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BOOK REVIEW

Biology and meaning: a reappraisal of semantic biology—a review of *The organic codes: an introduction to semantic biology*, by Marcello Barbieri

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The Organic Codes: An Introduction to Semantic Biology. Barbieri, M. 2002. Cambridge University Press, Cambridge. 316 pp. Hardback $75.00. ISBN 0-521-82414-1. Paperback $25.00. ISBN 0-521-53100-4.

Marcello Barbieri is a developmental biologist, now at the University of Ferrara (Italy), who has always had a strong interest in theoretical biology, approached by system theory and mathematical modeling. In 1985 Barbieri published a book entitled "The Semantic Theory of Evolution" where he presented his original idea of the central role of *organic codes* in biological evolution and proposed a mechanism of evolution by *natural conventions*, to complement genetic drift and natural selection. This first book had a low impact on the scientific debate of that time. Now, some 20 years later, Barbieri is proposing an extended version of his work on the "semantic theory" that aspires to shed new light on life, development, and evolution. The book is introduced with a foreword by Michael Ghiselin and is concluded with an afterword by Jack Cohen. An appendix lists more than 60 definitions of life, proposed during the last two centuries.

Semantic biology, as Barbieri calls this broader version of his view of life, aims to extend the Darwinian paradigm. What was missing is an understanding of the "logic" of development that has deep consequences for the evolutionary process. Posed this way, it might seem that it is a book in the direction of the frequently announced, though not yet fully formulated, "evo-devo new synthesis" (Arthur 2002). However, it is very different from any other contribution to the subject, and the book escapes an easy classification.

The central idea of Barbieri's thesis is the concept of an organic code. A code is a correspondence between two independent worlds, and in organic codes the correspondence rules are supplied by molecular *adaptors* (or *codemakers*) that connect two independent classes of organic structures. Any such rule of correspondence involves "meaning," from which comes the epithet "semantic" applied to his evolutionary theory and, more recently, to his idea of biology. For instance, in the already acknowledged genetic code, the adaptors are the transfer RNAs that create a codified correspondence between the polynucleotide world and the world of polypeptides. In the organic codes, therefore, meaning is not an abstract quality but the structure that is "described" by another structure via a code. Barbieri claims that the peculiar mode of evolutionary change occurring in codified processes has been dismissed by the current evolutionary paradigm, that there are more organic codes than the two kinds traditionally acknowledged (i.e., the genetic code and the codes of human languages), and that major macroevolutionary transitions are associated with the appearance of new organic codes. In the four billion years that separate the appearance of the genetic code at the origin of life from the development of the linguistic codes typical of the last phase of hominid evolution, the history of life is punctuated by the appearance of new codes that once settled never disappear. Among these there are *splicing codes*, *adhesion codes*, *signal transduction codes*, *pattern codes*, and *cell migration codes*. Barbieri believes that many others are waiting to be discovered or acknowledged.

In development, following DNA transcription, the arena where organic codes exert their function is epigenesis. Barbieri's model of epigenesis gets inspiration from the problem of reconstructing a three-dimensional structure from an incomplete set of projections. A particular family of

reconstructing algorithms, which uses auxiliary memory matrices and a code for exploiting the information deposited in these matrices, supplies an operational model for epigenesis. Then, his argument, as very clearly summarized in the last chapter, develops as follows: Epigenesis is a defining quality of life; in turn, epigenesis is defined as the property of a system to increase its own complexity in a *convergent* way toward a more complex target form. But at the same time, epigenesis is a process of *reconstruction from incomplete information* (the genome) and this requires *organic memories* and *organic codes*. This is because *all* systems that increase their complexity in a convergent way *must* use memories and codes. The logical derivation of this universal principle from a specific strategy of reconstruction is, at least, not very clear to me.

This new view produces hypotheses and explanations for many evolutionary events. Among these, the origin of life, the emergence of eukaryotic cells, and the Cambrian explosion of animal life are discussed in the book in detail. The theory presented should embrace all forms of life, but it must be said that, even if not explicitly declared, the developmental and evolutionary discussion in the book focuses progressively on metazoan evolution. Other multicellular forms of life, like plants and fungi, are simply ignored.

The book has certainly the merit of drawing attention to the role of meaning in developmental and evolutionary biology. Organic codes have probably not received the attention they deserve. In morphogenesis and pattern formation, every time the transformation of a (pre-)pattern into a pattern of a later developmental stage is not strictly fixed (constrained) by the laws of chemistry and physics, we say that the prepattern is "interpreted," thus realizing the following pattern. Evolutionary change can affect both the prepattern and the way it is interpreted, in the latter case changing its "meaning." We have beautiful examples of both processes in the evolution of the Arthropod body plan, affecting, respectively, *Hox* gene expression patterns and the downstream network of gene activation. At the same time, I would not be as ready as Barbieri is to acknowledge a specific ontological status for adaptors, totally separated from the status of the two classes of organic structures that they relate. I believe that, as in other biological processes, the status depends on the level of description, and like heterochronic change, which at another level of description can be read as a structural change (e.g., a point mutation), codes can be endowed with adaptors that at other description levels are molecular structures, exactly like the structures they connect. Consequently, I believe that recognizing the importance of meaning in epigenesis does not imply a new mechanism of evolutionary change, by *natural conventions*. I see a confusion between the description of the type of variation (the variation of the meaning, and therefore of the conventions) and the way this variation is sorted, which, when adaptive, is probably by natural selection (Fusco 2001). A specific *kind* of evolutionary change does not imply a specific *mechanism* of evolutionary change. For all I know, evolutionary change by heterochrony has never suggested a form of evolution by *natural retiming*.

The book is very rich in definitions, theories, and statements, more or less strictly correlated with organic codes. Examples are a definition of life, a definition of epigenesis, a theory of the cell, a theory of embryonic development, a theory of mental development, a hypothesis on the origin of life, and even a repartition of living beings into seven kingdoms. Hardly a reader will agree or disagree with the totality of these statements, and although some of them are not discussed in depth, nonetheless the book pushes the reader to see things from an unusual perspective, which per se is never a useless exercise. For these reasons I believe it is really a pity that a book proposing so many new ideas lists so few nonhistorical references, sometimes definitely insufficient to allow the reader to evaluate independently the sources Barbieri uses for introducing and supporting his theses. Besides, I have the impression that, at least for some part of the book, "facts" are not sufficiently updated to match the recent debate. For instance, in discussing Cambrian explosion, there is no reference to the problem of a possible long cryptic phase of metazoan evolution, as supported by molecular phylogenies, to the discovery of pre-Cambrian fossil embryos, to the debate on the level of conservation of the phylotypic stage, and in general to the most recent theories (reviewed in Collins and Valentine 2001). For instance, I would have been interested in seeing Barbieri's model of *two-phased* development compared with the so-called *set-aside* hypothesis (reviewed in Peterson et al. 2000). This renders the discussion more idealistic than critical. Another drawback is that the discussion of the role of organic codes in evolution lacks a comparative approach. I would like to have seen the evolution of codes mapped onto an (updated) evolutionary tree of life, with references to monophyletic groups rather then to grades of biological organization. What is rendered instead is a progressive increase of functional codes along the steps of the long-discredited *scala naturae*, from the first cell to *Homo* (p. 233).

Beyond the many detailed ideas presented in the book, I confess that I have some difficulties with the general scenario depicted by semantic biology. What makes Barbieri's theory unconvincing, and not even insightful, is his definition of epigenesis, which seems to me too rigid and hierarchical to accommodate our knowledge of descriptive embryology, developmental genetics, and reproductive biology. I do not believe epigenesis is "reconstruction" because development is not merely the production of a viable adult and because the product of this (re)construction can result in phenotypes quite different from the parental ones, either in response to external signals or due to developmental instability. I do not believe

epigenesis is "assembly," as its emergent and regulative properties come mainly from complex interactions among the different parts of the organism and between these and the genome. For a zygote, the genome is not the only source of "information": There are several kinds of nongenetic heredity, and also environmental factors, like physicochemical gradients and the gravitational field, can contribute to its spatial organization. Moreover, there is not always an egg at the beginning of a new life form: Metagenetic life cycles, some forms of asexual reproduction, indirect development through metamorphosis, and regeneration show that epigenesis incorporates (re)organizational principles that are not simply directed by the information deposited in the genome.

It seems to me that semantic biology, in separating information from structure, follows too closely the well known software-hardware paradigm, which leads inevitably to a form of genetic determinism. The introduction of a third party, the adaptor, does not change this scenario, merely producing a sort of "ribo-genetic determinism."

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