with a mere speculation. It strikes me as possible that we shall need *two* fundamentally distinct frameworks for understanding cognition. One framework would explain how, given a set of temporarily recruited resources (given an effective connectivity pattern), the organism solves a specific problem. Here, we may well be on familiar ground, able to exploit computational and representational stories of a moderately conventional kind (though with distributed encodings, processes of cooperative computation, partial, action-oriented representations, etc.). The other framework, still barely imagined, would deal with the way multiple specialized neural resources exploit complex feedback and feedforward pathways, and dynamically modifiable links, so as to create the right instantaneous cognitive architecture to solve the problem at hand. Comprehending this latter process requires us to do simultaneous justice to the (genuine) specialization of neural structures and to the complex interdependencies and interactions that create new, temporary functional wholes from this underlying cloth. It is my suspicion that this latter process, though arguably at the heart and soul of higher-level cognition, is itself either *not a cognitive process* at all, or else is a cognitive process of some fundamentally different stripe – one perhaps best investigated using the rather different resources of some (information-processing-friendly?) version of dynamical systems theory.

The basic framework sketched by Arbib et al., with its valiant attempt to balance considerations of anatomical structure, potentially distributed functionality, and complex self-modifying dynamics, offers a detailed, valuable, and timely window onto this kind of new and puzzling territory. But the big issue (here surfacing as the superficially innocent question, how do we acquire, modify, and appropriately activate coordinated control programs?) remains unresolved.

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A moveable feast

Peter F. Dominey
Institut des Sciences Cognitives, CNRS UPR 9075, 69675 Bron Cedex, France. **dominey@isc.cnrs.fr** **www.isc.cnrs.fr**

Abstract: *Neural organization* achieves its stated goal to "show how theory and experiment can supplement each other in an integrated, evolving account of structure, function, and dynamics" (p. ix), showing in a variety of contexts – from olfactory processing to spatial navigation, motor learning and more – how function may be realized in the neural tissue, with explanatory and predictive neural network models providing a cornerstone in this approach.

In *Neural organization,* Arbib, Érdi, and Szentágothai undertake the quite noble but difficult task of weaving into a coherent tissue a multidimensional characterization of their collective views on modern neuroscience. At first sight of the table of contents, the reader will be quite pleased with the variety of subjects treated, from nervous system development, dynamics, and chaos to the olfactory system, cortex, thalamus, basal ganglia, and more – a true intellectual feast. But the reader may also wonder how such a broad range of topics could be treated in a single volume, if not just as a collection of unrelated chapters.

The final result of the authors' efforts here, however, has yielded a volume that will be of significant value in the training of new and confirmed neuroscientists for two related reasons. First, many of the chapters stand alone as excellent treatments of topics of central importance. At the same time, through the "meta chapters" and extensive cross-referencing between chapters, the book does achieve the difficult task of providing an excellent and unique view of the connections among these topics, showing in a variety of contexts, from olfactory processing to spatial navigation and motor learning, how these functions may be realized in the neural tissue with explanatory and predictive neural network models providing a cornerstone in this approach.

In the remainder of this review, I will not repeat the contents of the book, but rather comment on specific aspects of special noteworthiness. Thus the first two major parts treats the thematic issues of structure, function, and dynamics. The structure chapter provides among other things a quite useful perspective on the adult nervous system by way of embryological development. In the function chapter, schema theory is introduced as a methodology for describing function and allowing the mapping of function onto neural systems, which can then be tested in corresponding neural network models. Of particular value here were case studies demonstrating the utility of the interaction between experimentation and modeling in frog approach versus avoidance behavior and in primate reaching and grasping. The chapter on dynamics provides an excellent treatment of this topic (including clear introductions to ideas of state spaces, attractors, stability, chaos, etc.) and its relevance and application to neuroscience. Relating back to ideas developed in the treatment of structure in Chapter 2, self-organization is addressed within this framework.

While Part I thus introduced the thematic foci, Part II then treats six of the major neural systems in modern neuroscience, the olfactory system, hippocampus, thalamus, cerebral cortex, cerebellum, and basal ganglia, and then terminates with a synthesis and prospective for the study of the neuroscience of cognition. At first glance it might seem rather presumptuous to treat, in single chapters, topics as vast as the olfactory system or the cerebral cortex! But within the framework established for this book I think that the authors have done an excellent job in treating these topics from the perspective of systems neuroscience. That is, they have looked at the defining neuroarchitectural properties of the system in question, characterized the functional role of the system and presented – when possible – neural network models that achieve the specified function within the identified structural constraints.

Thus a central strength of the book is this systems neuroscience approach that is applied to a rather overwhelming collection of brain systems. The importance of this approach should not be underestimated. While it is true that great progress is being made in more fine-grained approaches to neuroscience, including molecular biology, progress in understanding system-level function can only proceed by putting these elements together into system-level models. A second major strength of this book comes from the effort, already alluded to, of the authors to assure the connectivity among the interwoven topics. A clear example of this is in the chapters devoted to thalamus, cortex, and basal ganglia, with extensive referencing among these chapters.

The obvious criticism that can be levied at this book is that by treating, in a series of chapters, topics that merit complete volumes themselves, the authors must have been forced to cut some corners. Indeed, it is clear that a treatment of "the basal ganglia" in thirty pages cannot be complete. Thus, for example, it would have been interesting to see how data from the treatment of Parkinson's disease by selective lesions and stimulation in the basal ganglia nuclei can provide important constraints for improved models of basal ganglia function. To such criticism the authors can offer two responses. First, while Chapter 10 itself is only thirty pages long, this is in fact misleading, since the basal ganglia and their fundamental role in thalamocortical interaction is already illustrated in the chapters on thalamus and particularly cortex. In other words, the whole is greater than the sum of its parts.

The second response to the criticism that "they tried to do too much" is related to the stated objective of the book. It does not pretend to be a complete reference volume on neuroscience – such animals already exist. Instead, in its stated goal to "show how theory and experiment can supplement each other in an integrated, evolving account of structure, function, and dynamics" (p. ix) the book is a clear success. It provides a series of examples for affirmed and developing neuroscientists of exactly this – the fruitful interaction between theory and experiment, providing a guide for the systems neuroscience methodology that will clearly play an important role in the ongoing challenge of understanding the brain and its structure, function, and dynamics. What may now be required is an effort to integrate the pieces (i.e., the models of cerebellum, basal ganglia and cortex, hippocampus, olfactory system, etc.) into a system model, with "macaca computatrix" as the descendent of "rana computatrix."

Brahe, looking for Kepler

Shimon Edelman

Department of Psychology, Cornell University, Ithaca, NY 14853-7601.
se37@cornell.edu kybele.psych.cornell.edu/~edelman

Abstract: Arbib, Érdi, and Szentágothai's book should be a required reading for any serious student of the brain. The scope and the accessibility of its presentation of the neurobiological data (especially the functional anatomy of select parts of the central nervous system) more than make up for the peculiarities of the theoretical stance it adopts.

> . . . inkhorns, arrows, loaves, cruses, fetters, axes, trees, bridges, babes in a bathtub, shells, wallets, shears, keys, dragons, lilies, buckshot, beards, hogs, lamps, bellows, beehives, soup-ladles, stars, snakes, anvils, boxes of vaseline, bells, crutches, forceps, stags' horns, watertight boots, hawks, millstones, eyes on a dish, wax candles, aspergills, unicorns.
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> – Joyce, *Ulysses,* p. 325

1. A scrambled mosaic. One bright June day in graduate school, I asked my advisor to recommend some reading material for the approaching summer. One of the articles thus recommended left me with an impression sufficiently vivid to prompt total recall on the slightest provocation (such as groping for an opening line for the present review). The article in question (Gilbert 1983), albeit informative and well-written, evoked a lingering feeling of disappointment, no doubt because its title – "MicroCircuitry of the Visual Cortex" – had initially sounded misleadingly suggestive to a literal-minded ex-electrical engineer such as myself. That article listed all manner of neurons and their distribution throughout the visual cortex, but, alas, did not quite specify wiring diagrams.

Satisfyingly, *Neural organization* does provide some actual wiring diagrams, and not just for the visual cortex. The anatomy of other neocortical, archicortical, thalamic, and cerebellar structures as well as their development and models of their function are discussed. All this adds up to a grand tableau resembling nothing as much as a Joycean procession of saints "bearing symbols of their efficacies," complete with buckshot, beards, bellows, and beehives (not to mention eyes on a dish).[1]

The attempt undertaken by Arbib et al. to introduce some order into the masses of currently available findings on brain function is highly commendable. That the result appears less orderly than