Computers in Command

THE DREAMS OF REASON

The Computer and the Rise of the Sciences of Complexity.
By Heinz R. Pagels.
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By Brian Hayes

PEOPLE who work or play with computers often speak of "the real world" and "real time." These are haunting phrases. Even as they acknowledge reality, they also imply there is an alternative, a somewhere else, a time out of time. The elsewhere in question is the land behind the computer's glowing screen, and it is a peculiar place indeed. On the one hand, it is a world entirely of our own devising, where the programmer's whim becomes the law of nature. In this created world, made out of pure thought, we can command the rivers to flow uphill if the notion amuses us, or we can make time run backward. And yet the computer is not merely an instrument for indulging childish megalomania. In the world of the computer our daydreams take on a life of their own — with the result that they are no longer fully ours. A computer program is not simply a work of the imagination, like a novel or a movie; it unfolds according to its own internal logic. The programmer, more often than not, cannot predict what the program will do. There is no choice but to let it run its course to see how it comes out in the end.

Heinz R. Pagels became a distinguished visitor to the land inside the computer. He was not native to the territory — on the contrary, he was a committed resident of "the real world" — but he was not a tourist either. Pagels, who died last month in a mountain-climbing accident in Colorado, was a theoretical physicist, adjunct professor at the Rockefeller University and executive director of the New York Academy of Sciences. He was also the author of two earlier works of popular scientific exposition: "The Cosmic Code" (on the quantum theory) and "Perfect Symmetry" (on modern astronomy and astrophysics).

A physicist might be expected to have certain misgivings about the world-building claims made on behalf of the computer. Of all the sciences physics has the biggest stake in the idea of a singular universe, a reality to be discovered rather than invented. If we can make up the laws of nature as we go along, physics is pointless and silly. In "The Dreams of Reason" Pagels does seem to be made slightly queasy by the computer's untethered flights of fancy; but he is also full of enthusiasm for its potential as a scientific instrument. Indeed, he sees it as the preeminent instrument for the next generation of scientists, as the basis for "part two of the scientific revolution."

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Pagels's argument for the importance of the computer in the sciences runs as follows. Each of the great transformations and spurts that mark the history of science is associated with a new instrument, a new means of getting at the truth of nature. The best-known examples are the telescope, which revealed the large-scale structure of the universe, and the microscope, which

The Power of Wisdom

Francis Bacon said that knowledge is power. How right he was. But his remark leaves open the question of whether we possess the wisdom to exercise that power, and whether we who possess it are ready to extend it to the billions who are powerless. Sometimes I wonder if it will be the poverty of the poor or greed of the rich that will be our undoing. Yet I remain an optimist and believe that the liberating capacity of our knowledge, along with a little wisdom, will affirm the power of life over death. I continue to believe that the distant day will come when the order of human affairs is not entirely established by domination.

From "The Dreams of Reason."

brought into focus the invisible components of the material world — from the cells of living organisms on down to atoms. Now the computer is the engine of another major advance. Whereas the earlier instruments disclosed what was too large or too small to be seen with the unaided eye, the computer elucidates what is too complex to be understood with the unaided mind.

Computers perform many mundane chores in science. They control machines, gather data, assist in statistical analysis; they are used, as in any office nowadays, for writing letters and keeping track of the payroll. These are essential tasks, but they hardly portend a revolutionary change in the way science is done. When Pagels speaks of the computer as a new scientific instrument, he has in mind quite different ways of putting it to work. The idea is not to install a computer in the laboratory but rather to build a new laboratory in the world inside the computer.

Consider the problem of figuring out what happens to a large star as it reaches the end of its life and explodes as a supernova. There are clearly limits on how much the experimental method can tell us about such events; we cannot explode a star in a test tube. We can wait for nature to run the experiment for us, but supernovas are rare and (fortunately) far away. Theoretical methods are also of limited utility. The basic physical processes at work inside the exploding star — the transfer of energy, the relation of pressure to temperature, and so on — are understood well enough, but there is so much going on at once that traditional mathematical analysis is overwhelmed. This is where the computer comes to the rescue. We can build a model of a supernova, based on those well-understood physical processes, and set it running inside the computer. If the model star explodes the way a real star does, then we can have some confidence that the model is correct.

The use of computer simulation in realms such as astrophysics is now well established, and it provokes little controversy. Even those who think simulation is not a very good way to understand a supernova may have to admit that it is the best way available. In some other disciplines, however, the new computer-based science is viewed with greater skepticism. For example, attempts to simulate the origin of life have so far failed to impress most biochemists. And in the social sciences, where the objects to be simulated can be as complex as the world economy, successes have been even fewer.

The most obvious hazard of simulated science is oversimplification. As Pagels acknowledges, however, the opposite danger, overelaboration, seems to be more worrisome. Imagine a vast computer model — say a model of the living cell — constructed over a period of many years or decades. To gain greater realism and predictive power the creators of the model continually embellish it, simulating every detail of cellular structure and function they can discover. The eventual result might be an accurate imitation of nature, but a biologist would find the model no easier to comprehend than the real cell. The model is like a map at a scale of 1 to 1; it takes up as much space as the territory it charts.

In some cases no small but accurate map can be drawn. A remarkable fact that has gradually come to light in recent years is that certain physical systems cannot be encompassed by any simple model, not even in principle. The classic example is the weather; any computer or computer program that could accurately simulate the weather would have to be as large and complex as the earth's atmosphere. This is bad news for weather forecasting, but it is a phenomenon worthy of study in its own right. It is at the very root of what Pagels calls "the sciences of complexity."

THE big test case for any science that would claim to master complexity is the human brain and mind. Simulating mental processes is surely as hard as simulating the weather, but the technical question of how to do it is not the only issue in this case. There are also philosophical questions, which Pagels treats at some length. A computer model of the weather, no matter how faithful, always remains a model; when the rain begins to fall in the land beyond the screen, no one in the laboratory opens an umbrella. But if a computer successfully simulates a mind — if the machine thinks or feels, fears or loves — the categories are no longer so clear-cut. Is the computer then simulating a mind, or does it have a mind? Are we in "the real world" or somewhere else?

"The Dreams of Reason" is a casual, discursive book. It contains as much philosophy as science, and it includes a generous measure of informal autobiography and anecdote as well. Social and cultural questions are not slighted. We get a capsule history of the American university since World War II, leading up to some speculation on how the new sciences of complexity will fit into existing institutions — or how they might create new ones.

If the computer really does turn out to rank with the telescope and the microscope, major academic adjustments will definitely be needed. But there has already been an institutional realignment that Pagels oddly neglects to mention. The telescope and the microscope, however important they may be, remain mere instruments of discovery; the computer, on the other hand, has already become a subject of inquiry as well as a tool. Very few advanced degrees are granted in telescope studies or microscopy, but dozens of universities have departments of computer science. People look *through* the telescope and the microscope, but they look *at* the computer. □

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