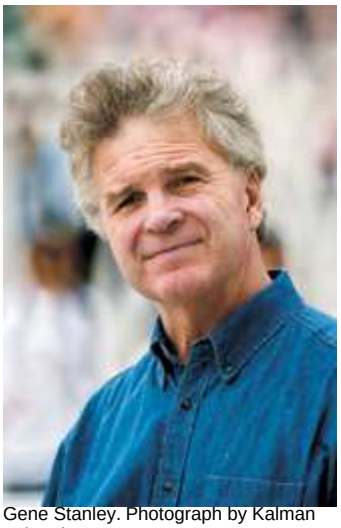
The Puzzle in Nature's Patterns

Gene Stanley finds hidden patterns in human nature, plumbs the secrets of water, and searches for the beginnings of Alzheimer's disease —it's all physics to him.

by Taylor McNeil

Gene Stanley doesn't think that people are mindless automatons, driven to action by forces outside themselves, without a trace of free will —it's just that the data seem to suggest it. So what's a physicist doing wading in waters normally the domain of social psychologists and philosophers?



Gene Stanley. Photograph by Kalman Zabarsky

Over the years, Stanley —a College of Arts and Sciences professor of physics, director of the Center for Polymer Studies, and a University Professor —has looked for and found what he calls correlated randomness in a wide range of human systems, such as the movement of people into cities, the decisions to buy and sell stocks, and even networks of sexual relationships. "These diverse systems have something fundamental in common: they all exhibit predictable behavior," Stanley says. "Thus, for example, three things that should be completely unpredictable —the number of cities of a given size, the number of stock price changes of a given size, and the number of lifetime sexual partners —all are completely predictable in a statistical sense."

In mathematics chance is called probability, Stanley notes. His specialty is statistical physics, which describes systems "for which you cannot say anything with certainty." Take, for example, the air molecules in a room. They are so numerous that even the best scientific equipment cannot possibly measure the speed of every molecule, but using the techniques of statistical physics, it's possible to know the probability that a molecule has a given speed.

"That a law can describe an inanimate molecule is not surprising. After all, Newton's laws describe the motion of falling apples and satellites," Stanley says. But consider the stock market, where people decide what to buy or sell. No one would question that free will is involved there. That said, a striking discovery made principally by two of Stanley's graduate students, Vivienne Plerou (GRS'96) and Parameswaran Gopikrishnan (GRS'01), shows that "the distribution of stock price fluctuations is not unlike the distribution of speeds of air molecules," says Stanley. "This has turned out to be very important, because it allows investors to estimate risk more accurately. If you know the exact chance that a stock price will change a given amount, then you can make allowances for this chance."

Research with Plerou, Gopikrishnan, and MIT economist Xavier Gabaix that involved looking for hidden statistical patterns in the records of some 100 million stock market transactions is part of a new interdisciplinary field called econophysics, the application of statistical physics to the study of economics. The name was coined by Stanley, and he's one of its founders and leading lights.

One wouldn't think that stock prices, controlled as they are by people, would behave like inanimate matter, such as air molecules, but they do. Why that happens is complex —every explanation Stanley gives is necessarily complex, one idea turning out to be part of a larger one.

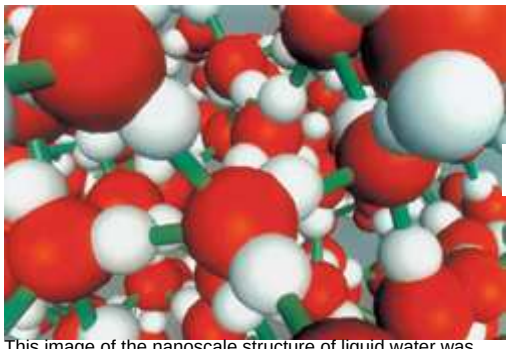
Let's start with another example: magnets. Each atom in a magnet has a little spin, like a compass needle. When all the "compass needles" are oriented in roughly the same direction, they create a strong magnetic field. "An approximate way to understand it is that the economy is a system comprised of many, many individuals, like you and me, who might own stocks, and traders who might trade with somebody else. And all of these people are like those interacting compass needles," he says. "Given a question, say, should we buy more Enron stock, more may say yes, buy it, than no, don't buy any more. More importantly, if a majority of those with whom you interact say yes, buy Enron, then you are more likely to buy it, because you assume that even if the people are wrong, if they all buy Enron, then the price will go up. So you buy Enron, perhaps even without thinking too much."

And that's the rub: "We do things without thinking too much; our free will is in fact less free as it is influenced by our neighbors' beliefs." And, it's safe to add, we don't consciously understand how we are influenced by our neighbors. "That we can be so influenced by what others believe that we temporarily suspend our own independent judgment," Stanley says, "has certainly had tragic consequences all through history, up to the present moment."

Stanley and his students have found other examples of human actions that fit the patterns of inanimate objects. "If anything should have free will," he says, "the number of one's sexual partnerships should." But a discovery he made with former graduate student Luis Amaral (GRS'96) certainly contradicted this expectation. Stanley, Amaral, and their collaborators made a simple chart showing the number of lifetime sexual partners of a sample population in Sweden. They expected to find two peaks, one corresponding to a reasonably small number of partners, and one corresponding to a huge number —the Don Giovannis of this world with, let's say, 1003 partners. Instead, "we discovered a distribution demonstrating that every number of partners was likely, with instead of two peaks, a uniform decrease from one to 1003," Stanley says. "This discovery of a 'sociological law' describing intimate sexual behavior is not only of scientific and philosophical interest, but it is also helping public health officials develop more effective plans to combat the spread of AIDS and other sexually transmitted diseases."

What explains the phenomenon? "I don't know," he says. "That's one of the things that fascinates me, especially because there are so many examples where individuals seem to conform to a statistical law, in the same way that these inanimate spins conform to a statistical law. The only suggestion I have is that the law somehow emerges not from the decisions of people, but from the way in which they are connected, which has little to do with free will. It's something I'm thinking a lot about."

No Rest for the Physicist



This image of the nanoscale structure of liquid water was produced by computer simulations carried out on a supercomputer by Francis W. Starr (GRS'99). "The red spheres represent oxygen and the white spheres hydrogen, while the tubes represent the bonds linking them together, on a structure that locally resembles a tetrahedron," says Gene Stanley. "Analogous structures are also found for silica —common beach sand —and for amorphous silicon. The study is leading to a unifying understanding of a range of common substances." Image courtesy of Gene Stanley

Send Gene Stanley a question by e-mail, and the reply is as likely as not to come at some hour around midnight. When, you wonder, does the man sleep? Students and research associates drop by his cramped, overflowing office at any time. With sixteen doctoral students studying under him this academic year, he's often in conference —advising, directing, prodding, encouraging. His group's work in econophysics gets increasing media coverage, and he fields the press calls. Then there are the papers to write: by early September, Stanley had coauthored sixteen published papers this year alone, many with his graduate students. He has some of the most cited papers in the profession: 16 in more than 200 other research papers, an enviable record. He's written or cowritten six books, his latest on econophysics now translated into four languages.

In July, Stanley was in Bangalore, India, at the conference of the International Union of Pure and Applied Physics, where he received the triennial Boltzmann Award, the highest prize in statistical physics. Earlier in the year, he was elected to the National Academy of Sciences, an elite group of some 2,000 scholars in the United States. It's tempting, Stanley says, to start to rest on those laurels. "It's a fact that most people who get a Nobel Prize never do anything comparable again," he says. "So I'm a little worried that since the Boltzmann might be the highest award I'll ever get, I'll sort of relax now, and that's not good to do."

And Stanley also knows that's not the way to make scientific progress. "You do that by wanting results so badly that you're conscious of it day and night," he says, "and think about it and do whatever you need to do to get it done."

Waterworks

Slacking he's not, though, especially in his quest to understand the nature of water. It's a simple thing, water —a couple of hydrogen atoms linked with one of oxygen. But water's behavior is very complicated, and until recently not well understood despite its importance to all life on earth.

The first breakthrough came in 1991 when Stanley's student Peter Poole (GRS'90,'93) was doing large-scale computer simulations of water. What Poole seemed to be seeing was the signature of a previously unknown phase transition, where two different forms of water can coexist. Stanley worked with Poole and postdoc Francesco Sciortino to understand this finding. "Of all the many things that I study, it's perhaps the work I'm most curious about," Stanley says, "because the implications of understanding water's strange behavior are important for many fields of basic and applied science."

But let's back up and explain. "If I put an ice cube in water, it will float," Stanley says, "which is a little unusual, because usually when you cool things they shrink and when you heat things they expand. Obviously an ice cube is colder than water, so it should shrink and be more dense and go to the bottom, but it doesn't. And that's the puzzle —that's the tip of the iceberg, so to speak."

Now put this ice water in the freezer, and cool the water very close to zero degrees Celsius —say 0.001 Celsius. The structure of the water becomes closer to the structure of ice, the state it's going to change into next. That suggests that there might be two different structures in the liquid water —becoming indistinguishable from each other at what's called the critical point. Stanley and his graduate students and research associates later confirmed this hypothesis in computer simulations. "That discovery was published in Nature, and has been cited over 300 times," Stanley says. "The challenge now is to invent laboratory experiments that can prove this hypothesis is 100 percent true. A definitive experiment is always extremely difficult to do, and much effort worldwide is going into trying to design the right experiment."

That said, "In science, you never prove something correct completely, but you can prove something is wrong," he points out. "In the period since this hypothesis was made, there have been many, many attempts to disprove it —not because other scientists don't like me," he says with a chuckle, "but simply because this is how science works." Nothing thus far has disproved Stanley's hypothesis. "That's already one form of evidence that it's correct. In fact, in a really funny way," he says, "that's the main form of evidence for most science. If someone has an idea, and you can't disprove it, it's probably correct, particularly if it's an attractive idea and economical in the sense that a single idea explains a vast range of empirical data."

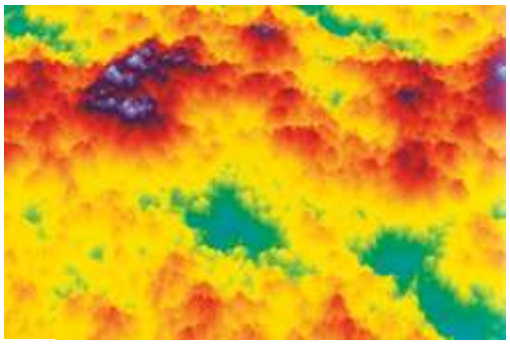
The work with water, if correct, ranks as "possibly the major discovery about water made in the twentieth century," Stanley says. "The trigger to this discovery," he adds proudly, "was made by a graduate student right here at BU," pointing to the lab across the hall from his office.

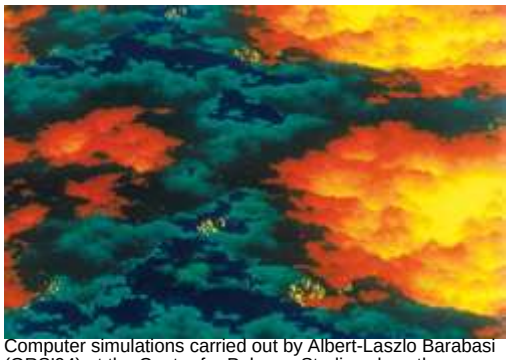
"The more time goes on, the more likely it's true. I think among water experts, ten to one would say it's more or less proved, and the other 10 percent would say you never know," he says. "And I fall in the second group. Why? Partly because if I say it's proved true, there's nothing more to do. I work hard at encouraging people to do these experiments and simulations. The more things that are done, the more plausible it becomes."

And Stanley is continuing the work. Along with researchers at Princeton, the University of Texas, and the University of Arizona, he was recently awarded a National Science Foundation five-year, $3 million grant to study phase transitions in water.

Babylon in the Lab

Stanley didn't set out to be a scientist growing up. While science came naturally to him, he would have happily been an archaeologist or a musician —he played the clarinet. But he was steered to a career where jobs would be easier to find, and studied physics at Wesleyan on a National Merit Scholarship. He spent a Fulbright year in Germany with Nobel Laureate Max Delbrück and got his Ph.D. at Harvard. Soon he was teaching at MIT and in 1976 came to BU.





Computer simulations carried out by Albert-Laszlo Barabasi (GRS'94) at the Center for Polymer Studies show the irregular, nanoscale surface formed during imbibition, a process that occurs when, "for example, a dry sponge becomes filled with water if it is left touching a puddle of water —or when your necktie accidentally dips into your coffee," Gene Stanley says. "In addition to its scientific interest, the physical understanding of the 'imbibition time' problem has implications for oil recovery." Image courtesy of Gene Stanley

He was born in Oklahoma City, but he's not really from there. His family had moved seventeen times by the time he was in fifth grade —his father was an industrial chemist with DuPont —and some rootlessness still seems a part of him. If you were trying to place him by his accent, you might in fact guess he was from somewhere in eastern Europe: in his deeply resonant voice, he sometimes drops articles the way a native Russian speaker might, and his inflections and turns of phrase are anything but Oklahoman. Maybe it's because so many of his students and colleagues are from abroad —Argentina, Russia, India, Greece, China, Portugal, almost anywhere but the United States. Stanley's Center for Polymer Studies in the Metcalf Science Building is a melting pot, with two common languages: accented English and physics. (Lest there be any doubt, the language of physics is as unique as any: they talk of the "fractal properties of the highly branched patterns formed in viscous fingering," "lattice spin models," and " Monte Carlo renormalization-group methods of percolation.")

That international side of physics has led Stanley down unexpected avenues in his career. Recently he received the American Physical Society's Nicholson Medal for Humanitarian Service, in part for aiding Russian refusniks in the seventies: a story in itself. Back in 1973, many Russian Jews were applying to leave the Soviet Union to immigrate to Israel. Their applications were refused, and most lost their jobs. That year, Stanley happened to be chairing the opening session of a scientific conference in Moscow, and learned the night before that several Russians refusniks had been barred from the conference. "This made me very unhappy, for purely ethical reasons, so that night I hatched a plan so those attending who wanted to hear the Russians' talks could go during the free time to their homes" for the presentations, he says.

He announced this "very deadpan" at the conference the next morning, "and the minute I said that, they stopped the translation, and men in trench coats, just like in the movies, took me off the podium into the elevator to the top of the building. It was lined with windows, and they gave me the impression that they were going to push me out. They didn't push me out, but it scared me —the worst scare of my life." In the end, he did lead a delegation to the refusniks' homes to hear their talks, and "it changed my life," he says. He became chairman of a new organization of U.S. scientists putting pressure on the Soviets to release refusniks, and was active in it for a number of years.

The Nicholson Medal also recognizes Stanley's work addressing the gender imbalance in physics. More than in any of the other sciences, women are underrepresented in physics, and Stanley has sought ways to correct that. He's had a higher percentage of female Ph.D. students than most physics professors in the United States, and in talks around the country he encourages others in the profession to focus on the issue.

Stanley is also active in the movement to improve science education. With grants from the National Science Foundation, he has teamed up with colleagues from the School of Education to create projects that seek to revamp the way science is taught in America.

Alzheimer's at the Onset

You'd think he had enough on his plate, but Stanley and his group are starting work on something else that you wouldn't normally associate with physicists: Alzheimer's disease. Employing some of the same statistical physics techniques used in studying econophysics, the group is now trying to uncover "the first three minutes of Alzheimer's," he says, using the term Steven Weinberg coined in his best-selling book describing the theory of the first minutes of the universe.

"The first three minutes is important, because if you know the sequence of events, you can intervene, by hook or by crook," Stanley says. "Many people believe that the beginning of Alzheimer's involves two polymers in the brain — two long molecules touching each other and sticking. If we can find out whether that's true, and if so, when and where they stick, then it's not the most difficult thing in the world to prevent that sticking, and we could have a way to prevent Alzheimer's disease by stopping it as it starts."

Stanley's group, with funding from the National Institutes of Health and an anonymous foundation, is using a

supercomputer to imitate the exact motion of all the polymers to see precisely how these two polymers come together and where they stick. This is not a simple process, he notes. “It’s like the first three minutes when a very timid boy meets a very timid girl on the junior high dance floor. That they meet at all is not that probable, and when they do meet, they don’t always stick.”

The work is in its initial stages, but Stanley is excited about it. He knows there is the potential for something significant here, and it seems to act as a spark for him. Regardless of the prizes and honors he’s received, relaxing doesn’t appear to be an option. “I will be solving science puzzles,” he says, “until the day I die.”