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'PROGRAMMING THE UNIVERSE,' BY SETH LLOYD

Welcome to the Machine

Review by COREY S. POWELL

Seth Lloyd certainly gives his readers a lot of bang for their buck. In the space of 221 dense, frequently thrilling and occasionally exasperating pages, he tackles computer logic, thermodynamics, chaos theory, complexity, quantum mechanics, cosmology, consciousness, sex and the origin of life — throwing in, for good measure, a heartbreaking afterword that repaints the significance of all that has come before.

The source of all this intellectual mayhem is the kind of Big Idea so prevalent in popular science books these days. Lloyd, a professor of mechanical engineering at M.I.T., takes as his topic the fundamental workings of the universe, which he thinks has been horribly misunderstood. Scientists have looked at it as a ragtag collection of particles and fields while failing to see what it is as a majestic whole: an enormous computer. Every physical event, everywhere, feeds information into it. And the output of the cosmic computer is nothing less than reality itself.

This all has a faddish, Matrix-like ring to it, but Lloyd's argument is rooted in ideas stretching back at least to the mid-19th century. At the time, the prevailing scientific philosophy held that the universe operates like a clockwork: the movement of each piece determines the movement of every other piece, and plugging the right numbers into the right equations could in principle predict the future of the cosmos with unlimited precision. Several prominent researchers recognized problems with that model, however. Any piece of machinery should operate backward as well as forward, but the real world clearly doesn't work that way. Candles don't unburn, the sun doesn't unshine and people never grow younger. Something keeps events moving irrevocably forward, toward a state of ever-greater disorder and complexity.

The German physicist Rudolf Clausius made the first stirrings toward Lloyd's information-based worldview in 1865, when he described that tendency toward disorder with a term he called entropy. Entropy is one of those words that almost everyone has heard and almost nobody can really explain. By my count, Lloyd defines it 21 times. Some of the attempts are quite entertaining (one involves his efforts to bond with his British classmates over a game of snooker) but none is entirely persuasive. If you want to follow Lloyd down his rabbit hole, however, this is the pill you have to swallow.

Broadly speaking, entropy is the amount of disorder and information in a system. Take, for example, a fresh, unshuffled deck of cards. In that state it has low entropy and contains little information. Just two pieces of data (the hierarchy of suits and the relative ranks of the cards) tell you where to find every card in the deck without looking. Give it a good shuffle and look again. The deck has a lot of entropy and a lot of information. If you want to locate a particular card, you have to hunt through the entire deck. There is

only one perfectly ordered state but about 1068 disordered ones, which is why you will never, ever accidentally shuffle the deck back into its original order.

Amazingly, this process of generating entropy is universal. It is what happens when a candle burns, when the sun shines and when your stomach digests your lunch. In every instance, there is an inexorable, irreversible trend toward disorder and an increase in the total amount of information in the world. Lloyd traces this growth in data all the way down to the subatomic scale. Just as the shuffling of cards increases the entropy of the deck, the bumping and jostling of particles and atoms and molecules increases entropy in the world around us, with each interaction acting to exchange or create information. Lloyd then goes a step farther, making the case that such an exchange is equivalent to the flow of data in a computer — but only the right kind of computer.

Ordinary desktop computers are a flawed model of the physical world, Lloyd argues, because they handle everything as clear "yes" or "no" commands, while the universe operates according to the rules of quantum physics, which inherently produce fuzzy results. But Lloyd happens to be one of the world's experts in a new kind of computing device, called a quantum computer, which can produce similarly vague answers like "mostly yes but also a little bit no." Such computers — a handful of labs have built rudimentary prototypes — mimic the natural world perfectly, Lloyd claims: the two systems are not just similar, they are the same. The universe is a quantum computer whose computations are the movements of information that define the world we experience.

These discussions of quantum uncertainty and computer logic are true mind-benders and yet, oddly, they are not nearly so confusing as the section on entropy. Ideas as huge, and hugely weird, as the computational universe draw out Lloyd's visionary side, and he does a commendable job of weaving in jokes and personal anecdotes to leaven the undeniably heavy material. He is consistently charming and fun. He just isn't always entirely convincing.

More than once, I found myself recalling a scene in "Animal House" in which one of the Delta House guys has a cosmic epiphany during a cannabis-fueled conversation with his professor (Larry: "That means that one tiny atom in my fingernail could be. . . ." Professor: ". . . could be one little, tiny universe." Pause. Larry: "Could I buy some pot from you?") Is Lloyd doing anything more than playing physics head games? He anticipates the question, asking, "Just what does this picture of the universe as a quantum computer buy me that I didn't already have" thanks to our "perfectly good quantum-mechanical theory of elementary particles?" For one thing, he answers, it could be a powerful new research tool. One of Lloyd's M.I.T. colleagues, David Cory, has used a simple quantum computer to study how information flows through the subatomic world. If these devices truly match the workings of the universe, expanded versions could be used, for example, to develop a more complete theory of gravity, whose essence is still utterly mysterious.

On a deeper level, Lloyd thinks he has found a new way to explain one of the most basic questions in science: Why is the world so complex? If the universe began in a formless Big Bang, how did it develop into a place with stars, planets and people? His answer returns to the idea that information always begets more information. In a quantum-computer universe, new information and new complexity are

being born all the time. Indeed, Lloyd's universe is hard-wired for complexity. The eventual emergence of DNA, sex and consciousness is practically inevitable.

It's a fascinating and profoundly comforting idea, but it lies on the far side of empirical science. For now, a more telling test is how well it works as a metaphysics, a way of understanding the universe and our place in it. That test comes in a startlingly dark passage at the very end of "Programming the Universe," where Lloyd addresses the death of the brilliant physicist Heinz Pagels, one of his mentors. The two men were mountain climbing in Colorado in 1988 when Pagels missed a step and took a fatal fall into a gully. Lloyd stood above, utterly helpless.

The pain is still fresh as Lloyd recounts the episode, and his effort at finding solace in information, not in religion, is touching. "We have not entirely lost him," he writes. "While he lived, Heinz programmed his own piece of the universe. The resulting computation unfolds in us and around us." That elegy reveals a central but previously hidden aspect of Lloyd's theorizing: information as thread that binds past and future so that nothing is ever truly gone — not a great idea, not a great man, not even love itself.

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