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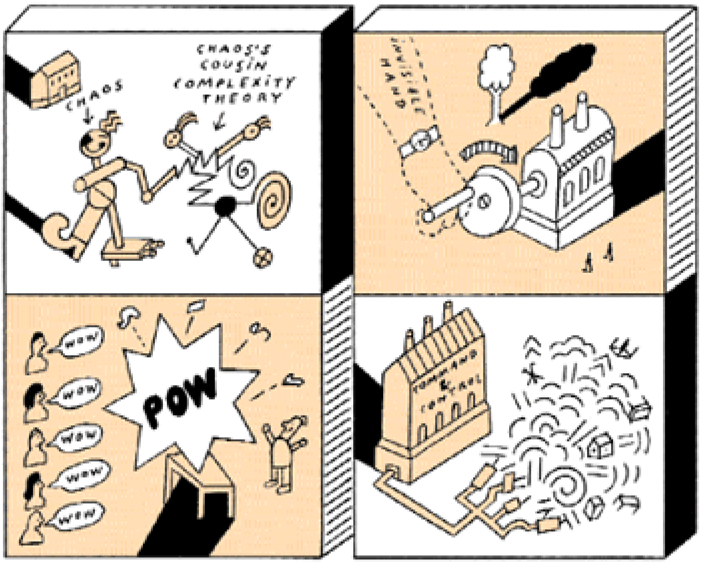
Complexity Theory: Fact-free Science or Business Tool?

By David Berreby

Complexity theory is at the forefront of science and math. It is being used to map biological events and forecast earthquakes. Can it be useful in manufacturing? The answer is yes, but ...

Other speakers at the fifth annual conference on "Chaos in Manufacturing" in Santa Fe, N.M., last April showed slides and played videotapes. Stuart Daw, a researcher at the Oak Ridge National Laboratory in Oak Ridge, Tenn., decided instead to illustrate the practical, real-world industrial usefulness of chaos theory by blowing something up.



And so on a chilly afternoon, the 60 or so attendees are engaged in a spontaneous demonstration of a bedrock principle of chaos's fancier cousin, complexity theory: A group of separate and distinct individuals, each freely acting on his own motives, can collectively behave as a single entity. That makes it possible to make predictions about the behavior of the whole group, even though there is no way to predict what any single member will do.

We -- a collection of people, almost entirely male, in jeans and casual shirts, some of us making effortful jokes about fire extinguishers -- are a fine case in point. If the big, darkened room were a ship, it would now be listing aft.

Dr. Daw opens what looks like a one-pound can of coffee wrapped in silver. It is filled with fuel. He ignites a flame. "There's a lot of fuel in the can, mixing with the air, so you get a nice yellow dancing flame," he explains in that calm Southern drawl you hear from the cockpit when it is time to put your tray table up for landing. "Now, you can see it diminishing. It's turning blue. The composition of the mix of fuel and air in the can is changing as fuel is used up. And now according to our model, we should see a ... POW! ... transition," Dr. Daw says. The can has exploded on cue, more quietly than a firecracker but loudly enough that we all wait a beat to be certain neither Dr.

Daw nor anything else has caught fire.

Here at "Chaos in Manufacturing," an event for business people run by the inventor Richard E. Morely, Dr. Daw has made the biggest impression so far. It is not just the suspense he created about whether we would all live to network at tonight's open house. More important, he walked us through a typical industrial process -- in this case combustion -- and showed that he could predict what it would do beyond the moment when most engineers would have said they could no longer be certain it was safe. Older engineering techniques could tell us only that the fire had entered a realm in which it might burn on or it might cause the can to explode. Dr. Daw's model replaced that general outline with certainty, and the implication was not lost on the managers and consultants who have gathered here.

Industrial chaos theory, which will allow engineers to push the envelope of temperatures and tolerances into regions they did not dare enter before, is the star of this three-day grab bag of celebrations, information, networking and, at a folding table set up outside the meeting room, the brisk sale of "chaos wear" sports shirts. Thanks to the combination of mathematics and computer simulations that constitutes chaos theory, furnaces are going to burn hotter, metals will be more stressed and other industrial processes will be able to push the envelope safely.

In fact, Dr. Daw goes on to say, one potential use of his chaos model could apply to the most ubiquitous and typical of all industrial machinery, the automobile engine.

"Every combustion event in a cylinder is a little different from the last," he says. "Engines don't exhaust perfectly, so there's always something left over, and since the next combustion is extremely sensitive to tiny changes in initial conditions, you get chaotic behavior. That's engine flutter."

His approach, he says, could extend the range of control into the chaotic region and thus help cars burn cooler without stalling out. He cannot discuss proprietary information, Dr. Daw says, "but I can tell you that we are working with an automobile company and if the economics works, you will see this very soon in cars."

Chaos theory has come to manufacturing, and it will have more and more practical applications, which may be why an oft-repeated observation at the conference is that participants simply cannot afford not to know what chaos theory is about. Again and again during the sessions, the attendees see signs that chaos theory will have more and more practical applications in manufacturing. As for what it might offer the more psychologically delicate art of management, though, there they see signs that the jury is still out. A vigorous argument is raging between those who maintain chaos theory will change management as much as it changes the factory and those who complain that it is one more intellectual movement that is getting too big for its britches.

The atmosphere of complexity work is of a construction site, not a completed building, which has led in the last few years to complaints that the grand edifice cannot be erected. In this atmosphere of greater skepticism, the talks by engineers here have a reassuring concreteness. No one can yet define complexity or say exactly how to manage a company in accordance with its principles. But computer tools exist to predict explosions and metal fatigue where once the timing of such a failure was anybody's guess.

At the coffee break after Dr. Daw's talk, there are lots of admiring comments. Among the executives, engineers and consultants who have paid $795 each to sample chaos in manufacturing over three days, light bulbs are going off. "What really clicked in my mind is that there's this residue from the last interaction that sets conditions for the next one," says one participant. "I'm glad I came," says a consultant. "This is really remarkable that this is actually going to be in cars," says a third.

I was invited here to speak from an observer's point of view about the state of complexity research. My fellow attendees range from an oil executive who wants to know if complexity theory might enable him to make explicit his experienced hunches, so they could be passed on to younger staff members, to an engineer who works with experimental robots in which independent programs compete for control of the machine, to management consultants and managers.

The atmosphere is of intellectual curiosity mixing easily with an all-embracing enthusiasm for laissez-faire. After all, one central idea of complexity theory is that rigorously controlling a complex system is impossible. You must simply set it in motion and see what happens. This is a lesson computer researchers take to very well, because their interacting programs have become so elaborate that it is impossible to know all possible outcomes of all possible combinations of computer programs. Now economists and businessmen have come to this fold, because the self-regulating systems that interest complexologists are close cousins of Adam Smith's "invisible hand."

If there is one thing complexity mavens, computer wonks and business executives will agree on, it is that complex systems composed of many actors should be allowed to regulate themselves. After all, as several speakers point out, New York City never runs out of food even though no central authority runs the systems that feed it. Ant colonies stay organized. Stock markets seldom crash. Smith's invisible hand is hovering over this conference, so often invoked and so much praised that I start to imagine its fingers contentedly patting Mr. Morely's bald crown.

Indeed, if chaos and complexity do not have the sheen they did when James Gleick's "Chaos" became a best seller in 1987, part of the reason may be that the rest of the intellectual world has caught up. The notion of a centralized "command and control" faculty is dying out not only as a model for manufacturing, servicing and managing, but as an intellectual tool for understanding psychology and biology.

A decade ago a manager might have run his plant according to a complex, top-down plan for keeping track of all the events in the manufacturing process. He might have understood himself as centrally controlled, a "self" who managed thoughts and emotions as they popped up from his subconscious. He might have understood the economy as driven by a few key factors, like unemployment and inflation. Nowadays, all those assumptions are under challenge.

Biologists, animal behaviorists, students of mind and brain, and economists -- whether or not they are persuaded about complexity theory's importance -- are all becoming more interested in theories that describe the world, to use a phrase often heard at this conference, from the bottom up, not the top down. In other words, the free-market metaphor will dominate our approach not just to business but to ourselves, our society and nature.

Such is the prospect as capitalism sweeps the world. But what is far less certain is that "chaos," Mr. Morely's catchall word for chaos, complexity, dynamical systems and related research, will provide the mechanism for explaining it all. It may be that the laws of complexity will one day offer managers a way to maximize the autonomy of each employee, team and division while preserving an ability to predict what the whole company will do. Or it may be that complexity theory merely provides stimulating ideas and metaphors -- a new round of inspirational books and slogans, not a new set of tools. This will not be clear for some time. "The invisible hand is a term for a property we don't know very much about," says John Holland, a prominent exponent of complexity theory, who teaches at the University of Michigan and does research at the Santa Fe Institute.

How complexity theory might be of some use in a deregulated future world run by the invisible hand is one subject of a talk by A. Martin Wildberger, a researcher at the Electric Power Research Institute in Palo Alto, Calif. EPRI is a consortium supported by the electric power industry. While the shape of the coming utility deregulation is far from clear, Mr. Wildberger says, the general tendency toward a free market is clear.

Already, he says, the Marriott Marquis in Manhattan uses a system of neural networks to cut power consumption at peak hours, because Consolidated Edison has instituted hour-by-hour pricing. Computers adjust air conditioners and other equipment to keep consumption low during the hours when rates are highest. "In the future," Mr. Wildberger says, "your refrigerator will bid for electricity moment by moment, in cooperation with other appliances in your house, trying not to buy at peak periods and trying to stay off as long as it can before the food spoils. All your appliances will do this. Electricity will be metered by the minute, and its price will constantly vary."

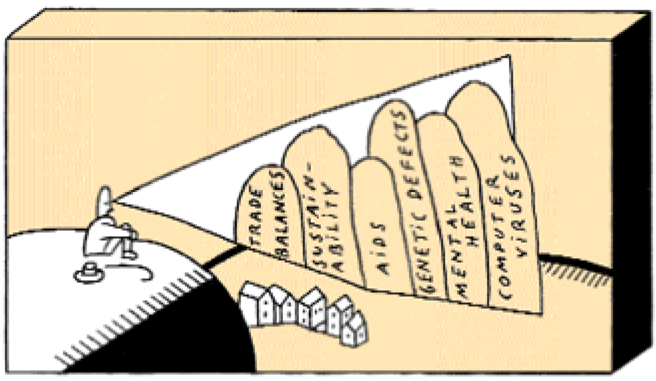
It is a vivid example of why the complexians expect a big future for their ideas. An electrical grid that is so decentralized and so subject to market forces could never be controlled, and very likely some of its behavior would be unpredictable. But if it ever crashed, there would be a national disaster, and so techniques for predicting at least the broad outlines of behavior -- enough to avert a catastrophic failure -- are going to be very much in demand.

But a detail in Mr. Wildberger's talk also illustrates neatly that complexity's day is still in the future. EPRI research has to be supported in part by specific member companies, and he has not been able to get any of the utilities to pay for research on applying chaos theory to the newly emerging decentralized grid. "All I have is an abstract model," he tells the group. "I don't have any code running because I can't get any of our members to say, 'O.K., spend my matching funds on this.' "

Similarly, Abhijit Deshmukh of the University of Florida's School of Manufacturing, speaking about how he studied fire ants to learn how a manufacturing system made up of 40 independent robots could avoid catastrophic failures, says he is "about a year and a half away" from implementing his conclusions on an actual factory floor.

Simulations

In a smaller, living-room-sized, conference room at the Santa Fe Radisson, a group of about 20 of us have gathered for the management applications workshop. In front of the room Teresa Parker of Ernst & Young's Center for Business Innovation is presenting demonstrations that make some managers ooh and ahh.



On a screen behind her, virtual birds -- blue, silver and purple in the garish hues of video games -- flap their wings with that peculiar fluidity of computer-generated beings, just a hair too slow and too smooth. This is a computer simulation created by Craig Reynolds called "Boids."

It is remarkably lifelike: The virtual flock swoops and turns as one, swinging round one obstacle and then dividing like a stream to avoid the next, just like a flock of real pigeons.

The simulation is a perfect illustration of complexity because the flock is not controlled by the programmer, or indeed, by any one bird. In fact, each obeys only four simple rules, she says:

1. Steer to maintain a certain distance from others.

2. Steer for the roost.

3. Fly at a constant speed.

4. Avoid collisions.

Each bird's obedience to the simple rules produces the fluid and complicated-looking motions of the flock as a whole.

To which Ms. Parker quite reasonably says, so what?

"Does anybody know why managers say, 'oh, wow' to this?" she asks.

"Maybe because they see behavior without someone telling everyone what to do," someone says.

"They don't realize that means there's nothing for managers to do," someone else calls out.

Over laughter, Ms. Parker says: "Oh, I'm getting to that. The bathrooms will always need cleaning."

Next on the screen is a simulation based on an idea of the Santa Fe Institute's Stuart Kauffman, a medical doctor and biologist who works on the connections between evolutionary biology and complexity. Orange dots fill a window on Ms. Parker's computer screen. The computer begins connecting them with yellow lines, at random. At a certain point, the lines stop looking random -- it begins to look more like a well-organized web. It is an example of how patterns begin to emerge out of random connections, she notes.

Pondering the increasingly complicated pattern, one executive is reminded of the mechanics of introducing a new form of communication to his employees. To him it is an illustration that "if you're setting up your e-mail, enough people have to use it." He adds: "If people aren't using it all the time, you can't be sure that a message you send is being received in time. So you need to make sure people use it."

How? "Well," says another participant, "we let people use it for anything. We encouraged them to play with it. Then we added business functions. In other words, first you provide the cow paths, then you pave the cow paths."

Another impressive simulation she shows is a video of an audience full of people flying a simulated airplane. On a big screen in a darkened room, clouds zip by and mountain peaks loom up. But the virtual plane manages to avoid obstacles and stay on the course outlined in a little red box on the screen, even though it is being controlled not by an individual but by the whole audience. Each member has a wand whose movements affect the virtual plane's position. Half have power over up and down motion; the others control right and left. The collective decisions of the crowd translate into movements accurate enough to keep the virtual plane up -- canceling out individuals who are incompetent, inattentive or even trying to crash the plane.

"I think we're seeing social programming here," says one skeptical management consultant. "People are goal oriented and they want to succeed." Plus, adds another, these people are getting instant feedback about the consequences of their actions. That is not realistic.

"To use this in management, you might think, 'Well, it shows that you need to show people the positive feedback that results from their work,' " Ms. Parker says. Heads nod.

She returns to struggling with the Windows program on her laptop. ("It's not a Powerpoint file. So do I need to get back to Windows Explorer?") The conferees call out suggestions and a solution evolves that gets the next simulation up on the screen.

The triumph of Microsoft over the better Apple system is taken up as an example of complexity -- a few key decisions by Microsoft and Apple early on leading to enormous consequences years later. Once a certain level of connectedness is established, there is no going back. "That's why we can't do anything about Windows," Ms. Parker says.

The managers are intrigued, and the discussion does not flag. But as they begin to discuss the practical aspects of getting people to use Lotus Notes or carry their cell phones, the complexity talk is replaced by the usual 90's jargon: "In our company communication is foremost." "We're a very flat organization." "We try to keep decision making at the most appropriate level." Whatever may be in the pipeline, in this room, at this time, complexity's ideas remain food for thought, not tools.

"There's no doubt this is a fad, and the fad will pass," says Robert R. MacDonald over lunch in downtown Santa Fe. But Mr. MacDonald, a venture capitalist and executive who has been president of four start-up companies, thinks there will be much of value left when the fad passes. He is counting on it, in fact. He moved from Boston to Santa Fe a week before this conference began, to become president of the Bios Group L.P., a new venture that he started with Dr. Kauffman. The new company is aiming to market practical applications to businesses and consumers, Mr. MacDonald says.

"Some of them are concrete, like plant scheduling and dynamic feedback control of chaotic systems, and others are more abstract, such as sizing an organization, structuring for innovation and interactions of competitors, suppliers and customers in economic webs," he e-mails after the conference.

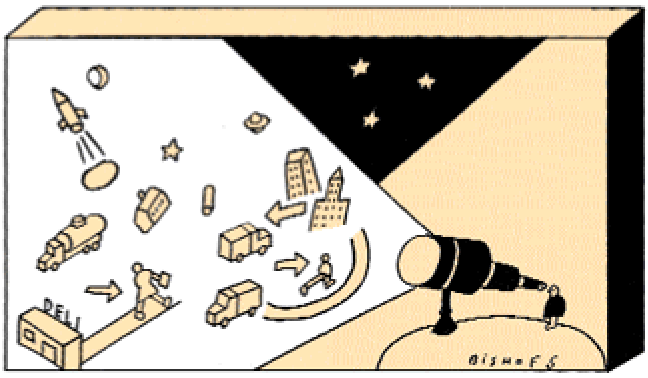
Already, Bios is forming a new start-up to commercialize the kind of engineering techniques of which Dr. Daw's talk was an example -- methods to extend control over mechanical, chemical or electrical processes. There are also companies already selling software for scheduling and design that use complexity concepts to evolve their solutions. The Bios group wants to pursue those avenues, Mr. MacDonald writes. "An example of interest to us is acquiring a manufacturing or other scheduling software company and injecting the proven techniques of genetic algorithms or autonomous agents to perform the scheduling."

For the more abstract process of management, Mr. MacDonald concedes, the uses of complexity are not as well defined. "I am not sure if we will ever be able to accurately predict the exact number of divisions in which to divide a company," he says, "but we can model it and offer suggestions." For example, he says, Dr. Kauffman's research on organizations suggests that a company exhibiting signs of unpredictable ups and downs may be placing too many conflicting demands on its units. So while a manager's instinct dealing with unpredictable oscillations in performance might be to consolidate, the model suggests that breaking up the organization into smaller units, each trying to satisfy fewer demands, might make more sense. "It is a major benefit for a manager just to know what variable to change and which direction to go," Mr. MacDonald says.

Practical Applications

Chaos theory and complexity theory share a history -- especially at the Santa Fe Institute, the epicenter of complexity publicity and the reason Mr. Morely holds one of his annual conferences here (the other is in Boston). But the two enterprises are distinct.

Chaos theory promises better predictions of complex processes because it offers a mathematics that extends further than linear equations could. A linear equation is one in which a consequence is proportional to a cause -- for instance, twice as much gasoline leads you to drive twice as far in one day. A nonlinear equation describes a process in which consequences are not proportional to causes. A fine example from Mr. Morely is a friend from Australia who E-mailed him that "his wife was terrible and his kids were awful and he hated his job and he had to change everything." He continues: "A few months later I ask him how things are going and he says, 'Everything is great; my wife is wonderful, my kids are wonderful, the job is swell. Oh, by the way, I bought the Harley.'



"Like most human passions the Harley was a cause whose effects weren't proportional to its size."

When it is used as shorthand for "nonlinear dynamics," chaos implies more sophisticated math that will allow a plant manager or engineer to push the envelope of control a little further. For example, Tom Flynn, an engineer at the Babcock & Wilcox Company, a leading manufacturer of coal burners, speaking after Dr. Daw, explains that the company is already using nonlinear models of its coal burners because the linear approximations of the burning process were unable to discriminate subtle moment-to-moment changes in the flames.

In contrast to chaos theory, or nonlinear dynamics, complexity theory is grander and vaguer. Claiming to explain everything from why New York City never runs out of food to how stars age and how the immune system works, complexity theory may yield profound unifying insights about the universe or it may have its day and pass, as some insist it already has.

Complexologists assume that there are principles underlying all such "emergent properties," whether they emerge in the interaction of elements in a superheated star or in the interactions of grocers and truckers and food shoppers. Unfortunately, the proof that this assumption is reasonable has not arrived, and complexity is not rigorously defined. Instead, its intellectual status is still akin to pornography's: it is hard to nail down, but you know it when you see it.

Mr. Morely is one of those who believe chaos and complexity thinking is a paradigm shift. A big hearty man with all the boundless confidence of a championship football coach, he took it upon himself to organize the first conference on chaos in business in 1992.

But this kind of meeting is not the only place where he has committed himself to chaos and complexity. Among the inventions that have come out of his barn in Vermont is a "bottom up" method of painting trucks as they roll off an assembly line, in which machines competing for each truck evolve an efficient distribution, without any oversight or planning before the work begins. (See "Between Chaos and Order: What Complexity Theory Can Teach Business," Strategy & Business Issue 3.) When General Motors installed the system in its plant in Fort Wayne, Ind., it installed one of the first concrete embodiments of complexity theory as a practical tool in an American factory.

Recently, though, G.M. converted the factory from liquid paint to powder, and in the retooling the company decided not to pay for a new robot paint-booth system. Mr. Morely's computer system still sells well in Asia, especially in Japan and South Korea, where it is used in many simulations. But its one practical application in an American factory has ended. That is indicative of the state of chaos and complexity applications for business: A first generation of easy and general promises has given way, after some naysaying, to more modest claims.

If anyone can boast of a complexity-theory invention that has practical applications, it is John Holland of the University of Michigan and the Santa Fe Institute. The Morely people are plainly pleased to have snagged him, and he has been given two hours to speak to us.

The genetic algorithm has achieved some impressive results. Dr. Holland, an open Midwestern face under a silver helmet of hair, dressed like a bank president in a coat and tie, gives a polished talk, the simple, friendly Reader's Digest version of complexity theory for business. But what begins as a canned talk for novices, pitched well below the level of most of the audience, soon evolves into a philosophical defense of complexity theory and a warning not to make too much of it. This is a little surprising.

In 1993, Dr. Holland said in a speech that the principles underlying all complex adaptive systems "point to ways of solving" problems as varied as "trade balances, sustainability, AIDS, genetic defects, mental health, computer viruses." The quotation was cited in a critical article titled "Is Complexity a Sham?" in Scientific American in 1995.

Apparently, Dr. Holland reads his reviews. Today, he tells us: "Chaos is an important concept, but we've had others. Catastrophe theory, for example, was touted a couple of decades ago as an explanation for everything. But be careful about treating this as some sort of overwhelming thing. It is not. It is simply one more thing we've learned that helps us look at our world."

Critics have also complained that complexity research, much of which takes place on computers, is a "fact free" science, a form of computers talking just to one another. Dr. Holland has apparently taken this to heart as well. He defends complexity's computer models as part of a tradition of abstracting problems in models that goes back to ancient maps and the first counting systems. But he also tells us that no model can substitute for familiarity and experience, what he calls the "taste" of a problem. His own invention, the genetic algorithm, he says, "is not magic." He goes on: "You can't pick up a package off the shelf and apply it. Refining the building blocks and developing a taste for the problem takes deep insight. You can't substitute for that."

Indeed, it is becoming clear here that as chaos and complexity enter their second decade of wide exposure, some researchers are as impatient with chaos models as once, 20 years ago, the chaoticians were impatient with linear models. Chaos models are too neat to represent the messy world, they say. Chaos, in other words, is not going to take the randomness and surprise and messiness out of manufacturing, management or daily life.

"Most nonlinear systems are a hybrid," Dr. Daw tells his post-explosion audience. They mix truly random noise with pockets of predictability with effects that can be represented with linear equations. Chaos-based models are no better at representing all of reality than models based only on the linear effects.

Of course, neither Dr. Holland nor Dr. Daw is saying that chaos and complexity theory have no usefulness. They were reminding us that, as Dr. Holland says, "there has been some hype," that chaos and complexity were not Theories of Everything but rather tools that can elucidate part of the picture. Dr. Daw says chaos theory, though it is imperfect, can help round out a picture of complicated processes like combustion. Neither linear equations nor chaos models are a complete picture of reality, he says. In fact, a complete picture of reality is impossible. There will always be noise that cannot be fit in the model. But perfection is not required, he maintains.

"When travelers coming to medieval Europe wanted to describe a rhinoceros, they said it was like a dragon and a unicorn," he says. "Neither dragons nor unicorns exist, but they can help us envision something that does exist. And I think that's where we are now."

It is left to Barry McMullin of the Santa Fe Institute, in a talk on a "bottom up" simulation of how cells might assemble themselves out of simple organic molecules, to sound the theme more radically. Chaos and complexity, he said, are due for a serious shake-up at their very foundations.

Chaos models, he reminds the group, are based on "state space," a souped-up version of the Cartesian graph from calculus. Speed and distance, for example, can be represented on a Cartesian graph as x and y and plotted to produce a curve or parabola. A chaos model plots many more variables in this imaginary state space, producing more complex imaginary shapes. In addition to x and y, there might be a, b, c, d, e and f as well. Dr. McMullin's point, though, is that this model assumes that there are enough data to plot these eight variables, and that those variables are adequate to describe the system that is being graphed. This assumption, he warns, may be too tidy and neat to suit a real world in which the number of relevant variables varies from moment to moment.

"The primary tool for all this science is dynamical systems theory," he says in a bemused-sounding Irish brogue. "Seems to me there's a real danger that we're going to have to throw all that out the window, because many systems are aggregates that don't have a well defined state space."

Thousands of variables graphed in imaginary space sometimes produce spirals and circles in which the lines seem to be drawn again and again to a particular value, like water towards a drain. Such a point is dubbed a "strange attractor," which gave rise to another faintly eerie chaos term. But, Dr. Daw points out in his talk: "In real life the system is fuzzy. The attractor is not as clear."

So complexity theory, which once proudly proclaimed that it represented a real-world messiness unlike the false neatness of geometry and calculus, is being described as too neat and tidy in its turn. This raises a scary possibility: If the new world of multiple agents and emergent properties is too messy for complexity theory, then perhaps it is too messy for any theory. Perhaps the day of the powerful abstract model that can pierce through the particular has passed, not only for managers but perhaps more generally in the culture of science and engineering. Scientists can now attend conferences (one was held in Santa Fe itself) on the limits of science. John Horgan, the Scientific American staff writer whose 1995 article in that magazine asked "Is Complexity a Sham?", published a book last year whose title proclaimed "The End of Science."

The culture of science is changing. The ultimate tool in most fields, once the powerful equation, is now the powerful computer, and this change describes a shift from the quest for powerful abstract formulas to a more open-ended willingness to plug in the data and see what happens. It is a shift from a culture of powerful explanations to a culture of powerful descriptions. As Paul S. Linsay, an engineering consultant from Newton, Mass., puts it in his talk at the conference: "The data you collect are the model itself. There are no equations."

In his 1995 book "A Tour of the Calculus," the mathematician David Berlinski eloquently describes this sea change as a shift in importance from math to biology: "Living systems may best be understood in terms of their constituents. Going down, one encounters organ systems, organs, tissues, cells, cell parts and then, on a much smaller scale of organization, molecular constituents of which the most important are the proteins and the master molecule, DNA. But there, in contrast to physics, things come to an end. In place of depth, the biologist requires intellectual extent. He or she wishes to trace connections among biological constituents, following pathways across a living system and coming to understand how influences are transmitted.

"Mathematical science requires theories, molecular biology, facts. As one century gives way and another comes to replace it, the very nature of science as a distinctive human activity is ineluctably changing. Depth of explanatory power is being traded for adequacy of description, the penetrating theory proved Q.E.D., being replaced by the weight of details, facts, relationships, networks of related facts -- precisely the kind of information a computer can gather and represent."

In that light, complexity theory might be seen as the last hope of the theoretically minded to produce abstractions that can describe the world. Perhaps there are none, and all a manager can do is set things in motion and see what happens. In other words, our era of constant change and endless interaction among billions of actors is moving not just from command and control, but from the very idea that abstraction is possible. Perhaps the 21st century will be the century of messy details, and if complexity does not describe it, maybe nothing will.

The key theme of the conference, then, is not the question of whether this free-market, invisible-hand world of endless competition and the continual search for a better deal will arrive. It is certain to arrive. The question is rather: Will chaos and complexity theory explain that world? Or will we, as we always have in the past, find that we understand what we have wrought only long after we have begun to live in it? Can we get a handle on this world of unprecedented laissez-faire? "I was at the world economic forum," Dr. Holland tells us in his talk. "And the big issue there was how much can we let laissez-faire go and still have a workable world?"

Can complexity theory offer a reliable answer? It remains too early to tell. I leave the conference a little surprised about how relentlessly this new world is coming into being, whether we have the tools to master it or not. We can only hope for the best.

"If we could get to know all the consequences of our actions," the Italian critic Nicola Chiaromonte wrote, "history would be nothing but an idyllic and constant harmony of free wills, or the infallible unfolding of a rational design. We would then always act rationally, that is, we would not act at all, since we would simply follow a pre-established and sterile pattern. But then we would not be free. We are free, however, and this means literally that we do not know what we are doing."

Definitions

Like other schools of thought with ambitions to explain and revolutionize business, complexity has its own jargon, not all of which has been standardized and some of which -- to add to the confusion -- has started to seep into popular parlance. Herewith a guide to the buzzwords.

Agent-based systems: An approach to a problem in which independent agents, each following a few simple rules, are allowed to interact. The expectation is that a good solution will naturally evolve, as solutions have evolved in animals and in markets, without a need for central direction from above.

Butterfly effect: A well-worn cliché to describe nonlinear systems. The image is of a butterfly in, say, China, flapping its wings and causing a blizzard in, say, Chicago.

Chaos: That state of a dynamical system in which its behavior is completely unpredictable. More commonly, though, the term is a buzzword for ideas about how to extend predictability into realms once thought to be chaotic.

Complex adaptive system: An aggregate of many independent actors that behaves as a single unit, responding to its environment. Frequently cited examples are markets, which respond to economic news; genes, which respond to natural selection; brains, which respond to what the senses take in. A corporation, of course, can also be seen as a complex adaptive system.

Complexity: Not so much a concept as an intellectual construction site, where believers in complexity theory say they will erect a powerful concept in the future. Complexity is that trait shared by complex systems --economies, stars, brains and other aggregates of many separate actors that behave as if they were a whole, even though they are made up of many interacting constituents. Complexity seeks to get at such mysteries as how millions of independent actors can unintentionally evince patterns and what properties emerge in a system that are not present in any individual part of that system. What exactly complexity is and how it can be measured and used is being debated. At the moment, like pornography, it is hard to pin down, but most people believe they know it when they see it.

Dynamical systems theory: A way of describing a process that constantly changes over time, such as internal combustion in an engine or the ups and downs of a stock market.

Emergent properties: Traits that emerge out of the interactions of many different actors -- for example, an ant colony's ability to switch from a declining food source to a better one. No single ant makes the comparison, but the ability to compare emerges out of the interactions of all the ants.

Genetic algorithm: Adam Smith's invisible hand meets Darwin's principle of natural selection inside the computer. Components of a complex problem are broken down into building blocks, whose characteristics are represented in code. In a computer simulation, the units of code then recombine with each other to make offspring, just as parents' genes combine in children. The "best" offspring are then allowed to reproduce again, and as the generations pass, better and better code evolves, which can then be translated back into a real-world object. The technique, invented by John Holland, has been used to find solutions for a wide variety of complicated problems, from efficiently scheduling meetings with many participants to aircraft engine design.

Nonlinear: A description in which effects are not proportional to causes, so that a small change in a variable can have enormous consequences, or, conversely, a huge change has little effect. An example of the former might be a tiny increase in taxes that prompts a revolution. An example of the latter might be a doubling of the police force that fails to produce much of a decrease in crime. Complexians used to insist that nature was mostly nonlinear. At the Morely conference, however, several speakers noted that nature was neither linear nor nonlinear, but more like a hybrid of both -- plus noise that neither intellectual system can conquer.

Sensitive dependence on initial conditions: A property of nonlinear systems. If effects are not proportional to causes, then a slight change in the cause can have huge consequences. See the butterfly effect.

An Anti-Glossary

Intellectual movements often demonize that which has come before as old-fashioned, narrow-minded and false. Complexity is no different. Herewith a series of anti-buzzwords -- terms used pejoratively in complexity circles.

Command and control: This vaguely Stalinist-sounding term refers to any approach that tries to manage by centralizing all decisions and trying to foresee contingencies before they arise.

Linear: Strictly speaking, this describes equations and simulations in which effects are proportional to causes. More generally, though, it is a buzzword to describe thinking that does not take complexity and unpredictability into account.

Optimization: Held to be a naïve idea because an optimum is an end point, and there are no end points in ever-changing dynamic complex systems. Today's optimum may not meet tomorrow's conditions. "In evolution the point is not optimization," says John Holland. "It's getting better faster than the other guy."

Top-down: See command and control. s+b

Reprint No. 98104

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