But does it compute?

A New Kind of Science
By Stephen Wolfram
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REVIEWED BY **MICHAEL R. LeGAULT**

'The final truth about a phenomenon resides in the mathematical description of it; so long as there is no imperfection in this, our knowledge of the phenomenon is complete."

Sir James Jeans, physicist

When I was a graduate student, quantum mechanics, and in particular a single mathematical formula, Schrödinger's wave equation, was an unending source of perversely gratifying befuddlement for me. I remember being hunkered down in the library for hours with the wave equation, feeling that if I reread the textbook's previous 30 pages one more time, I might, to paraphrase Tom Wolfe, disappear up my own fundamental aperture and emerge in the fourth dimension as an attenuated Yaqui warrior. Mysteriously, this deceptively simple differential equation accounted for the strange interactions and properties of subatomic particles in the quantum netherworld. Even richer, except for exceedingly simple systems of one or two particles, the equation couldn't be solved.

This, Stephen Wolfram argues, is the snag we inevitably run into when we use mathematics to model the real world. The custom of modelling the features of the physical world lay at the heart of modern science. The idea is to try to concoct a description (usually in mathematical terms) that will capture its essence. When predictions (e.g., there will be a solar eclipse on June 9, 2006) based on these models agree with observations (e.g., the solar eclipse occurs on this date), the models, like obedient children, are considered good.

Mathematical equations serve us well enough for modelling and predicting simple systems: the heat it will take to boil a given amount of water, or the lift produced by air travelling over an airplane's wing. Try using math, however, to explain the swings in the stock market or global climate change, and the equations must, of necessity, become idealizations of this complexity, capturing some features and excluding others.

A better way of modeling the complex behaviour of physical and social phenomena, Wolfram claims, is to use simple computer programs. For the past 10 years, Wolfram, a British-born theoretical physicist and millionaire entrepreneur — who published his first scientific paper at 15, earned a PhD from Caltech at 20 and, in 1981, was the youngest-ever recipient of a MacArthur Foundation "genius" grant — has been fervently working independent of any academic or scientific institutions to produce evidence to support this claim. The result, much anticipated in science circles, where Wolfram has a reputation as brilliant but annoying, is this self-published manifesto containing more than 700 pages of main text, 500 pages of notes and 973 illustrations generated by his computational software, Mathematica.

Alan Turing (on the bus steps) with other members of the Walton Athletic Club in 1946: Founder of computer science, mathematician, philosopher and cracker of the Enigma Code during the Second World War, he is the precursor for Stephen Wolfram's grandiose claim that simple computer programs can be used to model physical and social reality.

The prose is clear, and the practical and philosophical implications of the book's thesis, if correct, are profound. However, the book could easily be cut by half, not only to the reader's gain, but to the author's. Also, Wolfram's self-aggrandizing style, which largely filters out or diminishes the contributions of others, at least from the main text, is bound to further anger scientists, many of whom are ultimately the ones that must pass judgment on his work and ideas.

Most problematic, however, are stickier technical questions about the viability of using programs to model complex systems, questions that could deflate this new science before it ever gets fully off the ground.

Wolfram bases his bold claim that algorithmic programs, not equations, are the key to understanding the way the universe works on thousands of programs (he terms them experiments) he has run; he calls them cellular automata. A cellular automaton consists of a single horizontal line of square cells, each either black or white. As one proceeds to the next line of cells, a rule is performed that dictates the colour of a given cell from the colour of that cell and that of its immediate neighbours to the left and right. Alan Turing — known as the founding father of computer programming, as well as for decrypting the German Enigma code, helping to win the Battle of the Atlantic during the Second World War — ran similar types of programs on a "Turing machine" to produce random sets of numbers.

The rules themselves are simple; for example, a cell should be black in all cases where it or either of its neighbours were black on the step before. Using a computer to perform the rule ad infinitum generates a visual pattern. Varying the rules produces different patterns, most containing intricate but nonetheless repetitive elements, such as nested triangular shapes.

However, in 1984, Wolfram, then just 25, discovered a program known as Rule 30, which produced infinitely random output. He has since discovered many more such rules, including one (110) that he considers a candidate for a universal computer, the simplest computer that can mimic an arbitrarily complex machine.

Wolfram presents this evidence,

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then performs something of an intellectual sleight of hand: a two-step syllogism. Just as simple programs cause complexity in cellular automata, so too do modest sets of rules govern the behaviour of complex systems in nature. He provides illustrations of programs that suggest pigmentation patterns in animals, the shapes of sea shells and the crystalline architecture of snowflakes. Indeed, Wolfram asserts that simple programs may be the answer to long-standing mysteries about the role of natural selection in evolution, human free will and the origins of the universe. "And could it even be," he asks, "that underneath all the complex phenomena we see in physics there lies some simple program which, if run for long enough, would reproduce our universe in every detail?"

The idea that the universe is perhaps a one-off produced from some giant Turing machine in the sky is certain to resonate with the computer-savvy generation. If such an omnipotent algorithm were ever found, it would certainly restore an elegance lost in the standard model of the forces of physics, string theory and other ungainly mathematical constructs physicists must abide to explain the universe.

However, the notion that the universe is a giant computer, continuously in the process of calculating its next state, is not Wolfram's — and it's not new. It traces back to the field of digital physics founded in the 1980s by researchers Tommaso Toffoli and Edward Fredkin of Boston University, as well as others. As detailed in a 1992 paper by Fredkin (A New Cosmogony), the key difference between digital and traditional physics is that digital physics assumes that reality, even at its most basic level, which is space-time, remains unalterably discontinuous or granular in some way.

This is a big deal, because the assumption of continuity underlies many of the most important scientific laws, including those of Newton and Einstein. Wolfram devotes the entire 112 pages of chapter nine to fascinating blue-sky speculation about how simple programs operating on the discrete quantities proposed by digital physics could account for many of the things we know about the universe (without once mentioning, even in the the chapter's notes, Toffoli, Fredkin or the term digital physics).

Wolfram proposes that at the smallest level, space consists of a giant network of "nodes." Interactions within the network, he says, can account for everything from to gravity to the formation of elementary particles such as quarks and electrons.

A bit of irony percolates while one reads Wolfram musing on the ways his New Science might explain results of Old Science. But there is a good reason he must go through with this exercise: Math-based Old Science theories like relativity and quantum mechanics have been confirmed experimentally over and over. The principles of quantum mechanics, for example, are verified in the operation of a host of everyday devices, from transistors to CD players to hospital MRI machines. Not that there couldn't be an alternative, more encompassing model of reality, such as the one Wolfram proposes. But how do we test for it experimentally?

In fact, for much of what Wolfram proposes, we can't. Even worse, unlike math-based models and equations, Wolfram's New Science is not intuitive: When Newton wanted to account for the existence of the colour red, at least he could be fairly certain the mathematical terms would involve the properties of light. With simple programs, there is no logical way to deduce what the rules of program might be for a given complex system — climate, for example. Nor is there any way to tell what the output of cellular automata programs will be beforehand. You must simply run them and see what you get — snowflakes or checkerboards.

In the end, Wolfram's *New Science* reads something like a Dostoyevskian discussion about the existence of God: provocative, consumingly ambitious, at times shot through with prodigious prescience. But it is not science. Not yet.

Michael R. LeGault, the editor of a technical/business trade publication and a freelance journalist, did eventually pass quantum mechanics.