

Book Reviews

***The Origins of Order: Self-Organization and Selection in Evolution* by Stuart Kauffman**

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The Origins of Order is a book about a profoundly difficult question. It is not written from the perspectives of physics or chemistry but from the perspective of mathematical biology, and it is biological order that is the subject of its pages. Even within the biological context, it covers mainly evolutionary population dynamics (Part I), molecular evolution (Part II), and morphogenesis (Part III). The order associated with the self-assembly of protein complexes, the genetic apparatus, membranes, and cellular organelles is not discussed.

I tell you what is not covered by the book, because it still runs to over 700 pages and many of these pages require a lot of thought, including excursions into the referenced literature. Thus one must be willing to dedicate no small effort to digesting its contents. These are organized into three parts: one concerned with the modern mathematical Darwinism of fitness landscapes, one focused on the origins of life, and one exploring models of morphogenesis. The author makes clear with the length of the book and with explicit statements that his work is in progress and that no final synthesis is presented in the book: "The title of this book, *Origins of Order: Self-Organization and Selection in Evolution*, states the book's task: to answer the question, 'What are the sources of the overwhelming and beautiful order which graces the living world?' To presume to ask such a question is also to know one must not presume to succeed."

He confronts us with a remarkably diverse, modern offering of recent achievements in the computerized mathematical approach to this question. Few authors are more suited to take on such a task than is Stuart Kauffman, who is one of the pioneers in the modern renaissance of mathematical biology. Indeed, when it appeared, I considered "Control of Sequential Compartment Formation in *Drosophila*" (Kauffman et al., 1978) clear and classic evidence that Turing's ideas ("The Chemical Basis of Morphogenesis" (Turing, 1952)) would have wide-ranging impact when applied by powerful modern mathematicians and mathematical biologists.

The repeated theme of the book is the interaction of selection and self-organization. This is perhaps most emphatically stressed in the central third of the book: Part II—The Crystallization of Life contains four chapters dedicated to the question of the origin of life. The author highlights what he calls "a new view," even describing it as "heretical." The putative novelty is: "In this theory of the origin of life, it is

not necessary that any molecule reproduce itself." Rather: "... This web constitutes the crystallization of catalytic closure such that the system of polymers becomes collectively self-reproducing." I confess that I find this point of view extremely appealing, but it is not new.

In his beautiful book *Blueprint for a Cell* (DeDuke, 1991), Christian DeDuke not only makes the case for the emergence of self-catalyzing networks of polymers, he does so at several successive hierarchical levels: a protometabolic thioester-iron world, a multimeric coenzyme network world, and finally a polymer world of proteinoids and proto-RNAs. There is no mathematics in his presentation, but the conceptualization is starkly clear and detailed. What is more, this biological order, in DeDuke's view, does not simply self-organize but, instead, is the result of an energy-driven dynamics having its foundations in light, sulfur, iron, and thioesters. Even earlier, in my book *Energy and the Evolution of Life*, I clearly enunciated the same notions: "With P~P energy driving this relatively simple system of reactions, a set of coenzymes could possess enough functional diversity to promote a connected system of reactions that also could regenerate the coenzymes." I then went on to later describe the same mechanism for closed catalytic networks of polymers (proteinoids and RNAs) and, like DeDuke, underscored the necessity for energy derived from light, sulfur, iron, and pyrophosphate. There are other, earlier, antecedents to these ideas, although much less detailed and partially incomplete (see DeDuke's historical account and references).

The novelty Kauffman has brought to this point of view is the desire to see this idea exhibited mathematically. To a considerable extent, the successes of Richard Bagley and Walter Fontana in this regard (see chapter 7 of *Origins of Order*) were stimulated by Kauffman's enthusiasm and prodding. There are enormously difficult algorithmic complexities associated with this approach (random-catalyzed reaction graphs). Computing progress has been made with these structures, and it will, no doubt, have wider ranging applicability. However, in both Bagley's and Fontana's expositions, there is an unambiguous dependency on energy to drive the network dynamics. The importance of energy as a driving impetus for organization, as distinct from mere, and also almost magical, self-organization, is missed in Kauffman's exposition, in my opinion. This conceptual ingredient, with its physical and chemical underpinnings, make up the

missing chapter in Kauffman's story that might have enabled him to approach true synthesis.

This said, I still agree with Kauffman (from the Epilog) that: "Evolution is not just 'chance caught on the wing.' It is not just a tinkering of the ad hoc, of bricolage, of contraption. It is emergent order honored and honed by selection." We see here Kauffman's literate writing style and his joy in exposition, features that make reading his difficult book much easier.

Biological order obeys the first and second laws of thermodynamics and it is molecular in character. Its conceptualization rests firmly in physics and chemistry. Mathematics can sharpen some of the ideas, and it can make some ideas more accessible to physical scientists, but it is no substitute for experimental evidence from real biochemical experience.

Empirically based conceptualization has come first and has been followed later by mathematical formalization. I encourage the continuing efforts in this direction and I applaud Stuart Kauffman for showing us some of what can be done.

REFERENCES

1. Kauffman, S., R. Shymko, and K. Trabert. 1978. Control of sequential compartment formation in *Drosophila*. *Science (Wash. DC)*. 199:259–269.
2. Turing, A. M. 1952. The chemical basis of morphogenesis. *Philos. Trans. R. Soc. Lond. B*. 237:37–72.
3. DeDuve, C. 1991. *Blueprint for a Cell*. Neil Patterson Publishing, Burlington, NC. chaps. 5 and 6.
4. Fox, R. F. 1988. *Energy and the Evolution of Life*. W. H. Freeman, New York. p. 64.