THE SMALL

WORLD *of* FINANCE

BY DANIEL ROCKMORE

The story is one of easy credit paving the way for a global economic crisis. No, it's not today's news. In fact, it's the news of about 20 years ago. At that time, it wasn't the microloans of ill-advised individual mortgages that formed the first tier of a financial house of cards, but instead, the bad paper of huge loans to developing nations. Much as today, the perspectives and proposed fixes ranged far and wide, but from a complexity science point of view, one reaction stands out.

It is that of John Reed, then CEO of Citigroup, whose company held billions of dollars of bad loans. To address Citigroup's predicament, and to better understand the dynamics of a highly interconnected network of economies, Reed decided that ideas and points of view from beyond neoclassical economics were needed. Perhaps, he thought, the more holistic, yet still rigorous, view of the scientists at the fledgling Santa Fe Institute—a point of view summarized in the phrase "complexity science"—would provide a framework for a deeper understanding.

In his book *Complexity*, Mitch Waldrop describes how Reed backed an SFI meeting of economists, physicists, and even a stray biologist or two. In so doing, Reed helped to foster a wide-ranging conversation about economics, physics, and the other sciences that continues at the Institute to this day, yielding insights into economies and markets, and influencing the way that practitioners and people view them.

Two decades later, the dramatic economic downturn of the past months has once again highlighted the interdependence of the financial markets (in truth, we seem to be "reawakened" to this interdependence every few years). Even more so than the events that brought Reed to SFI, today's crisis reveals an economic and financial system that is complexity in action: the result of interconnections and interdependence at many scales among numerous elements and sectors of the world-wide economy. As governments try to mitigate this crisis and to insert new capital and regulations into the financial infrastructure, the world economy as a complex adaptive system needs to be articulated, studied, and addressed.

The network-centric view of the economic crisis befits an age in which network science, a discipline that grew out of the work of many SFI researchers, most notably Duncan Watts and Mark Newman, plays such a prominent role. In the late 1990s, Watts and his colleague Steven Strogatz developed the first comprehensive model of the "small world phenomenon," which brought to widespread public attention the 1960s experiments of Stanley Milgrim. Today we see and study networks in all sorts of places—the network of neurons that makes up the brain, the hyperlinked network of the World Wide Web, social networks of interpersonal relationships, networks of genetic interrelations that give rise to disease and development, metabolic networks that detail the chemistry that gives life to a cell, and ecological ones that encode the delicate interdependence of species in an ecosystem.

Most relevant to the economy, of course, are the networks of finance that map how value, capital, credit, and risk circulate among market participants. The opaque and dense network of creditor/obligator relations that underlies the financial world has been exposed in the failures and

Opposite page: Evolution has given plants and animals robust and self-regulating circulation networks—and planners try to do the same for roads. Mapping the connections of financial networks might offer similar benefits for the economy.

OPPOSITE PAGE—LEAF VEINS: PAULA EASTWOOD; MAP: U.S. DEPT. OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

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A simple stoplight offers a metaphor for the dynamic interplay between regulation and innovation that is central to the history and development of many complex adaptive systems.

near-failures of Bear Stearns, Fannie Mae, Freddie Mac, Lehman Brothers, AIG, and many lesser-known hedge funds. A cascade of extinctions has spread through the ecosystem of the markets along lines of credit and risk, linking the institutions in which we park our money. Even the instruments themselves are a form of network—the value of a derivative object is linked to the value of some other object, which may in turn be linked to even another instrument or asset, and so on and so on.

The network of value is thus also a network of risk. And as we've seen, no matter how risk gets pushed around the network, eventually, like a game of financial Whack-A-Mole, it has to poke its head up somewhere. The unpredictability of this game and the assumed, but almost completely hidden complexity of this network have paralyzed credit sources, causing the economy to grind its gears. Credit makes the world go round. There's a basic necessity to understand its journey, to see the network and map its connections so we can comprehend the consequences of

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adding a new connection. This would create the transparency needed to reveal the multiple levels of obligation and exposure that are set up in any credit-based deal in a network of credit.

Such a map could, of course, be a consequence of some form of regulation. Regulation also plays a role in many of the healthy networks that we see in life, such as our circulatory and respiratory systems, the networks of plant life and root systems in a forest, the course of rivers, or even various road systems. Each of these can be thought of as branching networks of pipes for resource delivery in which the tubes keep getting smaller (up to some point). Explaining this interplay is part of the well-known work of SFI researchers Geoffrey West, Jim Brown, Van Savage, and others on "allometry"—the way that the form and function of living things change with their size. The network structure seen so frequently in living systems, with multiple levels of branching leading to branches of decreasing thickness, turns out to be the most efficient way to distribute a resource, such as blood in animals or water in plants, throughout a region. Implicit here is the idea that for these systems there is a natural "scaling law" in the movement of resources in the organism.

More recently, West and his colleagues have found that the same kinds of scaling laws can apply in social and economic settings. It would be interesting to see if these arguments provide insights into the recent crisis. For example, did the relaxation of financial regulations and the accompanying expansion of credit produce an unsustainable deviation from a "natural" allometric hierarchical progression of capital flow? Did we, in other words, overload the economy's pipes?

Such a "deviation" may have almost killed off the economic organism that it was meant to sustain. Perhaps each of the individual actors that sits at the branchpoints of the financial network needed to have something pushing back on their imposed on life by physics and chemistry, evolution has created extraordinary in the harshest circumstances.

natural inclination to pipe through as much capital as possible. In living things, the physics of the system does this job. Maybe in a financial network, some sort of regulation or local penalty could effect the necessary behavior modification. Interestingly, this kind of analogy suggests that perhaps markets and economies have under some conditions a maximal sustainable size. From energetic and structural considerations you can show that we can't have a 50-foot woman—maybe something similar is true of economic systems.

This kind of dynamic interplay between regulation and innovation is central to the history and development of many complex adaptive systems throughout biological, physical, social, and economic life. At times, regulation fosters innovation (e.g., the imposition of standards in technological development, or genetic response to environmental factors). In other instances, regulation can squelch innovation. Innovative responses can respect regulations or attempt to circumvent them. The responses generate new regulations that generate their own responses, and so on.

In this process of co-evolution, some systems flourish while others wither. With respect to markets, some folks argue that regulation stifles innovation. They stress that relaxed regulation is inextricably tied to the ability to create the "liquidity" so necessary to keep the markets fluid. Again, living networks might indicate otherwise. Even within the hard constraints imposed on life by physics and chemistry, evolution has created extraordinary adaptations to survive, even thrive, in the harshest circumstances. It would be interesting to explore what lessons we might learn by considering innovation and regulation across a broad spectrum of phenomena.

In sum, the financial network is a living complex adaptive system of millions or even billions of dimensions. In particular, financial networks have embedded in them the problem that their basic interacting units are people, an organism whose behavior is highly unpredictable—much more than the most complicated quantum effect. The idea that the old rules can manage this adaptive organism is preposterous. Like a monster from a bad bio-horror movie, it's already evolved to anticipate and then exploit the usual fixes. Its complexity begs for an analysis that brings to bear our understanding of the mechanisms that drive other living systems. It is huge, but it is highly likely that, like other living systems, its evolution and dynamics are driven by a relatively few fundamental principles that we now must try to tease out. Our economic and social future depends on it. ◀

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SFI'S CURRENT EFFORTS TO VIEW THE ECONOMY AND FINANCIAL MARKETS FROM A COMPLEX SYSTEMS PERSPECTIVE are summarized by two additional articles in this issue: "Aftershocks of the Financial Earthquake" by former SFI Science Writer in Residence John Whitfield, and "On Time and Risk" by former SFI Postdoctoral Fellow Ole Peters. Others have recently appeared in major journals and news publications: "End the Obsession with Interest" in *Nature,* and "Matters of Principal" in *The New York Times,* both by John Geanakoplos; "Leverage: The Root of All Financial Turmoil," a news article in *Science,* reported on work by Stephan Thurner, J. Doyne Farmer, and John Geanakoplos; "The (Unfortunate) Complexity of the Economy" in *PhysicsWorld,* by Jean-Philippe Bouchaud; and "Managing Economic Crisis in the Computer-Age," in *Nature* (in press), by J. Doyne Farmer and Duncan Foley.