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TECHNOLOGY AND BUSINESS

[COMPLEXITY THEORY SOFTWARE](#)

Complexity's Business Model

Part physics, part poetry--the fledgling un-discipline finds commercial opportunity

About a year ago bottlenecks were plaguing [Southwest Airlines's](#) cargo operations, frustrating handlers and delaying flights. Known for unconventional approaches such as open seating, Southwest turned to the [Bios Group](#), founded in 1996 by Santa Fe Institute luminary Stuart A. Kauffman to transform academic notions about complexity into practical know-how. Bios simulated Southwest's entire cargo operation to decipher so-called emergent behaviors and lever points--the key elements in complexity science. The goal was to find which local interactions lead to global behaviors and, specifically, what part of a system can be tweaked to control runaway effects.

Bios deftly built an agent-based model, the favored device of complexity researchers. Software agents--essentially autonomous programs--replaced each freight forwarder, ramp personnel, airplane, package and so on. The detailed computerized model revealed that freight handlers were offloading and storing many packages needlessly, ignoring a plane's ultimate destination. To counteract the emergent logjam, Bios devised a "same plane" cargo-routing strategy. Instead of shuffling parcels like hot potatoes onto the most direct flights, handlers began simply leaving them onboard to fly more circuitous routes. The result: Southwest's freight-transfer rate plummeted by roughly 70 percent at its six busiest cargo stations, saving millions in wages and overnight storage rental.

In this age of genomic gigabytes, miracle molecules and e-everything, more and more companies are finding that complexity applications can boost efficiency and profits. It hardly matters that neither a central theory nor an agreed-on definition of complexity exists. Generally speaking, "if you're talking about the real world, you're talking about complex adaptive systems," explains Santa Fe's John L. Casti. Immune systems, food chains, computer networks and steel production all hint at the variety of both natural and civil systems. Trouble is, the real world seldom reduces to clean mathematical equations. So complexologists resort to numerical simulations or models of one type or another, incorporating tools such as genetic algorithms, artificial neural networks and ant systems.

"Thanks to the computational power now available," researchers can move beyond the reductionist approach and tackle "the inverse problem of putting the pieces back together to look at the complex system," Kauffman expounds. Backed by Cap Gemini Ernst & Young, his 115-member, doctorate-rich Bios Group has advised several firms, including some 40 Fortune 500 companies, modeling everything from supply chains to shop floors to battlefields. Although Bios just released its first software shrink-wrap, called MarketBrain, most of its models are tailored for each client. "Application of complexity to the real world is not a fad," Kauffman says.

Computer scientist John H. Holland, who holds a joint appointment at the University of Michigan and at Santa Fe, sees historical analogies. "Before we had a theory of electromagnetism, we had a lot of experiments by clever people" like English physicist Michael Faraday, Holland says. "We sprinkled iron on top of magnets and built a repertoire of tools and effects." While academicians search for an elusive, perhaps nonexistent, overarching theory of complexity, many derivative tools are proving profitable in industry.

Probably no company better illustrates this trend than [i2 Technologies](#) in Irving, Tex., a leading e-commerce software producer. Customers include Abbott Laboratories, Dell Computer and Volvo, and annual revenues top \$1 billion. Since it acquired Optimax, a scheduling-software design start-up, in 1997, i2 has woven complexity-based tools across its product lines. Much of i2's software uses genetic algorithms to optimize production-scheduling models. Hundreds of thousands of details, including customer orders, material and resource availability, manufacturing and distribution capability, and delivery dates are mapped into the system. Then the genetic algorithms introduce "mutations" and "crossovers" to generate candidate schedules that are evaluated against a fitness function, explains i2 strategic adviser Gilbert P. Syswerda, an Optimax co-founder. "Genetic algorithms have proved important in generating new solutions across a lot of areas," Holland says. "There isn't any counterpart to this type of crossbreeding in traditional optimization analyses."

International Truck and Engine (formerly Navistar), for example, recently installed i2 software. By introducing adaptive scheduling changes, the software effectively irons out snags in production that can whipsaw through a supply chain and contribute to dreaded "lot

A Complexity Toolbox Sampler

- Genetic algorithms take their cue from natural selection, creating "mutations" and "crossovers" of the "fittest" solutions to generate new and better solutions.
- Intelligent agents are autonomous programs that can modify their behavior based on their experiences. Neural networks mimic biological neurons, enabling them to learn and making them ideal for recognizing patterns in speech, images, fingerprints and more.
- Cellular automata consist of a checkerboard array of cells, each obeying simple rules, that interact with one another and produce complex behavior.
- Ant algorithms use a colony of cooperative agents to explore, find and reinforce optimal solutions by laying down "pheromone" trails.
- Fuzzy systems model the way people think, approximating the gray areas between yes and no, on and off, right and wrong.

rot." In fact, the software cut costly schedule disruptions by a stunning 90 percent at five International Truck plants, according to Kurt Satter, a systems manager with the transportation Goliath. Genetic-algorithm optimization software can also find pinch points in manufacturing and forecast effects of production-line changes, new product introductions and even advertising campaigns, Syswerda asserts. The thousands of constraints under which businesses operate can be readily encoded as well. Such nonlinear modeling is basically impossible with conventional programming tools, he maintains.

"Many of the tools that come from complexity theory have essentially become mainstream and integrated into product suites, so they are not nearly as visible anymore," explains William F. Fulkerson, an analyst at Deere & Co. At his suggestion, Deere's seed division tried Optimax software in its Moline, Ill., plant in the early 1990s, about the time chaos theory hit Wall Street. (A subset of complexity, chaos pertains to phenomena that evolve in predictably unpredictable ways.) Production surged, and Deere now uses the software in several plants. "Five years ago the tool itself was the message," Fulkerson observes. "Now it's the result--how much money can you make" with complexity.

Indeed, a flurry of firms plying complexity have sprouted. And the applications run the gamut. Companies such as [Artificial Life](#) in Boston are using neural patterning in "smart" bots to model biological processes. Their bots are essentially computer programs that use artificial intelligence to analyze the repetitive content of speech patterns on the Internet so they can interact with humans. The bots, for example, can automate most of a company's e-mail, cutting costs by one third. The newly released line is ideal for businesses oriented toward customer service, such as the insurance industry, according to Eberhard Schoneburg, Artificial Life's chairman and CEO.

For now, financial applications generate the lion's share of Artificial Life's business, which reached nearly \$9 million in the first nine months of 2000. Its portfolio-management software, used by Credit Suisse First Bank and Advance Bank, relies on cellular automata to simulate communities of brokers and their reaction to market changes. Each cell can either buy, sell or hold a stock, its action guided by its neighbor's behavior. "When you then add simple rules governing how to fix a market price of a stock depending on the current bids, a very realistic stock-price development can be simulated," Schoneburg says.

Companies such as Prediction Co., founded in 1991 by Doyne Farmer and Norman Packard, report wild successes in using complexity applications to predict movements in financial markets. "Our results might be comparable to the biggest and best-performing hedge funds," claims CEO Packard, who won't divulge hard numbers because of confidentiality agreements. He also remains tight-lipped about how the company does it, saying that full disclosure would undermine their predictions because other firms would change their behaviors. Packard will say that their tools and models have evolved in sophistication: the duo started with chaos to decipher underlying patterns that signal market shifts and now embrace broader tenets of complexity, using filter theory, genetic algorithms, neural nets and other tools.

Complexity will most likely mesh well with the quick, data-intensive world of the Internet. Jeffrey O. Kephart, manager of IBM's agents and emergent phenomena division at its

Thomas J. Watson Research Center, uses complex computer simulations and intelligent agents to model the development of specialized markets and cyclical price-war behavior. Eventually the Internet may enable real-time feedback of data into models. "Ultimately it's the ability to adapt at the pace of customer order that's going to be a major component of success. Complexity enables that radical view of customer focus," comments Deere & Co.'s Fulkerson.

Some researchers wonder, though, if complexity is being pushed too far. "There's still a great deal of art in the abstraction of the agents and how they interact," says David E. Goldberg, director of the [Illinois Genetic Algorithms Laboratory](#) at the University of Illinois.

"Agent-based modeling is only as good as what the agents know and what they can learn." And currently most of the agents in models rank low on the intelligence curve. Moreover, most models fail to consider how people make decisions, notes Herbert A. Simon of Carnegie Mellon University, a Nobel laureate in economics who has also advanced the fields of artificial intelligence and sociobiology. "It will be a long time before the human interfaces are smooth," he predicts.

Supporters like Casti take this criticism in stride. "Complexity science is a lot closer to physics than it is to poetry," he remarks. "But that doesn't mean there's not a lot of poetry involved." And even though the fledgling field has probably picked the low-hanging fruit, much potential remains. "Probing the boundaries--what complexity can and cannot be successfully applied to--is one of the biggest intellectual tasks the scientific endeavor has faced, and we're still in the middle of it," Goldberg says. "The process may give insight into human innovation and provide an intellectual leverage like never before."

--Julie Wakefield

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