

Modeling Complex Systems

by **Nino Boccara**

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How to Do It

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Complex systems are those with many strongly interdependent variables. This excludes systems with only a few effective variables, the kind we meet in elementary dynamics. It also excludes systems with many independent variables; we learn how to deal with them in elementary statistical mechanics. Complexity appears where coupling is important, but doesn't freeze out most degrees of freedom.

Complex systems have been infiltrating physics for about two decades, just they have crept into biology, computer science and [economics](#). It comes to us from two sources. One is dynamics, studying the qualitative and effectively-stochastic ("chaotic") properties of nonlinear systems. The other is the statistical mechanics of critical phenomena. Criticality taught us to derive large-scale order from local interactions, and to expect that toy models of those interactions would yield universally valid results. (The latter source is under-appreciated by non-physicists, because "fixed point of the renormalization group" sounds duller than "strange attractor".) Both sources lead us to see computer simulation as an important source of knowledge.

It is now normal to find physics journals publishing papers on [animal populations](#), [botanical invasions](#), [cardiac arrest](#), [developmental biology](#), [evolutionary games](#), [finance](#), [gene regulation](#), [historical linguistics](#), [immunology](#), [junk DNA](#), [Kolmogorov complexity](#), [learning machines](#), [mass extinction](#), and so on to [Zipf's law](#). Nonetheless, we have had no sound introductory textbook --- one from which students would acquire more valid insights than dubious metaphysics. (This may account for the highly variable quality of those papers.) Happily, Boccara's new book is full of useful knowledge, and free from odd notions.

The book has three parts: two introductory chapters, three on "mean-field type models" and three on "agent-based models". Every chapter contains a truly remarkable number of examples, mixing classical and up-to-date models from many disciplines with physicists' contributions; a number of these, like the "susceptible-infected-recovered" model from epidemiology, recur across the chapters, revealing new aspects. The corner-stone is chapter two, where Boccara gives a marvelous demonstration of *how* one models complex systems, guiding the reader through the construction of increasingly elaborate models of predator-prey oscillations in ecology, incorporating more and more sophisticated mechanisms of interaction. and testing the results against (stylized) empirical facts. Much of the rest of the book unfolds the ideas glimpsed in this chapter.

The part on "mean-field type models" covers finite-dimensional global dynamics. Boccara carefully states rigorous results of nonlinear dynamics, especially bifurcation theory, together with precise definitions of the concepts involved. He omits proofs, instead using the theorems to analyze real models. The final part, on "agent-based models", delivers excellent, up-to-date chapters on cellular automata (Boccara's specialty), power-law distributions, and networks. (Readers should be aware that Boccara and

computer scientists or economists define "agent-based model" in different, though ultimately equivalent, ways.) The chapter on power laws deserves special mention: it gives cautionary examples showing how easy it is to mistake other things (e.g., log-normals) for power-laws, and a prophylactic introduction to statistical hypothesis testing. The cover promises deep thoughts on the nature of complexity, emergence, and so forth. In fact, Boccara wisely leaves these alone: while interesting scientific work has been done on these topics, it is quite advanced, and obscured by a much larger volume of fluff. Instead, he provides a guide to actual model-building, covering an astonishing range of subjects along the way.

That said, and allowing for the need to be selective, I was struck by three omissions. (1) What one might call "traditional physics" complex systems: spin glasses, turbulence, polymers, and generally soft or [far-from-equilibrium](#) condensed matter. (2) The theory of information and computation. These are crucial components in meaningful complexity measures, but surprisingly little-studied by physicists. (Badii and Politi's *Complexity: Hierarchical Structures and Scaling in Physics* is a great, but more demanding, guide to these subjects.) (3) Adaptation, whether at the individual and at the population or evolutionary level. No even cases where physical methods have been useful, like neural network learning, make it in. (Here the best introduction I know of is G. W. Flake's *The Computational Beauty of Nature*, which is at a lower mathematical level.) These topics, however, would have needed another hundred pages at least.

The ideal audience for this book is first- or second- year physics graduate students who have had a one-semester course in modern statistical mechanics, and so some grasp of the ideas of criticality, fluctuations, correlation functions, etc. Anyone so prepared will find the book clear and well worth reading. This ought to be the standard introduction to the physics of complex systems for the foreseeable future, and everyone seriously concerned with the subject should read it.

Disclaimer: I got a review copy of this book from *Physics Today*, but I have no stake in the book's success.

xii + 397 pp., numerous black and white diagrams, extensive bibliography, index

[Cellular Automata](#) / [Physics](#) / [Self-Organization, Complexity, etc.](#)

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