EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 1.2

Relations to Other Areas

simple programs to brains to our whole universe, the principle implies that there is a basic equivalence that makes the same fundamental phenomena occur, and allows the same basic scientific ideas and methods to be used. And it is this that is ultimately responsible for the great power of the new kind of science that I describe in this book.

Relations to Other Areas

Mathematics. It is usually assumed that mathematics concerns itself with the study of arbitrarily general abstract systems. But this book shows that there are actually a vast range of abstract systems based on simple programs that traditional mathematics has never considered. And because these systems are in many ways simpler in construction than most traditional systems in mathematics it is possible with appropriate methods in effect to go further in investigating them.

Some of what one finds are then just unprecedentedly clear examples of phenomena already known in modern mathematics. But one also finds some dramatic new phenomena. Most immediately obvious is a very high level of complexity in the behavior of many systems whose underlying rules are much simpler than those of most systems in standard mathematics textbooks.

And one of the consequences of this complexity is that it leads to fundamental limitations on the idea of proof that has been central to traditional mathematics. Already in the 1930s Gödel's Theorem gave some indications of such limitations. But in the past they have always seemed irrelevant to most of mathematics as it is actually practiced.

Yet what the discoveries in this book show is that this is largely just a reflection of how small the scope is of what is now considered mathematics. And indeed the core of this book can be viewed as introducing a major generalization of mathematics—with new ideas and methods, and vast new areas to be explored.

The framework I develop in this book also shows that by viewing the process of doing mathematics in fundamentally computational terms it becomes possible to address important issues about the foundations even of existing mathematics.

Physics. The traditional mathematical approach to science has historically had its great success in physics—and by now it has become almost universally assumed that any serious physical theory must be based on mathematical equations. Yet with this approach there are still many common physical phenomena about which physics has had remarkably little to say. But with the approach of thinking in terms of simple programs that I develop in this book it finally seems possible to make some dramatic progress. And indeed in the course of the book we will see that some extremely simple programs seem able to capture the essential mechanisms for a great many physical phenomena that have previously seemed completely mysterious.

Existing methods in theoretical physics tend to revolve around ideas of continuous numbers and calculus—or sometimes probability. Yet most of the systems in this book involve just simple discrete elements with definite rules. And in many ways it is the greater simplicity of this underlying structure that ultimately makes it possible to identify so many fundamentally new phenomena.

Ordinary models for physical systems are idealizations that capture some features and ignore others. And in the past what was most common was to capture certain simple numerical relationships—that could for example be represented by smooth curves. But with the new kinds of models based on simple programs that I explore in this book it becomes possible to capture all sorts of much more complex features that can only really be seen in explicit images of behavior.

In the future of physics the greatest triumph would undoubtedly be to find a truly fundamental theory for our whole universe. Yet despite occasional optimism, traditional approaches do not make this seem close at hand. But with the methods and intuition that I develop in this book there is I believe finally a serious possibility that such a theory can actually be found.

Biology. Vast amounts are now known about the details of biological organisms, but very little in the way of general theory has ever emerged. Classical areas of biology tend to treat evolution by natural selection as a foundation—leading to the notion that general observations about living systems should normally be analyzed on the basis of evolutionary history rather than abstract theories. And part of the reason for this is that traditional mathematical models have never seemed to come even close to capturing the kind of complexity we see in biology. But the discoveries in this book show that simple programs can produce a high level of complexity. And in fact it turns out that such programs can reproduce many features of biological organisms—and for example seem to capture some of the essential mechanisms through which genetic programs manage to generate the actual biological forms we see. So this means that it becomes possible to make a wide range of new models for biological systems—and potentially to see how to emulate the essence of their operation, say for medical purposes. And insofar as there are general principles for simple programs, these principles should also apply to biological organisms—making it possible to imagine constructing new kinds of general abstract theories in biology.

Social Sciences. From economics to psychology there has been a widespread if controversial assumption—no doubt from the success of the physical sciences—that solid theories must always be formulated in terms of numbers, equations and traditional mathematics. But I suspect that one will often have a much better chance of capturing fundamental mechanisms for phenomena in the social sciences by using instead the new kind of science that I develop in this book based on simple programs. No doubt there will quite quickly be all sorts of claims about applications of my ideas to the social sciences. And indeed the new intuition that emerges from this book may well almost immediately explain phenomena that have in the past seemed quite mysterious. But the very results of the book show that there will inevitably be fundamental limits to the application of scientific methods. There will be new questions formulated, but it will take time before it becomes clear when general theories are possible, and when one must instead inevitably rely on the details of judgement for specific cases.

Computer Science. Throughout its brief history computer science has focused almost exclusively on studying specific computational systems set up to perform particular tasks. But one of the core ideas of this book is to consider the more general scientific question of what arbitrary computational systems do. And much of what I have found is vastly different from what one might expect on the basis of existing computer science. For the systems traditionally studied in computer science tend to be fairly complicated in their construction—yet yield fairly simple behavior that recognizably fulfills some particular purpose. But in this book what I show is that even systems with extremely simple construction can yield behavior of immense complexity. And by thinking about this in computational terms one develops a new intuition about the very nature of computation.

One consequence is a dramatic broadening of the domain to which computational ideas can be applied—in particular to include all sorts of fundamental questions about nature and about mathematics. Another consequence is a new perspective on existing questions in computer science—particularly ones related to what ultimate resources are needed to perform general types of computational tasks.

Philosophy. At any period in history there are issues about the universe and our role in it that seem accessible only to the general arguments of philosophy. But often progress in science eventually provides a more definite context. And I believe that the new kind of science in this book will do this for a variety of issues that have been considered fundamental even since antiquity. Among them are questions about ultimate limits to knowledge, free will, the uniqueness of the human condition and the inevitability of mathematics. Much has been said over the course of philosophical history about each of these. Yet inevitably it has been informed only by current intuition about how things are supposed to work. But my discoveries in this book lead to radically new intuition. And with this intuition it turns out that one can for the first time begin to see resolutions to many longstanding issues—typically along rather different lines from those expected on the basis of traditional general arguments in philosophy.

Art. It seems so easy for nature to produce forms of great beauty. Yet in the past art has mostly just had to be content to imitate such forms. But now, with the discovery that simple programs can capture the essential mechanisms for all sorts of complex behavior in nature, one can imagine just sampling such programs to explore generalizations of the forms we see in nature. Traditional scientific intuition—and early computer art—might lead one to assume that simple programs would always produce pictures too simple and rigid to be of artistic interest. But looking through this book it becomes clear that even a program that may have extremely simple rules will often be able to generate pictures that have striking aesthetic qualities—sometimes reminiscent of nature, but often unlike anything ever seen before.

Technology. Despite all its success, there is still much that goes on in nature that seems more complex and sophisticated than anything technology has ever been able to produce. But what the discoveries in this book now show is that by using the types of rules embodied in simple programs one can capture many of the essential mechanisms of nature. And from this it becomes possible to imagine a whole new kind of technology that in effect achieves the same sophistication as nature. Experience with traditional engineering has led to the general assumption that to perform a sophisticated task requires constructing a system whose basic rules are somehow correspondingly complicated. But the discoveries in this book show that this is not the case, and that in fact extremely simple underlying rules—that might for example potentially be implemented directly at the level of atoms—are often all that is needed. My main focus in this book is on matters of basic science. But I have little doubt that within a matter of a few decades what I have done will have led to some dramatic changes in the foundations of technology—and in our basic ability to take what the universe provides and apply it for our own human purposes.