BOOK REVIEW

Marcello Barbieri (2003). The Organic Codes: An Introduction to Semantic Biology. Cambridge University Press. ISBN 0-521-82414-1.

Marcello Barbieri's *The Organic Codes* is an ambitious book. He attempts to outline a new conception of living systems and with it a new paradigm for the science of biology. Its central claim is that the existence of mechanisms for reading and writing codes, at all levels of biological organization, is a key, perhaps *the* key to one of life's defining features: the development and maintenance of organic complexity.

In broad outline, the argument that supports this claim is as follows: organisms are systems that have the unique ability to increase their own complexity in an orderly and well-defined manner (Barbieri calls this a "convergent increase in complexity"). In order to perform this feat, such systems must possess an ability to store information in a way that is both stable and reusable, i.e. they must posses what Barbieri calls an *Organic Memory*. The existence of organic memories entails the existence of codes, because in order for information to move back and forth from the developing cell/organ/organism to the built-in memory, there needs to be a format for reading, writing and transferring such information. This format, in essence, is a code.

The essential connection between codes and memories is established with the aid of a mathematical analogy: the author maintains that ontogeny is equivalent to a reconstruction of a three-dimensional image from partial two-dimensional projections of it. He presents a mathematical model for such reconstructions, which uses an iterative memory-based approach, whereby a computation is performed on the projections, and its results, at each stage, are stored in a memory matrix, thus enabling the extraction of certain important parameters of the original image as a result of the iterative character of the computation. On the basis of this analogy Barbieri claims that some type of memory structure, and as a consequence, some form of coding, are also necessarily at work during ontogeny. In Barbieri's view acknowledging the centrality of organic codes goes hand in hand with accepting a new outlook on biological organization, which entails a distinction between three different aspects of biological design: the energetic, the informatic and the semantic. The latter is a concomitant of coding, and recognizing it can and should transform our understanding of biology.

Barbieri goes on to explain the consequences of this semantic conception for a number of central developmental and evolutionary concerns. He touches on ontogenetic events such as cell determination and neuronal growth, and maintains that the emergence of new types of codes and memories supplies the key to understanding some of the major transitions in evolution, such as the emergence of eukaryotes and the Cambrian explosion.

The fundamental metaphor that lies at the heart of Barbieri's "semantic conception of life" is familiar - it is the metaphor of the organism as a computer. Barbieri seems to endorse a very strong version of the computational metaphor: life is made up of an array of naturally designed computing machines, arranged in organelles, cells, tissues, organs and bodies; developmental processes consist in the execution of reconstruction algorithms, so that the developing embryo is, in fact, engaged in an attempt to shape itself in the image of its parents. This is done on the basis of partial data, available in the form of coded instructions, which are embodied in different types of organic memory stores: genes, the cytoskeleton, signal transduction mechanisms, and body plans. The basic idea is that in order to build a cell, a tissue, an organ and an organism, one needs an information store and a clever algorithm. The rest is chemistry.

Barbieri introduces a number of new concepts in the course of the book, and uses several key analogies to illustrate and support his arguments. We find the definitions of these concepts wanting in some respects, and the analogies remain at the suggestive and metaphorical level. A short discussion of one central analogy and several key concepts will illustrate these difficulties.

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The analogy between ontogeny and reconstruction algorithms plays a central role in the book. The author believes that memory-based approaches to 3D reconstructions (Memory Reconstruction Methods - MRMs) have important implications for central biological problems. The chapter that presents these algorithms is entitled "A New Model for Biology". Barbieri begins by stating that since ontogeny is a process in which complexity increases in a convergent way, and since MRMs are reconstructions from incomplete information, the latter is "a model that could help us understand how it is possible for a system to obtain a convergent increase of complexity" (p. 71). He then goes on to present a mathematical apparatus for reconstructing three-dimensional images from two-dimensional images, and, upon finishing this technical detour, states that "What matters is not the formulae *per se*, but the general conclusions they allow us to reach" (p. 90). These conclusions are two: first, that there cannot be a convergent increase in complexity without memory, and second, that there cannot be a convergent increase in complexity without codes. Both conclusions, he claims, have "absolute generality". The statement that ontogeny is, in essence, a reconstruction from incomplete information, and the two conclusions drawn from it are three of the four central principles of Barbieiri's theory (the fourth being the statement that during ontogeny an organism achieves a convergent increase in complexity). Since the reconstruction-algorithm analogy plays such a central role in Barbieri's semantic theory of life it requires close scrutiny.

What does the analogy between the development of the embryo and 3D reconstruction from multiple projections actually mean? Barbieri suggests the following picture: a fertilized egg (or perhaps its DNA) is a projection, or a set of projections, of its parents. The embryo, in developing, is trying to reconstitute itself in the parental image. But what does it mean for the embryo to use "multiple projections"? Taking the analogy literally entails thinking in terms of an agent, a homunculus of sorts, performing the reconstruction. Surely this is not what is meant, but how else should we view the matter? Another, and perhaps more important, question would be how to account for environmental variables affecting the course of ontogeny. In Barbieri's conception, as in other computer-inspired models, the environment seems to almost vanish, since the task is seen to be one of reconstructing a complex organism out of existing, albeit partial information. In the light of what we know about the effects of environments on developmental outcomes, this cannot be a correct picture. But it is unclear how environmental variables fit in and how they may contribute to the outcome of a reconstruction algorithm. So, Barbieri's central analogy, although interesting, is in need of justification and clarification.

Let us turn now to several key concepts that are introduced early on, mainly in the third chapter, and that are used throughout the book. First, consider the closely related concepts of *Code* and *Memory*. Barbieri outlines three basic characteristics of codes:

1) They are rules of correspondence between two independent worlds.

2) They give meanings to informational structures.

3) They are collective rules which do not depend on the individual features of their structures.

As a characterization of codes this definition is unclear. It is not clear what the "independent worlds" are: Are they different molecules? Do they differ in their formal properties? What does it mean for a rule to "give meaning" to an informational structure? What does the term "information" denote in this context? How should we understand a rule as being "collective"? And how can a rule not be dependent on its structure? Barbieri does not say much about any of these difficult matters. On page 96 he refers to the fact that codes are ordinarily thought of as exclusively man-made phenomena, and brings together under the same heading "Grammar rules, chess rules, government laws and religious precepts". Here, as in several other places, he is speaking of conventions - correspondences that hold not because of natural, logical or mathematical laws, but because of agreement, usually between people in society, or powerful constraints following a "frozen accident", as with the genetic code. In other places, though, Barbieri seems to adopt a much narrower, and somewhat unorthodox sense of "code", one resembling the notion of a generative or a recursive rule, such as rules of grammar. Such codes/rules seem to be what Barbieri has in mind when he speaks of ontogeny as an algorithmic process. We believe that Barbieri may well be right about the existence and the importance of molecular systems that operate according to a set of "rules", as well as in his claim that such systems of "rules" operate at different levels of organization. He proposes splicing "codes" and signal transduction "codes" that may underlie regularities in these major biological processes, and mentions codes suggested by others such as the sugar code and the histone code, which may be involved in the meta-regulation of gene expression and of spatial organization. However, the attribution of "coding" to all these systems is at present entirely speculative, and it seems to us that Barbieri overstates the importance of distinct, grammar-like, sets of rules mediating between different biological systems. It is indicative of the general spirit of the work that when the author considers the relevance of his conception to the "mind problem" (Chapter 8), he speaks only of language acquisition, yet states that his conclusions have general application to the study of the mind.

A concept that is related to codes and is equally unclear is that of "organic memory". Here Barbieri gives even less by way of formal definitions. Relatively late in the book he states that "We can say that a memory is *a permanent deposit of information*" (p. 209). He goes on to say that this definition is "general enough to apply to all cases". However, cell memory, mental memory and computer memory mean rather different things. Cell memory entails the retention of functional or structural states in cell lineages, with no distinct system of "retrieval" from an independent memory store. It may be no coincidence that Barbieri does not discuss the known biochemical mechanisms of such cell memory (or epigenetic inheritance). Barbieri's discussion suggests, in fact, that what he usually refers to is something more similar to computer memory. This means that there is some form of memory store that enables the retrieval and modification of information stored in it. In view of this, it becomes very hard to understand how some of the examples discussed under the heading of Organic Memories fit into the definition. For example, the author accords a central place for the body plan as an organic memory, especially as part of his discussion of the Cambrian explosion. He states that "[T]he body plan is a set of characters that defines an animal phylum… but the body plan is also a memory, because it is a structure that appears at an early stage of development, and from that moment on, it remains in the organism for life, acting as a deposit of information for the three-dimensional pattern of organs and apparatuses" (pp. 209-210). It seems that the body plan, the expression itself should probably be taken metaphorically, sets constraints on the shape that an organism can develop. But this is a far cry from qualifying as a memory. Should we view any constraining structure, be it a skeleton or a piece of skin or a scaffold, as a memory store? It seems that the assertion that the body plan is a memory is a just a way of saying that there are sets of powerful morphological constraints on the development of morphology. Any deeper sense in which the body plan stores retrievable and modifiable information remains obscure. Yet, according to Barbieri, the emergence and the evolution of the body plan is the key to understanding the Cambrian explosion. Since his discussion of the body plan as a memory store is metaphorical, his explanation of the Cambrian explosion suffers a similar fate. Moreover, he believes that this explosion (and other, less dramatic increases in organizational complexity), was the result of a transition from a genetically rigid determination of development to a more open, epigenetically-driven, plan. Although there is no doubt that new types of epigenetic systems emerged and operate in higher organisms, there are very good reasons to believe that a tight and close relationship between genes and form is a highly derived state, preceded by an earlier, very much looser mapping between genomes and form (Newman and Müller 2000).

Conceptual problems also arise in connection with other terms. "Information", for instance, is a term used extensively throughout the book. It is notoriously hard to formulate a definition of information in biological systems, but Barbieri does not acknowledge this difficulty and makes no attempt at defining it. This has the consequence that it is not always clear what is meant by "storing", "transferring" or "giving meaning" to information and to "information structures". Another central concept, that of complexity, though briefly defined, is hardly discussed.

The Organic Codes is an attempt to provide a comprehensive model of biological organization. The broad outlook and the theoretical effort manifested in this work are badly needed in biology today. The book contains interesting suggestions and worthwhile insights, and points to the importance of looking for biological systems that may underlie and specify important regularities in the processes of gene regulation and spatial organization. However, it is often difficult to make clear sense of what is contended, and it seems that the author has neglected some important and challenging conceptual questions.

REFERENCES

Newman S.A. and Müller G.B. 2000. Epigenetic mechanisms of character origination. Journal of Experimental Zoology (Molecular Developmental Evolution) 288: 304-317.

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