

The Science of Surprise

Can complexity theory help us understand the real consequences of a convoluted event like September 11?

By Dana Mackenzie

Photography by Jennifer Tzar

For tourists, September on the Côte d'Azur is a time for soaking up the last rays of summer and for gambling at Monte Carlo's famous casino. For executives in the insurance industry, however, it's a time for serious business. Every fall, the city that is synonymous with chance becomes the world capital for people who hate to take chances.

At the Rendez-vous de Septembre each year, representatives of the world's insurance and reinsurance companies gather for one week to assess global market conditions and the catastrophes that might occur in the coming year. Over cocktails at the Café de Paris and on yachts in Fontvieille Harbor, they bargain to cover portfolios of risk, such as shares in the California earthquake market or the East Coast hurricane market.

Roger Jones, cofounder of the consulting and software-development firm Complexica Inc., traveled to Monte Carlo last September to offer his considerable expertise at calculating catastrophic risk. Jones's background is unusual for the world of insurance. He worked for 17 years as a physicist and computer scientist at the Los Alamos National Laboratory before heeding the siren call of a loosely affiliated group of scientists in nearby Santa Fe who call themselves complexity theorists. This new breed of scientist builds elaborate computer models to simulate the dynamics of complex systems as diverse as cities, rain forests, and the stock market. Since 1997 Jones has been developing a software program called Insurance World, which uses complexity theory to simulate the entire industry. "Insurance is the industry of surprise," he says. "And complexity is the science of surprise."

But Jones and all the other insurers at Monte Carlo last year were still taken by surprise on September 11. "A taxi driver told me about this attack on New York, and I didn't believe him at first," Jones says. "Then I tried calling the United States on my cell phone, and the lines were jammed. That's when I started thinking, uh-oh." By the time he got to



Complexity theorist Stuart Kauffman studies how systems composed of many small parts coalesce spontaneously into organized units. "The theory ties together many things," he says. "If you squint a little, you have the feeling that something similar is happening in the biosphere and the econosphere."

the conference center, the place was deathly quiet. "Two thousand people immediately stopped negotiating and went home," he says. As insurers, they knew instantly that they were facing by far the costliest catastrophe in history. This was a new world so full of risk that none of them could even be certain if their own companies would be solvent in a year's time. All of that week's deals—not to mention untold millions of life and property insurance policies—might become as worthless as the reams of paper that rained on downtown Manhattan as the twin towers disappeared in a cloud of toxic smoke.

Jones promptly sent a message to his home office in Santa Fe to begin to adjust his unique computer-modeling program to reflect the new reality. "Insurance is a classic complex system with many different entities—insurance companies, reinsurance companies, consumers, government regulators, and various capital markets—all following their own individual rules of behavior," Jones says. "Since the international economy is becoming so globalized, the interaction among all these entities is very strong, and simple ideas of cause and effect no longer apply. The Insurance World software captures what all the entities are doing and serves as a kind of brain prosthesis for insurers, expanding their intuition so they can adapt to surprises and survive in a complicated environment."

Jones's efforts to predict structural changes in the insurance industry in the volatile months ahead could also be a singular opportunity to test the very young science of complexity theory, which so far has promised much but delivered little.

Complexity theory researchers have created many different computer simulators in the last decade in an attempt to find simple rules underlying the normally unpredictable behavior of intricate systems, including those made up of cells, people, and corporations. Jones's friend and business associate Stuart Kauffman, a molecular biologist and complexity theory expert, even built a computer model that simulates how molecules in Earth's primordial soup may have self-organized into living cells billions of years ago. But most complexity models have shown only mixed results, and some scientists think they are based on wishful thinking. Nevertheless BiosGroup Inc., a firm co-owned by Kauffman, has done more than 50 projects for Fortune 500 clients. The company uses complexity theory analysis to tackle such tangible problems as how to control crowds at an amusement park or how to decrease the amount of time it takes a manufacturer to get its products into neighborhood stores.

Complexica and BiosGroup are part of a high-tech community in Santa Fe dubbed Info Mesa, which in recent years has sprouted a host of start-up companies. Most of these companies develop software for government labs, universities, biotech companies, pharmaceutical manufacturers, investment firms, and businesses that need to crunch mountains of raw data into comprehensible patterns. Info Mesa draws on a remarkable talent pool: New Mexico boasts the largest concentration of Ph.D. scientists per capita in the United States. BiosGroup alone employs some 50 scientists, including researchers who once specialized in solar neutrinos, epileptic seizures, and remote sensing.

The birthplace of complexity theory is the Santa Fe Institute, a nonprofit think tank, where Kauffman joined forces in the mid-1980s with computer scientist John Holland, economist Brian Arthur, mathematician John Casti, and physicist Murray Gell-Mann. "It was an intellectual blowout," Kauffman says. "It was staggeringly fun and exciting and ebullient. We were studying the science of complex adaptive systems, and none of us knew what we were talking about."

Kauffman and his cohorts soon decided that a key feature of all complex adaptive systems is that their behavior patterns as a whole are not determined by centralized authorities but by the collective results of interactions among independent entities. A flock of birds offers a rudimentary example. The flock's fluid movements appear to be choreographed, even though most flocks do not have a leader. A flock acts in concert because each individual bird follows a set of basic rules. In one of the most successful complexity simulations to date, computer scientist Craig Reynolds created a flock of artificial "boids," as he calls them, that spontaneously navigate around random obstacles in a synchronized and orderly fashion, even though there is no master design for group behavior. (For a demonstration, surf to www.red3d.com/cwr/boids.) Reynolds programmed each individual bird to avoid collisions, match the speed and direction of its closest neighbor, and move toward the center of the flock.

Examples of systems that self-organize, what Kauffman and other complexity theorists call emergent behavior, are everywhere: The organized foraging of an ant colony is determined not by the dictates of the queen but by local interactions among thousands of worker ants; neighborhoods in a modern industrial city evolve not by the dictates of a central planning board but by the independent choices made by individual people.

But perhaps the most stunning application of complexity theory and emergent behavior is Kauffman's attempt to explain the origin of life on Earth. Long convinced that Darwin's theory of natural selection does not fully account for the patterns of order and diversity in the natural world, Kauffman designed an elaborate computer simulation to demonstrate that individual enzymes—protein molecules—could organize themselves into a self-reproducing collection of enzymes. In the model any particular enzyme might have a one-in-a-million chance to catalyze a given reaction, thus forming another enzyme. Kauffman theorized that with enough enzymes and enough energy, a self-perpetuating, self-replicating, nonequilibrium system would emerge—in other words, a model of life. The system might use DNA to replicate itself, but it might not. In Kauffman's view, only two things mattered: N , the number of potential enzymes in the system, which had to be a big number, and P , the probability that any enzyme could catalyze a particular reaction.

When N reached 10,000, P had a ratio of about 1:1 billion, and the model worked beautifully. Artificial life exploded and flourished. But so far no one has even tried to duplicate Kauffman's feat in a wet lab. "This does not mean that Stuart is wrong," says Andrew Ellington, a biochemist at the University of Texas. "It just means that, as usual, he is way too far ahead of his time."

By the mid-1990s, that same rap had come to be used against complexity theory itself. Even Kauffman's friend and mentor, evolutionary biologist John Maynard Smith, described the computer modeling as "fact-free science." Around the same time, however, investors began prowling around the Santa Fe Institute. In 1995 a consulting firm that is now known as Cap Gemini Ernst & Young made Kauffman an offer he didn't pass up: \$6 million in seed money to form a new partnership, which turned out to be BiosGroup. This was a far different intellectual playground than the lab in which he'd led experiments to create artificial life—now he was responsible for helping executives make money.

One executive Kauffman subsequently enlightened was Larry Kellam, coordinator of Procter & Gamble's supply chain. His problem: how to get Pampers, Charmin, and 250 other products to retail stores faster. A supply chain for a major manufacturer like Procter & Gamble is a loosely structured network that includes wholesale distributors, warehouses, trucking companies, and retail outlets. Each agent in this network has its own, and sometimes conflicting, goals. A warehouse manager, for example, might want to keep inventory low and steady to reduce costs. The manufacturer, on the other hand, may want to turn out a product in large batches. For decades, Procter & Gamble's supply-chain cycle, from raw materials to delivered product, averaged 130 to 140 days. Eliminating some of the most obvious problems of bureaucracy and waste, the company managed to reduce the cycle to 65 days. Kellam was given the challenge of shortening it to 30 days.



The formulas Roger Jones incorporates into the Insurance World simulation enhance the intuition of executives. "If you immerse yourself in the data, you can tell the right answer," he says. "And you don't know why."

Simply looking at the problem in terms of networks and complexity theory was part of the solution. Bill Macready, a BiosGroup physicist who studied superconductivity in graduate school, says: "Imagine you're parked at a curb, somebody is parked in front of you, and somebody else is behind you, with only one inch between bumpers. You can't get out. But if all of you coordinate your slacks, you can all get out." In the case of a supply-chain network, the "slacks" are the little margins of error that each business builds into its operation—flexibilities in location, lead time, and capacity. One trucker's ability to go a different route or one warehouse's ability to accept a larger shipment could make the whole chain run smoothly. So a team led by Macready built a computer model of the network to locate the synergies hidden in the complex system. Kellam says Procter & Gamble will not only meet its 30-day target but will also reduce the cost of getting goods from the manufacturer to the consumer by 20 percent. Procter & Gamble bosses were so impressed that they recently made a \$5 million investment in BiosGroup.

Still, controlling a supply-chain network, no matter how complex, is a relatively simple task compared with modeling insurance risks in the wake of September 11. In complexity

theory parlance, the insurance industry is a complex adaptive system at the edge of chaos—a delicate balance between control and failure.

The event that prompted Roger Jones to simulate the dynamics of insurance was Hurricane Andrew, which slammed into South Florida in 1992 and led to an unprecedented insurance payout of more than \$20 billion. Several large insurance companies folded. John Casti of the Santa Fe Institute subsequently brought together a consortium of insurance and reinsurance company executives who were interested in developing a model to predict the effects of future disasters. Casti enlisted the help of Jones, and as the design for the Insurance World software evolved, Complexica was born.

Insurance World is one of the most elaborate computer simulations ever designed by complexity theorists. The model incorporates 100,000 variables representing different aspects of individual companies, including customer loyalty, pricing strategy, and their degree of exposure to such risks as litigation, product liability, changing regulatory policies, and changing demographics. It calculates the direct impact an external event—a hurricane or a flood—will have on the flow of capital in the industry, as well as its ripple effects as rates fluctuate and individual firms adjust their strategies over time.

The recent terrorist catastrophe made Jones acutely aware that insurance is intertwined with other complex systems, such as governments and capital markets. The fall of the Soviet Union more than a decade ago is a case in point. "Government bureaucracies were slow to react to the sudden shift in the geopolitical landscape. Consequently the intelligence community still had a cold-war mindset and was not prepared for what happened on September 11," Jones says. "That intelligence failure led to the biggest financial losses ever faced by the insurance industry, which in turn affects the stock market because that's where the insurance industry off-loads some of its risk."

The immediate effect of the September attack was to suck capital out of the world insurance market to the tune of about \$40 billion. Jones describes that loss as "a large but manageable perturbation"—unless another huge catastrophe occurs. "The industry can absorb another natural disaster as long as it's not as big as Hurricane Andrew," Jones says. "But many small companies would go out of business." There would also be pressure on the federal government to step in as an insurer of last resort. "But the government itself is a complex system in a state of near paralysis. Bureaucrats are not accustomed to responding to sudden changes or making quick decisions. And on top of everything else, with the anthrax scare, we had the spectacle of senators forced out of their offices and trying to conduct business on the sidewalk."

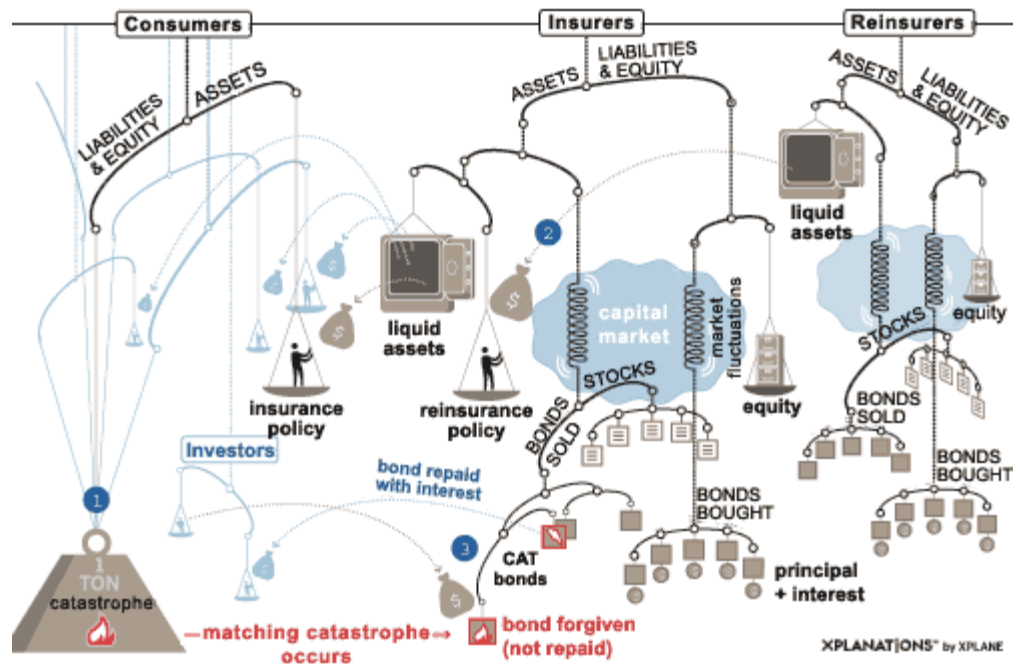
Emotion is a factor Jones has found particularly difficult to quantify. "Now, even accidents become correlated with the threat of terrorism," he says. "Take the crash of American Airlines Flight 587 in New York in November. Typically, after an air crash people resume flying after a week, but not this time. Then there's the case of the guy who ran down an escalator the wrong way in Atlanta and shut the entire air system down for half a day. That's a whole new level of risk we never thought of before."

These days Jones is confident of only one thing: The adaptive capabilities of the system as a whole will help the insurance industry. "Even if some companies go out of business, the demand for catastrophe insurance will go up. Rates will go up. And that will make it attractive for start-up companies," he says. "This is an industry accustomed to catastrophe. That is their business. And most of these people have nerves of steel."

In the meantime Kauffman offers another prediction: The prognosis for complexity theory is good. "We've shown that we can apply these tools of simulation to very practical business problems," he says.

"We've started a new industry."

A Model of Complexity The insurance industry has a large web of financial resources to balance out payment to consumers in the event of a major loss. But unusually large catastrophes like Hurricane Andrew in 1992 or the terrorist attacks last September 11 can overwhelm even the most resilient networks. Catastrophe (CAT) bonds are one way of counteracting this. With keen foresight, an insurance agency can sell CAT bonds to help lessen the hit on its assets.



1. A catastrophe will affect a large number of policyholders and create a huge number of claims for an insurance company to handle. This puts a severe drain on that company's liquid assets.

2. Many insurers cover their liabilities by taking out "reinsurance policies" from reinsurers. Insurers and reinsurers will also balance their assets by investing in stocks and bonds on the capital market.

3. One source of financial protection for insurers is the sale of catastrophe (CAT) bonds. These high-yield bonds are sold with an agreement that if a specific catastrophic loss takes place, repayment of the debt will be partially or completely forgiven. For insurers and investors, this leads to a high-risk, high-yield guessing game: Is this the year for fires? Floods? Earthquakes?

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