Reviews
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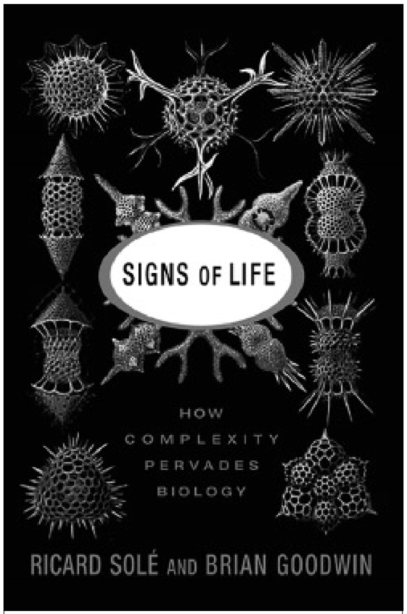
How Complexity Pervades Biology

The demonstration that seemingly random interactions among parts can generate order at the level of the whole represents a fascinating contribution of complexity theory to the natural sciences. This contribution has been particularly relevant in areas where traditional reductionism has failed. Studying the behavior of individual ants is a frustrating and fruitless endeavor if one aims to understand how ant societies function. Even detailed knowledge of the food preferences of each individual species may not be enough to predict under what set of circumstances a food web will be stable and maintain itself and when it will deteriorate. In *Signs of Life: How Complexity Pervades Biology,* Ricard Solé and Brian Goodwin portray how complexity theory can help to understand these and other complex, nonlinear systems. Over 300 pages and 10 chapters, *Signs of Life* presents a cross section through biology and how complexity theory can contribute to answering fundamental questions that disciplines ranging from neuroscience to ecology and evolution have been struggling with for decades.



SIGNS OF LIFE: HOW COMPLEXITY PERVADES BIOLOGY
by Ricard Solé and Brian Goodwin, Basic Books, New York, 2000 322 pp, $30 (hardcover), $17.50 (paper), ISBN 0-465-01927-7

The first chapter plunges right into it and introduces the reader to the deterministic yet unpredictable nature of chaos and strange attractors and to the spontaneous emergence of order in systems as diverse as Bénard cells and slime mold life cycles. Chapter 2 then discusses characteristics of emergent, ordered systems, their self-similar, fractal nature, and their strong dependence on initial conditions, as well as means of, and difficulties associated with, studying such systems. These first two chapters serve as an introduction to general complexity theory, and the chapters that follow then apply and extend these concepts and approaches through all levels of biological organization and occasionally even beyond biology. Given the breath of topics covered in Chapter 3–10, which include embryonic development, physiology, brain dynamics, social insect behavior, ecosystem dynamics, the origin of life, and macroevolution, this book seems to have been written for an audience coming from a wide range of backgrounds and with interests in a wide range of topics. For such an audience, however, the introductory chapters are challenging to say the least; for some they may simply be insufficient. So much in complexity theory tends to be obscured by jargon, by terminology that is meaningless unless defined explicitly (e.g., attractors and why some are strange) or carries with it connotations that differ from the often narrow, technical definition of the word (e.g., chaos and where and why it has an edge) that it is crucial to define terminology clearly and precisely, especially when one is likely to deal with an audience of interested amateurs such as myself. I therefore found myself longing for either a glossary or set-aside text boxes that would have shed light on terms and definitions. Because neither was available, I ended up consulting additional books, Web sites, and even my own class notes, which sometimes, but not always, helped. Although some of their writing in these early chapters could have been more transparent, Solé and Goodwin do an outstanding job right from the start in explaining the often complex mathematics behind the many models they cover. Starting with the first chapter, models are presented in separate text boxes, together with a verbal and mathematical description, allowing the reader to follow the main text as long as he/she wants, and to return to the mathematical details once one has room to think about them.

Once past the introductory chapters, one is in for an interesting and thought provoking application of complexity theory to life through organismal space and time. Chapter 3 focuses on enzyme kinetics and embryonic development, Chapter 4 discusses complex physiological processes such as homeostasis, circadian rhythms, and heart beat regulation, whereas Chapter 5 examines brain dynamics and neural networks. These chapters cover a wide range of interesting topics in an engaging manner, and as before mathematical models receive thorough and largely transparent treatment in set-aside text boxes. However, all three chapters share a similar architecture, and each one left me a touch disappointed in the end. In each case Solé and Goodwin provide arguments suggesting that complex systems from enzymatic cascades to neural networks have self-organizing properties stemming from the interactions of their component parts. They then go ahead and present models that formally describe these interactions and show that the patterns and system-wide behavior that emerge mirror some aspect of real organisms. Each chapter then ends with the promise that complexity theory may provide promising approaches to uncover the secrets behind, e.g., how our brains function or the causes of sudden cardiac arrest. To me, the connection between what complexity theory has been able to contribute so far in these fields, and what it, according to Solé and Goodwin, has yet to offer, seemed sometimes a bit of a stretch.

Things change, however, in Chapter 6, which explores the role of self-organization and emergence of order in social insects, covering such spectacular behaviors as nest building in termites and wasps, and raids in army ants. Here the match between patterns generated through modeling colony behavior and real life is staggering. But it does not stop there. For example, by modifying parameter values such as the rate at which a trail pheromone decays and is being renewed, different foraging patterns can be generated that match differences between foraging patterns of real ant species. In fact, these differences in parameter values evolve if virtual, alternative foraging strategies are allowed to compete with each other while being exposed to a certain set of virtual, external conditions, such as the size and distribution of resources. Here suddenly, complexity theory makes concrete predictions that a behavioral ecologist can test, in this case regarding the physiological mechanisms by which foraging patterns diverge, and the ultimate, ecological causes that may drive such divergences. To me this chapter provided some of the strongest evidence that complexity theory can inform and advance other branches of science, with mutual benefit.

The following three chapters then explore ecological dynamics, the origins of life, and macroevolution. Of those I found the chapters on ecological dynamics and macroevolution the most engaging and thought provoking. In particular, the discussion of what it takes to maintain a certain level of diversity of interacting species in a given ecosystem, what to expect when species start to drop out of the food web, and the often counterintuitive roles of weak and strong interactions within ecosystems all have important implications for predicting, and possibly guiding, the continuation of life on this planet. *Signs of Life*'s last chapter looks beyond the biological frame of reference and explores of the roles of chaos, emergence, and initial conditions in the rise and fall of human societies, market dynamics, urbanization, and traffic on paved and virtual highways.

Overall this is an engaging and interesting book. Complete newcomers to the field will be challenged and will most likely have to consult additional resources, such as the many references in the appendix, to work their way through the entire piece. In return, however, one can be a witness to order and structure emerging in space and time, from developing embryos to maturing ecosystems, and to how complexity theory can assist in uncovering the causes, mechanisms, and consequences of these processes. Although reading this book left me with the impression that we are still far away from a true synergism between complexity theory and the traditional natural sciences, *Signs of Life* offers plenty of encouragement that we are on the right track.

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How do such simple creatures as ants and termites manage such complex behavior as building nests? Why did all the animal kingdom's basic body plans appear in a single geological era, and no new ones since? Yet, as Ricard Sole and Brian Goodwin show, various tools of complexity theory can offer us new ways to understand these phenomena." Author. R. V. SolÃ© & B. C. Goodwin. Complex adaptive systems, in : G.A. Cowan, D. Pines, D. Meltzer (Eds.). Complexity. Metaphors, models and reality, Wesley Publishing Co., Reading, MA, 1994, pp. 17â€“45. [Google Scholar]. R.F. Gesteland, T.R. Cech, J.F. Atkins. The RNA World. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 2006. [Google Scholar].Â R. SolÃ©, B. Goodwin. Signs of Life. How Complexity Pervades Biology. Basic Books, New York, 2000. [Google Scholar]. R. Sousa. Structural and mechanistic relationships between nucleic acid polymerases. Trends Biochem. Sci., 21 (1996), 186â€“190. How does morphological complexity evolve? This study suggests that the likelihood of mutations increasing phenotypic complexity becomes smaller when the phenotype itself is complex. In addition, the complexity of the genotype-phenotype map (GPM) also increases with the phenotypic complexity.Â In the preface to their book Signs of Life e How Complexity Pervades Biology, Sole & Goodwin (2000) state that: Biomechanical Attractors â€“ a Paleolithic prescription for tendinopathy & glycemic control. Article. Complex adaptive systems, in : G.A. Cowan, D. Pines, D. Meltzer (Eds.). Complexity. Metaphors, models and reality, Wesley Publishing Co., Reading, MA, 1994, pp. 17â€“45. R.F. Gesteland, T.R. Cech, J.F. Atkins.Â Signs of Life. How Complexity Pervades Biology. Basic Books, New York, 2000. Sousa, R.. Structural and mechanistic relationships between nucleic acid polymerases. No AccessGeneral Biology. Signs of Life: How Complexity Pervades Biology. By Ricard SolÃ© and , Brian Goodwin. New York: Basic Books.