

New model army. Janjaweed fighters interact with many other groups in a model of the Darfur conflict.

NEWS

Ourselves and Our Interactions: The Ultimate Physics Problem?

In the field of complex socioeconomic systems, physicists and others analyze people almost as if they were interchangeable electrons. Can that approach decipher society and what ails it?

ZÜRICH, SWITZERLAND—Janusz Holyst sounds frustrated. “When I look to the textbooks on emotion, there are no numbers, there are no equations,” laments the theoretical physicist from the Warsaw University of Technology. Holyst hopes to supply what the books are lacking, however. He aims to develop the tools to analyze emotions quantitatively. Then he intends to use them to literally read your feelings.

With €3.6 million of support from the European Commission, Holyst and eight collaborators aim to develop a computer program that can analyze dialogue from Internet chat rooms and tell when people are growing excited, angry, and so on. Flagging key words isn’t enough, he says, because people use language differently. Some, for example, curse regardless of their mood. Ultimately, Holyst hopes to decipher group emotion, such as the euphoria that pervades a stadium full of sports fans when the home team wins. “There are tens of models of opinion formation,” he says, “but there are no models of emotion.”

Holyst is one of a small but growing number of physicists who are turning from atoms and electrons to study social phenomena such

as terrorism, the growth of cities, and the popularity of Internet videos. Joining with social scientists, they treat groups of people as “complex socioeconomic systems” of many interacting individuals and analyze them using conceptual tools borrowed from physics, mathematics, and computer science. Last month, 130 researchers of various stripes gathered here to discuss such work.*

Foreshadowing “sociophysics” began in the early 1970s. Physicists proposed, for example, that individuals interact to form public opinion much as neighboring atoms make a crystal magnetic by aligning their magnetic fields; researchers analyzed the social phenomenon by adapting the Ising model used to describe such magnetic interactions. In the 1990s, many physicists turned to economics in the controversial subfield of econophysics (see sidebar, p. 408). Now, the movement seems to be gathering momentum, as

*International Workshop on Coping with Crises in Complex Socio-Economic Systems, 8–12 June 2009.

complex-systems researchers have made solid contributions in the study of traffic, epidemiology, and economics. Some are now tackling more-daunting problems, such as the emergence of social norms.

“The problems are more complicated than most natural scientists assume, but less hopeless than most social scientists think,” says Dirk Helbing, a physicist-turned-sociologist at the Swiss Federal Institute of Technology Zürich (ETHZ). Oversimplification is a risk. “In some fields, physicists have a bad reputation for applying the Ising model directly” to cases in which it may not fit the facts, says Stephen Eubank, a physicist at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg who models epidemics.

Nevertheless, physicists and social scientists are working together on increasingly nuanced and realistic models, Helbing says. The complex-systems approach could help avert—or at least explain—systemic crises such as the current global economic meltdown, he says. “We spend billions of dollars trying to understand the origins of the universe,” Helbing says, “while we still don’t understand the conditions for a stable society, a functioning economy, or peace.”

Complex is as complex does

Scientists can’t say exactly what a complex system is in the same way they can define an atom or a gene. Rather, they tend to describe how a complex system looks and behaves. “If you ask a biologist, ‘What is life?’ he will give you a list of characteristics. He probably won’t give you a strict definition,” says Inge Simonsen, a physicist at the Norwegian University of Science and Technology in Trondheim. “It’s similar with complex systems.”

First off, a complex system consists of many elements that interact so strongly that they tend to organize themselves in one way or another. This “emergent behavior” makes the group more than the sum of its parts. A car may be complicated, but it is not a complex system, as each of its parts interacts with a few others in a predictable way. But cars in traffic form a complex system, as drivers’ jockeying for position can lead to surprises such as “phantom” traffic jams that arise for no obvious reason.

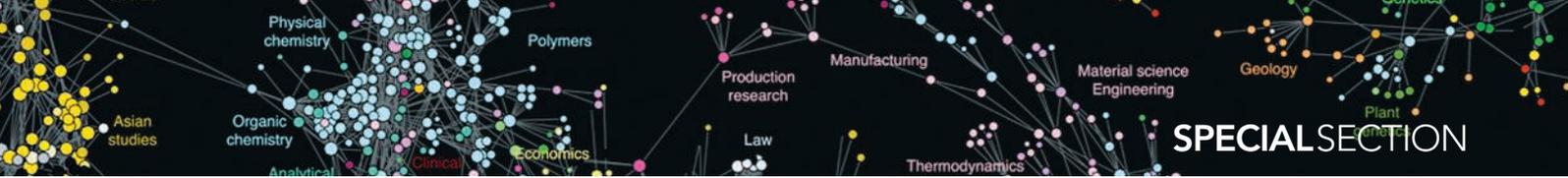
Complex systems also tend to be persnickety. A tiny change among the pieces may lead to a big swing in the behavior of the whole

Online

Podcast interview with author Adrian Cho.

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system—as when, on 4 November 2006, the disconnection of a single power cable in northern Germany triggered regional blackouts as far away as Portugal.

The systems are often hard to control and may be impossible to “tune” for optimal behavior. At the same time, “there are so many ways for a complex system to fail that it’s impossible to prepare for them all,” says Eubank.

Like the riveter’s trade, the field is defined largely by its tools. Researchers borrow from statistical physics the theories that describe phase transitions—in which interactions among many atoms lead to dramatic changes in a material as a whole, such as the freezing of water into ice and the emergence of magnetism as hot iron cools—to probe how, say, public sentiment can suddenly turn against a once-popular war.

Much work also relies on networks that represent individuals—such as victims of an epidemic—as points or “nodes” and the social ties between them as lines or “edges.” Researchers often use “agent-based models”: computer simulations in which myriad virtual agents interact like robots following predefined rules. Such models might help reveal, for example, how interactions between investors, hedge funds, and banks trigger market swings.

Behind it all lies the assumption that, at least within distinct types, people are like subatomic particles: basically the same. “We like to think that we are unique,” says Alessandro Vespignani, a physicist at Indiana University, Bloomington, who works on networks. “But probably for 90% of our social interactions, we are not so unique.” The approach appeals to a physicist’s penchant for divining the simple mechanisms that underlie complex phenomena, Vespignani says: “Physicists bring a special balance between mathematical rigor and computational approaches and intuition for the problem. We are artists of the approximation.”

Germ and traffic jams

Over the past decade, complex-systems researchers have made some signal advances. For example, they have developed a deeper understanding of traffic, which, to a physicist, resembles a fluid flowing through a tube. There are key differences, however. Because the atoms in a fluid bounce off one another, a fluid typically speeds up when it flows

through a constriction. Drivers avoid collisions at all costs, so when a highway narrows, traffic inevitably slows down.

To capture the essence of traffic, scientists have to include the “forces” between vehicles—actually, drivers’ reactions to one another. In the 1990s, physicists and others developed mathematical models that do that and can accurately simulate highway and city traffic, and those models are now built into commercial software used by municipal planners and others. Researchers can also explain surprising effects, such as how pedestrians passing in a hallway spontaneously form two opposing lanes and how putting an obstacle in their path can actually speed the flow.

Complex-systems experts have also made contributions in epidemiology. In 2001, Vespignani and colleagues showed that in certain types of highly connected networks called “scale-free,” it’s impossible to stop the spread of an epidemic no matter how many



What’s the holdup? Researchers can explain how traffic flow breaks down—although they can’t necessarily prevent it from happening.

people are inoculated. Conversely, in 2003, Shlomo Havlin, a physicist at Bar-Ilan University in Ramat Gan, Israel, and colleagues found a simple strategy for inoculating against a disease that beats picking random individuals. By going a step further and picking randomly chosen *friends* of those individuals, health officials can, on average, inoculate people with more social ties through which to spread the disease.

Some of the work is timely—even urgent. At the meeting, Vespignani presented a detailed model of the spread of the swine flu, H1N1, which includes the network of all the world’s airline routes and detailed transit maps of major metropolitan areas. Such input allows researchers to predict not only the prevalence of a disease but also the geograph-

ical path of its spread, Vespignani says. His preliminary results suggest that 30% to 60% of Australians may catch H1N1 by October.

Such efforts are working their way into mainstream epidemiology. Vespignani’s work is funded by the U.S. National Institutes of Health, as is modeling by Eubank, and federal officials have sought the modelers’ input on problems such as the spread of H1N1. “Some of this is an ongoing effort by midlevel people to convince higher-level people to let science play more of a role” in responding to epidemics, Eubank says.

The hard social sciences

Traffic and epidemics may look like physics problems, but researchers are also tackling phenomena that seem purely social. To probe the emergence of social norms—the unwritten rules that keep us from, say, asking others how much they earn—some are turning to the computer simulations of evolutionary game theory, in which myriad virtual players engage in logical contests. In one classic setup, neighbors on a grid face the “prisoners’ dilemma”: Both are rewarded if they cooperate, and both are punished if they betray each other, or “defect.” But each reaps a bigger reward for being the only defector and a stiffer penalty for being the sole cooperator. The logic of the situation drives both to defect.

To make the games more interesting, however, players’ strategies can evolve. Players might imitate their most successful neighbor, or they might move closer to more-successful players. In either case, defectors dominate the field, Helbing finds. But imitation and migration together lead to the growth of colonies of cooperators.

More intriguing, Helbing has set two populations playing the same game with different reward schemes and, hence, different dominant strategies. However, interactions can cause players from one group to adopt the other’s strategy. That resembles the emergence of a norm, Helbing says, as the interactions cause the players to change their behavior. The result may seem remote from the proscription of nose picking, but norms are often arbitrary, Helbing notes, “and for that reason we think it’s okay to abstract them from their content.”

Other researchers are analyzing historical movements. Europe in the Middle Ages con-

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Econophysics: Still Controversial After All These Years

In 1997, physicists Imre Kondor of the Collegium Budapest and János Kertész of the Budapest University of Technology and Economics organized a conference on the budding field of econophysics, which has since enjoyed a mixed reputation. It is the biggest branch of complex-systems research, and physicists have flocked into finance. But many economists view econophysicists as dilettantes. "Shortly after this conference, I went to work in a bank, and I never met any animosity at all," Kondor says. "The reaction of the academic community has been markedly different than that of the practitioners."

Traditional economic theory is fundamentally flawed, econophysicists say. It relies on "representative agent models" in which a hypothetical average Joe interacts with monolithic economic forces. Such models ignore correlations that lead to, say, booms and busts. To prove rigorous theorems, economists assume that market fluctuations follow a bell-shaped "Gaussian distribution,"

which underestimates the probability of big swings. "Traditional economics is about creating mathematical models that are well-defined, tractable, and have nothing to do with reality," Kertész says.

Econophysicists claim to take a more data-driven approach. They have yet to score a major

breakthrough, but they say their contributions are gaining wider acceptance. For example, econophysicists have introduced new tools to analyze correlations among stocks and more efficiently optimize a portfolio, Kertész says. They have also exploited new types of data, he says, such as high-resolution records of the smallest movements in a market and a market's limit order book, which records every offer to buy or sell a stock regardless of whether it leads to a transaction.



Uh-oh. Big market swings are inevitable, econophysicists warn.

Physicists are also helping to change the emphasis in research, Kondor says. Economists have long known that, for example, the returns on stocks do not fluctuate up and down as mildly as their models assume. The real distribution of returns has "fat tails" at its extremes, which means very large gains and losses are far

Even more ambitiously, Jürgen Scheffran, a political scientist at the University of Hamburg in Germany, hopes to model the impact of climate change on regional conflicts. He and his colleagues are modeling the ethnic conflict in the Darfur region of Sudan, where the southward expansion of the desert has driven Arab herders onto the land of sub-Saharan farmers. "This may be one of the first cases where climate change has already affected a conflict," he says.

Over the next 5 years, Scheffran and colleagues aim to reproduce the conflict in a detailed agent-based computer model. That daunting task requires quantifying the interactions between numerous actors, including farmers, herders, rebels fighting on behalf of the farmers, the Janjaweed militiamen who oppose them, the Sudanese government, aid organizations, and others. "Hopefully, we

more likely than assumed. But most economists continue to view such events as flukes instead of game-changing inevitabilities. "The physicists were the ones who started to systematically work through the consequences of the fat tails," Kondor says.

Still, econophysics does not impress some economists. "In my opinion, it is without influence and will continue to be without influence," says Ernst Fehr of the University of Zürich in Switzerland. Physicists apply their models to problems without grasping the details, he says. "I employed a physicist once, and I was really disappointed."

But Thomas Lux, an economist at the University of Kiel in Germany, says that, especially in Europe and Japan, growing numbers of economists are searching for alternatives to standard economic theory. "Interactions are what produce the economy, but economics ignores interactions," he says. In contrast, the multiple-agent models favored by econophysicists are ideal for scrutinizing interactions, Lux says.

With droves of physicists in finance, some critics have blamed them for the current global economic meltdown. That is unfair, econophysicists say: Most physicists working in finance were asked to devise and evaluate instruments—such as the notorious credit default swaps—with the tools they were given, not to invent better tools. Moreover, says Didier Sornette of the Swiss Federal Institute of Technology Zürich, "physicists have been the most critical of the axioms underlying the pricing, hedging, and risk analysis associated with these instruments." **—A.C.**

would get better strategies for limiting the violence," Scheffran says.

How the field of complex systems will evolve remains to be seen. It appears to be growing faster in Europe, where the European Commission has recently committed €20 million to such research in the next 4 years. Researchers in the United States face tougher funding prospects, says Neil Johnson, a physicist at the University of Miami in Florida, who fits modeling of terrorist networks in with work on the mathematical ecology of fish, a strong suit at the university.

Still, with successes to build on and creative scientists tackling new problems, researchers are confident that further important results will come—even if they can't predict exactly where this network of idiosyncratic efforts will pay off most handsomely.

—ADRIAN CHO

sisted of kingdoms, each ruled by a hierarchy of lords who collected taxes from those below them and passed them to those above. That system of indirect rule gradually gave way to one in which sovereigns ruled their countries directly, and Lars-Erik Cederman, a political scientist at ETHZ, has modeled that process.

Cederman represents each lord by a spot on a map and a node in a network resembling tree roots that can rearrange to funnel money upward most efficiently. Indirect rule won't arise at all, Cederman finds, if a lord's might begins to wane at the manor doorstep. But as the lords' influence spreads further into the countryside—presumably because of technological progress—the network of lords simplifies and eventually disappears. "The model, we claim, is the first to capture this historical trend," Cederman says.