EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 1.3

Some Past Initiatives

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My goals in this book are sufficiently broad and fundamental that there have inevitably been previous attempts to achieve at least some of them. But without the ideas and methods of this book there have been basic issues that have eventually ended up presenting almost insuperable barriers to every major approach that has been tried.

Artificial Intelligence. When electronic computers were first invented, it was widely believed that it would not be long before they would be capable of human-like thinking. And in the 1960s the field of artificial intelligence grew up with the goal of understanding processes of human thinking and implementing them on computers. But doing this turned out to be much more difficult than expected, and after some spin-offs, little fundamental progress was made. At some level, however, the basic problem has always been to understand how the seemingly simple components in a brain can lead to all the complexities of thinking. But now finally with the framework developed in this book one potentially has a meaningful foundation for doing this. And indeed building on both theoretical and practical ideas in the book I suspect that dramatic progress will eventually be possible in creating technological systems that are capable of human-like thinking.

Artificial Life. Ever since machines have existed, people have wondered to what extent they might be able to imitate living systems. Most active from the mid-1980s to the mid-1990s, the field of artificial life concerned itself mainly with showing that computer programs could be made to emulate various features of biological systems. But normally it was assumed that the necessary programs would have to be quite complex. What the discoveries in this book show, however, is that in fact very simple programs can be sufficient. And such programs make the fundamental mechanisms for behavior clearer—and probably come much closer to what is actually happening in real biological systems.

Catastrophe Theory. Traditional mathematical models are normally based on quantities that vary continuously. Yet in nature discrete changes are often seen. Popular in the 1970s, catastrophe theory was concerned with showing that even in traditional mathematical models, certain simple discrete changes could still occur. In this book I do not start from any assumption of continuity—and the types of behavior I study tend to be vastly more complex than those in catastrophe theory.

Chaos Theory. The field of chaos theory is based on the observation that certain mathematical systems behave in a way that depends arbitrarily sensitively on the details of their initial conditions. First noticed at the end of the 1800s, this came into prominence after computer simulations in the 1960s and 1970s. Its main significance is that it implies that if any detail of the initial conditions is uncertain, then it will eventually become impossible to predict the behavior of the system. But despite some claims to the contrary in popular accounts, this fact alone does not imply that the behavior will necessarily be complex. Indeed, all that it shows is that if there is complexity in the details of the initial conditions, then this complexity will eventually appear in the large-scale behavior of the system. But if the initial conditions are simple, then there is no reason for the behavior not to be correspondingly simple. What I show in this book, however, is that even when their initial conditions are very simple there are many systems that still produce highly complex behavior. And I argue that it is this phenomenon that is for example responsible for most of the obvious complexity we see in nature.

Complexity Theory. My discoveries in the early 1980s led me to the idea that complexity could be studied as a fundamental independent phenomenon. And gradually this became quite popular. But most of the scientific work that was done ended up being based only on my earliest discoveries, and being very much within the framework of one or another of the existing sciences—with the result that it managed to make very little progress on any general and fundamental issues. One feature of the new kind of science that I describe in this book is that it finally makes possible the development of a basic understanding of the general phenomenon of complexity, and its origins.

Computational Complexity Theory. Developed mostly in the 1970s, computational complexity theory attempts to characterize how difficult certain computational tasks are to perform. Its concrete results have tended to be based on fairly specific programs with complicated structure yet rather simple behavior. The new kind of science in this book, however, explores much more general classes of programs—and in doing so begins to shed new light on various longstanding questions in computational complexity theory.

Cybernetics. In the 1940s it was thought that it might be possible to understand biological systems on the basis of analogies with electrical machines. But since essentially the only methods of analysis available were ones from traditional mathematics, very little of the complex behavior of typical biological systems was successfully captured.

Dynamical Systems Theory. A branch of mathematics that began roughly a century ago, the field of dynamical systems theory has been concerned with studying systems that evolve in time according to certain kinds of mathematical equations—and in using traditional geometrical and other mathematical methods to characterize the possible forms of behavior that such systems can produce. But what I argue in this book is that in fact the behavior of many systems is fundamentally too complex to be usefully captured in any such way.

Evolution Theory. The Darwinian theory of evolution by natural selection is often assumed to explain the complexity we see in biological systems—and in fact in recent years the theory has also increasingly been applied outside of biology. But it has never been at all clear just why this theory should imply that complexity is generated. And indeed I will argue in this book that in many respects it tends to oppose complexity. But the discoveries in the book suggest a new and quite different mechanism that I believe is in fact responsible for most of the examples of great complexity that we see in biology.

Experimental Mathematics. The idea of exploring mathematical systems by looking at data from calculations has a long history, and has gradually become more widespread with the advent of computers and

Mathematica. But almost without exception, it has in the past only been applied to systems and questions that have already been investigated by other mathematical means—and that lie very much within the normal tradition of mathematics. My approach in this book, however, is to use computer experiments as a basic way to explore much more general systems—that have never arisen in traditional mathematics, and that are usually far from being accessible by existing mathematical means.

Fractal Geometry. Until recently, the only kinds of shapes widely discussed in science and mathematics were ones that are regular or smooth. But starting in the late 1970s, the field of fractal geometry emphasized the importance of nested shapes that contain arbitrarily intricate pieces, and argued that such shapes are common in nature. In this book we will encounter a fair number of systems that produce such nested shapes. But we will also find many systems that produce shapes which are much more complex, and have no nested structure.

General Systems Theory. Popular especially in the 1960s, general systems theory was concerned mainly with studying large networks of elements—often idealizing human organizations. But a complete lack of anything like the kinds of methods I use in this book made it almost impossible for any definite conclusions to emerge.

Nanotechnology. Growing rapidly since the early 1990s, the goal of nanotechnology is to implement technological systems on atomic scales. But so far nanotechnology has mostly been concerned with shrinking quite familiar mechanical and other devices. Yet what the discoveries in this book now show is that there are all sorts of systems that have much simpler structures, but that can nevertheless perform very sophisticated tasks. And some of these systems seem in many ways much more suitable for direct implementation on an atomic scale.

Nonlinear Dynamics. Mathematical equations that have the property of linearity are usually fairly easy to solve, and so have been used extensively in pure and applied science. The field of nonlinear dynamics is concerned with analyzing more complicated equations. Its greatest success has been with so-called soliton equations for which careful manipulation leads to a property similar to linearity. But the kinds of systems that I discuss in this book typically show much more complex behavior, and have no such simplifying properties.

Scientific Computing. The field of scientific computing has usually been concerned with taking traditional mathematical models—most often for various kinds of fluids and solids—and trying to implement them on computers using numerical approximation schemes. Typically it has been difficult to disentangle anything but fairly simple phenomena from effects associated with the approximations used. The kinds of models that I introduce in this book involve no approximations when implemented on computers, and thus readily allow one to recognize much more complex phenomena.

Self-Organization. In nature it is quite common to see systems that start disordered and featureless, but then spontaneously organize themselves to produce definite structures. The loosely knit field of self-organization has been concerned with understanding this phenomenon. But for the most part it has used traditional mathematical methods, and as a result has only been able to investigate the formation of fairly simple structures. With the ideas in this book, however, it becomes possible to understand how vastly more complex structures can be formed.

Statistical Mechanics. Since its development about a century ago, the branch of physics known as statistical mechanics has mostly concerned itself with understanding the average behavior of systems that consist of large numbers of gas molecules or other components. In any specific instance, such systems often behave in a complex way. But by looking at averages over many instances, statistical mechanics has usually managed to avoid such complexity. To make contact with real situations, however, it has often had to use the so-called Second Law of Thermodynamics, or Principle of Entropy Increase. But for more than a century there have been nagging difficulties in understanding the basis for this principle. With the ideas in this book, however, I believe that there is now a framework in which these can finally be resolved.