NEWS FEATURE

Agents of influence

Models of complex systems have become a staple of business strategy, and now they are showing early promise for improving economic forecasts.

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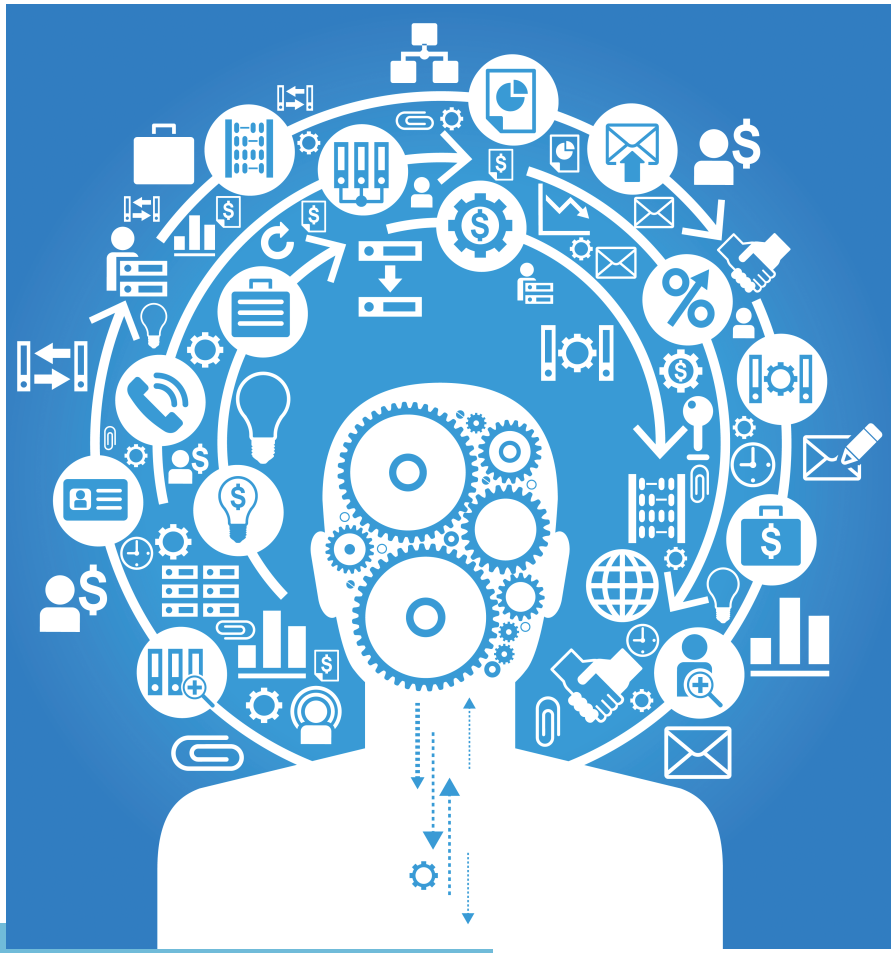
Science Writer

For cargo carriers, the most direct route is not always the cheapest. In the early 2000s, Southwest Airlines adopted a new approach to shipping: Rather than switching cargo from one flight to another to minimize the distance it covered, the airline would take circuitous routes to destinations on fewer flights. The strategy seemed counterintuitive, but it has saved the company millions of dollars in storage rentals and cargo handlers' wages.

Southwest's strategy sprung from a made-to-order computer model that predicted the behaviors of virtual cargo handlers, truck drivers, and airline pilots. Such agent-based models simulate decision makers (the agents) interacting with the world according to prescribed rules, and they have been helping businesses to find efficiencies in complex systems for more than a decade. A number of consulting companies now offer generic versions for customers to analyze their own businesses, and almost every industry has found uses for these off-the-shelf tools.



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The academic researchers behind the models have benefitted too. Their work has attracted substantial funding from companies and governments that want to simulate increasingly complex systems such as traffic flow, military battles, and influenza outbreaks. Now they are turning to their greatest challenge: modeling the economy to help guide financial policymaking.

"Agent-based models provide a new opportunity to model an economy in a realistic way," says J. Doyne Farmer, codirector of the complexity economics program at the Institute for New Economic Thinking at the Oxford Martin School, University of Oxford, United Kingdom. They "allow you to capture the feedback loops and the dynamics of an economy in ways that traditional methods don't," he says. Those traditional methods sometimes fail to predict booms and busts because they rely on statistical forecasting

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from past data—known as econometrics—or on assumptions that many economists have criticized as too simplistic to accurately represent the real economy. In a 2009 opinion piece in *Nature* (1), Farmer partly blamed the current economic crisis on an over reliance on those traditional methods, concluding that "the leaders of the world are flying the economy by the seat of their pants."

Imperfect Copies

Farmer is also the scientific coordinator of the Complexity Research Initiative for Systemic InstabilitieS (CRISIS) project, which aims to build much more sophisticated models than those used by businesses such as Southwest Airlines. Rather than simulating hundreds

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of agents, they could in principle capture the financial behavior of millions of individuals and companies. Funded in part by a €3 million award from the European Commission, CRISIS kicked off in 2011 and should deliver by the end of 2014 an agent-based model that will fully account for the heterogeneous economic behaviors of households, companies, and governments.

Yet simulations such as these will never be perfect copies of the real world, cautions Robert Axtell, who chairs the Department of Computational Social Science of the Krasnow Institute for Advanced Study at George Mason University, Fairfax, VA. "In this early time of harnessing computing for social sciences," he says, "our models are the first foray into what will obviously be, in the long run, a much bigger project."

Axtell's department is only a few years old, but it is at the vanguard of a few dozen similar programs that are popping up at universities across the United States and European Union. The field is so new, Axtell says, that many students come "with naive ideas about what can be accomplished with computing." One misconception, Axtell explains, is that policymakers will automatically follow the guidance provided by such models, rather than view the models as one of many tools informing policy decisions.

But there is growing evidence that agent-based models can offer policymakers vital advice. Axtell points to research (2) that described strategies to mitigate pandemic influenza in the United States. "A policymaker would want to make heavy, heavy duty use of the models" in that kind of situation, Axtell says.

More Information, More Control?

Researchers like Axtell and Farmer have long sought to give those flying the economy more information and a better control stick, with agent-based modeling the latest control in a history that goes back at least as far as Isaac Newton. While serving as England's Master of the Mint, Newton established the cause of a monetary crisis gripping the nation—silver coins had become worth more when melted down and exported—and dealt with it by switching to the gold standard and introducing paper currency. In the 20th century, mathematical economist Irving Fisher described the global economy in terms of factors like interest, income, capital, saving, and consumption, and was so successful that his work remains important to current economic theories (3). Common to Newton, Fisher, and today's agent-based modelers is a desire to construct better descriptions of the economy by adding more layers of complexity.

Yet formal efforts to understand that complexity are quite recent. Using an expanding set of mathematical tools loosely termed "complexity theory," the study of these complex systems originated at the Santa Fe Institute (SFI), NM, a not-for-profit research center founded in 1984 by scientists from nearby Los Alamos National Laboratory. Two years later, John Reed—then CEO of banking giant Citicorp—invited SFI researchers and economists to develop a better way to predict market crashes, something that the company's own economists, informed by conventional theories, had not been able to achieve. By the mid-1990s, a spinoff of SFI, BiosGroup Inc. (now NuTech Solutions), started consulting for Fortune 500 companies on applications of complexity theory, including building models of Southwest Airlines' cargo routes.

Creating more complex models that involve more agents, more nuanced behavior, and more rules is an obvious route to increasing their predictive power, says Axtell, who is also an external professor with SFI. But additional complexity incurs costs, which are often unexpected. Newton had to contend with counterfeiters as a result of introducing paper currency, for example (4), while Fisher's theories led him to famously predict that the stock market had reached a permanently high plateau just weeks before the crash of 1929. For agent-based modelers, "the challenge is coming up with good behavioral, decision-making rules that take into account people's ability to reason," says Farmer, also an external professor at SFI. "In general, that's hard to do. So one has to devote a lot of time and attention to getting that part right."

In other words, because people often behave unpredictably, even the best models sometimes produce results that are dead wrong.

Better Models, Better World

Dealing with this inherent uncertainty in a global system has strong parallels with climatology, where researchers modeling chaotic systems know that a tiny perturbation in starting conditions can lead to a very large change down the line. The answer is to "quantify the uncertainty that we have due to our ignorance of the system," says climatologist Gavin Schmidt of NASA Goddard Institute for Space Studies at Columbia University, NY. The best way to do this, he says, is to run the model "over and over and over again, changing the various things that we don't quite understand to see what the range of results would be."

While Schmidt sees this repetition as a way to improve the model, Axtell believes that it could offer an opportunity to improve the real world. "We could use computational social science to spin out thousands or millions of alternative social institutions, measure which ones work best, and—if we have enough verisimilitude in our models—then we could actually rank them and find out which ones have much better performance than the ones we have at present," Axtell says.

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Reaching that lofty goal would require models with unprecedented levels of complexity, and one promising approach is to draw on quantum information processing theory when setting the rules that govern agents' behaviors. "The statistics that quantum physicists get from their experiments look a lot like the statistics we get in our psychology experiments," says cognitive scientist Jerome Busemeyer of Indiana University, Bloomington, IN. "You get the same pattern of results."

These similarities stem from the sensitivity of individual agents to external factors—the decisions of other agents, or the specific order of events—just as subatomic particles are constantly influenced by their environment. That includes a well-known factor in both quantum physics and psychology: the "observer effect," in which measuring the system changes it.

Self-Aware Agents

Busemeyer is helping to develop the theories needed to create "quantum agents" in future models. These would need to contain additional feedback loops, in which some agents' actions are informed by the existence and output of other agent-based models.

This approach may be particularly suited to the world of high finance. As investors learn more about complexity theory, they become aware of their status as agents in predictive models, and they also run agent-based models to inform their own decision making—

just like Busemeyer's quantum agents.

Ultimately, though, none of these models will offer iron-clad predictions, because they have to make simplifying assumptions about human behavior. The true test will be whether those assumptions, and the resulting outputs of the models, convince policymakers to act on their advice.

"The way that our computational approach will eventually outrun conventional analytical and numerical methods in economics and finance is by having much more supple and succinct representations of human behavior," says Axtell. But even then, "we don't want policymakers to simply take the results of the model completely at face value without any use of their own judgment."

1 Farmer JD, Foley D (2009) The economy needs agent-based modelling. *Nature* 460(7256):685–686.

2 Germann TC, Kadau K, Longini IM Jr, Macken CA (2006) Mitigation strategies for pandemic influenza in the United States. *Proc Natl Acad Sci USA* 103(15):5935–5940.

3 Dimand RW, Geanakoplos J (2005) Celebrating Irving Fisher: The legacy of a great economist. *Am J Econ Sociol* 64(1):3–18.

4 Levinson L (2010) *Newton and the Counterfeiter: The Unknown Detective Career of the World's Greatest Scientist* (Mariner Books, New York).

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