Comment

Summer reading

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It isn't a thriller, or a romance, or an historical novel. It's not a biography, or a tell-all memoir. Nor is it a self-help manual or a new diet. The 23rd-most frequently ordered book on the sales list at Amazon.com at the time of writing is a hardcover book that's 1,197 pages long. It has approximate dimensions (in inches) of 2.5 x 10 x 8, so it's not exactly the sort of thing that fits comfortably on your lap on the beach, or while you're sitting on an airplane seat, or in the bathroom. Your laptop computer is probably smaller and lighter. And it isn't published by Knopf, or Random House, or Chapman and Hall, or any other publisher you've ever heard of. The book (ISBN 1579550088), published on 14 May, 2002, is *A New Kind of Science* by Stephen Wolfram. It has its own website, [http://www.wolframscience.com], where you can read sample sections, glowing reviews, and comments from admirers. You can also read a summary of the book, which begins like this:

> "This long-awaited work from one of the world's most respected scientists presents a series of dramatic discoveries never before made public. Starting from a collection of simple computer experiments - illustrated in the book by striking computer graphics - Stephen Wolfram shows how their unexpected results force a whole new way of looking at the operation of our universe.
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> Wolfram uses his approach to tackle a remarkable array of fundamental problems in science, from the origins of apparent randomness in physical systems, to the development of complexity in biology, the ultimate scope and limitations of mathematics, the possibility of a truly fundamental theory of physics, the interplay between free will and determinism, and the character of intelligence in the universe. Written with exceptional clarity, and illustrated by nearly a thousand original pictures, this seminal book allows scientists and nonscientists alike to participate in what promises to be a major intellectual revolution."

All of which sounds terrific until you realize that the publisher is Wolfram Media, Inc., so that the modest claims of being "long-awaited and written (with exceptional clarity) by one of the world's most respected scientists", and so on, are … well … written by someone employed by the author, if not by the author himself.

And yet, this isn't some crank claiming perpetual motion. Stephen Wolfram actually is a highly respected scientist. He was born in London and educated at Eton, Oxford, and Caltech. He received his PhD in theoretical physics in 1979 at the age of 20, on the basis of significant work in physics and cosmology. He received one of the first MacArthur 'genius' awards. He's also been successful in business: in 1986 he founded Wolfram Research, Inc. and began the creation of *Mathematica*, now the world's leading software system for technical computing and symbolic programming (which explains where the money to start Wolfram Media, Inc. came from). Whatever he is, he's no crank. This is a man who's been highly successful at everything he's tried to do.

Which may be the problem. Early success is wonderful, I'm sure - one seems to be favored by the gods - but it creates the heavy burden of perpetual high expectations. Wolfram, by his own account, has spent the last ten years of his life on the science in this book. (He estimates that while writing it, he typed 100 million keystrokes and moved his computer mouse more than 100 miles.) Now 53 years old, he may feel under tremendous pressure to have another huge success - after all, that's all he's ever known. Working alone, self-funded, doing all his 'experiments' on a computer, he has been insulated from the real world of controls and peer review, from the need to be practical, from criticism of any kind. That may well be the ideal environment for producing a truly novel idea, but it isn't the ideal environment for any sort of reality check. The best scientists tend to be their own toughest referees.

What has Wolfram done, actually? I can save you the trouble of trying to read all of it - I'm sorry, I don't think it's written

with “exceptional clarity”; I find it repetitive, self-indulgent (how could it be anything but?) and tedious. But having said that, I think a lot of people ought to read at least some of it, because while I don’t believe that Wolfram has created a new kind of science, I do think he has created a very powerful tool that may have some if its best applications in genome-driven biology. The book focuses on the use of cellular automata - a type of computer algorithm that Wolfram popularized in the 1980s - to simulate the behavior of a host of natural phenomena. Cellular automata are, in the simplest sense, rules that specify how the colors of each row of squares depend on the colors of the previous row. Suppose one has a grid consisting of a set of squares arranged like a chessboard. One such cellular automaton might go like this. Start with a single black square in the middle of the first row. Then a square in the next row should only be black if one or the other, but not both, of its neighbors on the previous row were black. Such a rule produces a pattern of nested triangles. Since the output of cellular automata depend not only on the rule being used to generate the color pattern but also on the initial conditions - the arrangement of colors in the first row - chaotic patterns as well as regular patterns can be produced by them. In fact, some of the most dramatic examples Wolfram uses generate patterns that are regular in parts and seemingly chaotic in others, on the same diagram. He is able to model an impressive number of natural phenomena using these very simple concepts, with no use of equations. He does not, however, model general relativity, or predict the Higgs boson. If his method really is able to reproduce everything in the universe, he doesn’t demonstrate it.

Part of the problem with his claim that he can reproduce everything is, of course, that the whole book might be based on a gigantic fallacy: Wolfram assumes that because complex behavior is widespread in nature and because it can be modeled by cellular automata, all complex behavior must be produced by cellular automata. There’s no real evidence for that assumption. But while this difficulty makes it likely that his self-glorifying claim to have explained nearly everything in the universe is, to say the least, a trifle overblown, it does not mean that he hasn’t done something important.

Genomics is driving all of biology back to the level of the whole cell, and the whole organism. Understanding such enormous complexity demands that the results of reductionist approaches such as biochemistry, cell biology and structural biology ultimately be combined into models that predict morphology and behavior. Consider the discovery that the gradient of a single chemical substance controls body pattern in the developing fly or zebrafish embryo: it used to be assumed that adequate descriptions of the progression from simple phenomena to such complex systems would require complex mathematical expressions. That assumption has probably retarded the development of systems biology, because most biologists tend to shy away from higher mathematics - that’s often the reason they were drawn to biology rather than to, say, physics, in the first place. Wolfram has shown that very complex patterns can arise from extremely simple rules. Although he seems to think that concept is novel, it isn’t; nearly every biologist I know of has always believed that, and genomics has only reinforced that belief. Genome sequences show that free-living organisms can be created from less than 1,000 genes, and even the most complex organisms, such as humans, seem to require far fewer than 100,000 genes. At heart, biology is simple; Wolfram is telling us nothing new when he asserts that. But the problem has always been how to generate complexity from that simplicity. Wolfram may or may not have found the way that complex systems arise - my bet is that he has for some things, but not all of them - but regardless, what he may well have done is to take biocomplexity out of the hands of the mathematicians and give it back to the biologists. The tool he has developed - computer simulations with cellular automata - can be carried out by anybody. Cellular automata may or may not be what Nature uses, but if they provide a rapid and accurate way of modeling what happens, they will help to drive understanding forward. Developmental biologists in particular should find them thought-provoking, but so should those genome scientists who are beginning to try to model signal transduction networks and the rest of the parallel, interconnected, highly redundant circuitry of the cell.

Downloadable programs for generating cellular automata are available online at [http://www.wolframscience.com/nks/programs/]; they are simple enough to allow anyone to try these ideas out. Have a go: it’s fun, and you can decide for yourself if Wolfram has indeed come up with something that will make a real contribution to our ability to understand how complex systems work. But as for it being a new kind of science ... well, as far as that goes, some of the best advice I ever received was this: if someone says they have something that’s better than sliced bread, you should probably invest immediately - in sliced bread.