When Diversity Vanishes

BY DON MONROE

Complex systems, from ecologies to economies, do interesting and unexpected things. Much of this rich behavior can be traced to the networks through which the underlying "agents" affect each other. Often, however, diversity of the agents themselves is essential. If they act too similarly, the entire system can cease to function. At the annual symposium of the Santa Fe Institute Business Network, November 1–3, 2007, an array of experts explored this "diversity collapse" in contexts ranging from ecology and the food we eat, to finance and organizational structure.

ECOLOGICAL COLLAPSE

The most dramatic diversity collapses are mass extinctions, which have wiped out much of life five times in Earth's history. Doug Erwin, of the National Museum of Natural History and SFI, said that one of these, the end-Permian extinction, wiped out "90 to 95 percent of everything in the oceans, about 70 percent of everything on land, and by all accounts was about the best thing that ever happened to life on Earth." The extinctions made room for later innovation—but not right away. "Eventually the diversity got bigger than before, but it took four million years to even get started."

In contrast to some observers, Erwin does not believe that we are entering a "sixth wave" of extinction. "At least if we're lucky, we're not," he said. Nonetheless, "the crisis is real." Erwin emphasized that there are many types of diversity, which do not have the same impact. For example, individual species on different branches of the tree of life forms can become extinct without substantial effect, but losing the same number of species on a single branch could eliminate that entire branch.

Global extinction reflects the combined changes in smaller, individual ecosystems around the world. Andrew Dobson of Princeton University described what he called "probably the best-studied" ecosystem: the Serengeti National Park in Tanzania. Established in 1951, this park and the surrounding areas provide "a natural example of what happens when we perturb an ecosystem," he observed. Outside the park, the ecology changes dramatically because of farming and grazing. The difference is most notable at the highest trophic levels in the food chain, Dobson observed.

Dobson contributed to the Millennium Ecosystem Assessment, which framed the contributions of healthy ecosystems, at least in part, in terms of the economic "services" they provide to people. Almost half of the value, Dobson said, comes from the most basic level, including bacteria, and another one third from plants. These lower levels also tend to be more resilient. Higher trophic levels, including grazers and

The Global Seed Vault on the Norwegian island of Svalbard opened in February 2008. Descending almost 500 feet under the permafrost, it is designed to withstand earthquakes, extreme temperature fluctuations, and bomb blasts.

ABOVE: DEAN C.K. COX

predators, are more visible but provide less value, he said. They are also more sensitive to changes, so "monitoring these brittle species gives an early warning" of damage.

"We have a scarily short time scale to understand how ecosystems collapse," Dobson commented. "Most large natural ecosystems will be destroyed in the next 30 to 50 years. The quality of human life on this planet is dependent on the economic services supplied by those webs."

Historically, said Mercedes Pascual of the University of Michigan and SFI, ecologists viewed complexity in food webs as an essential feature of healthy ecosystems that helps them to resist disruption. In contrast, monocultures, such as the endless fields of U.S. Midwestern corn, can succumb to a single pest.

The important work of Robert May in the 1970s, however, showed that complexity actually reduces stability in some mathematical models. Ever since, Pascual said, ecologists have tried to understand "how more realistic structures lead to higher stability."

Instead of studying small perturbations as May did, Stefano Allesina, of NCEAS, and Pascual looked at major shifts such as the disappearance

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Natural ecosystems, which have evolved complex webs of interactions, are ideally "managed" by leaving them alone. The images above and on the facing page depict the contrast between the pristine land of the Serengeti National Park in Tanzania and land outside the park, where grazing and other uses have prevailed.

of prey causing a predator to become extinct. They also used food webs taken directly from ecological studies instead of mathematically generated networks. They then determined which pathways are functional and which are redundant, from the perspective of secondary extinction, and found that in real webs about 90 percent of connections are functional, independent of the size of the ecosystem.

As a result, Pascual observed, "Even when secondary extinctions are not observed, the loss of species makes ecosystems more fragile to further extinctions." There may be little warning of an approaching "tipping point," in which the entire ecosystem collapses.

Pascual suggested that work by SFI External Professor Ricard Solé may clarify the dynamics of interacting populations contributing to extinctions in these ecological networks. In his model, as species continually become extinct and new ones immigrate into a region, the food web forms a self-organized state, with many of the features observed in real webs.

Although the system as a whole seems static, individual species are not. "Individual populations…are all going up and down like crazy," Pascual said. These fluctuations at one level may even enhance the stability at a higher level. The extinction of individual species may therefore be a misleading measure of the loss of diversity.

The question of the best level for gauging diversity also arose in work by Katia Koelle (Penn State), Sarah Cobey (University of Michigan), Bryan Grenfell (Penn State), and Pascual on the evolution of flu. Genes evolve continuously, but often with no effect on the "phenotype": the surface proteins that determine immune response. The researchers modeled genetic evolution coupled with the prevalence in the human population of immunity to particular variants. In this model, viruses multiply rapidly whenever they take on a new phenotype, quickly crowding out other variants. "This pattern of boom and bust is explained by an interaction of genetic drift and selection, and not exclusively one or the other," Pascual said.

MANAGED ECOSYSTEMS

If the ecologists are right, natural ecosystems, which have evolved complex webs of interactions, are ideally "managed" by leaving them alone—when possible. In stark contrast, agricultural crop management resembles control theory—an engineering tool developed for much simpler systems—and features simplified ecosystems that depend heavily on external inputs. Much of the corn in the U.S. is grown with petroleum-derived pesticides and fertilizer, and fed to cattle whose excrement then becomes toxic waste rather than nutrition for plants.

An alternative was described by Joel Salatin, who recovered marginal land in Virginia by using cow manure to fertilize the grasses that are the natural food for cattle. But Salatin complained that the many regulations aimed at industrial-scale production present formidable barriers to small farms like his.

In spite of such efforts, local production is likely to be an anomaly in an industrial food system that prizes cheap and abundant food. But Cary Fowler of the Global Crop Diversity Trust asserted that this system depends on underappreciated diversity of plant varieties.

Even as agriculture has focused on fewer species over the past 12,000 to 15,000 years, Fowler said, "diversity in some sense was increasing," as farmers in different regions selected variants with different traits. "There are about 120,000 different varieties of rice, each as distinct one from the other as a Great Dane from a Chihuahua," he commented.

Industrial agriculture, Fowler said, threatens this variation within species, although scientists still cannot agree on how to measure it. In response to new challenges, he wondered, "can we continue to develop our agriculture without diversity?" His answer: "Obviously we can't."

The expected global warming in coming decades makes these issues especially urgent. "My guess is we are ill-prepared for this kind of change," Fowler said. "But if we are prepared, it will be because of the gene banks and the diversity they contain."

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PAULA EASTWOOD

Numerous gene banks have been storing seeds for crops and other plants around the world. Unfortunately, Fowler said, many of them are poorly funded and maintained. He stressed that for a modest cost—an endowment of some $250 million—“we can conserve the gene pool of our major crops in perpetuity.” As a start in this direction, Fowler’s organization is funding a facility above the Arctic Circle to provide a global seed repository, sometimes called the “doomsday vault.”

VALUING DIVERSITY

No such vault exists to preserve human culture. “The forces of homogenization are rampant,” said Suzanne Romaine of the University of Oxford. She described the rapid extinction of languages, as large ones like Mandarin, Spanish, and English spread at the expense of smaller ones.

As a linguist, Romaine values languages as data for her own work. But she sees linguistic extinction as part of a larger problem. “It’s not just languages that are at stake, but forms of knowledge,” she said. “They can’t be separated from people, their identities, their cultural heritage, their well-being and their rights.” She also stressed that language diversity and biodiversity often disappear together.

In a similar way, shared communication drives a homogenization in computer systems, said Gabriela Barrantes, of the University of Costa Rica and SFI. The dominance of Microsoft in personal computer software is only the most visible example of this diversity collapse, she said.

This uniform computing environment is sensitive to threats, just as monocultures are vulnerable to agricultural pests. Barrantes and Stephanie Forrest, of the University of New Mexico and SFI, have been exploring how artificial variability in computer systems can slow the spread of malware. In any successful scheme, she stressed, computers must still interoperate with similar performance and cost.

LEFT: Though much industrial agriculture favors cheap and abundant food, a great deal of diversity, such as these varieties of beans, can still be found.

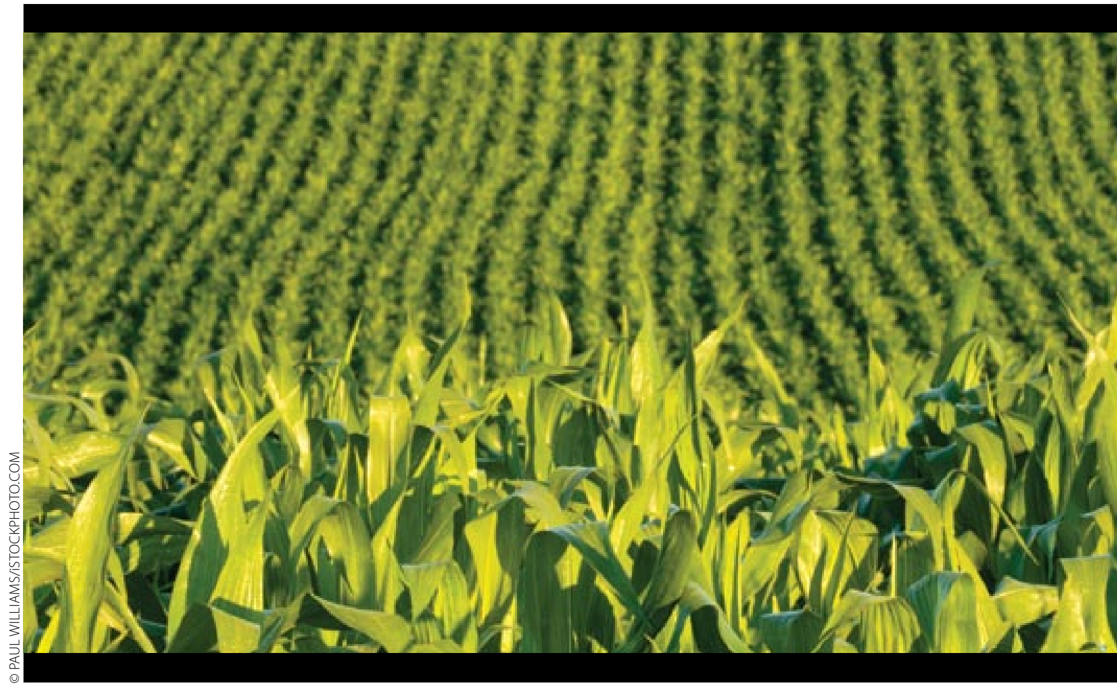
Diversity can be introduced at many levels, Barrantes said. For example, the well-known “buffer overflow” attacks rely on long data spilling into areas of memory intended for programs. Varying the locations of these segments can often thwart the spread of infection between different machines. This kind of artificial diversification is “currently being used in two major operating systems,” Barrantes said.

Diversity collapse in computer systems is probably well ahead of that in ecosystems, Forrest suggested. But she noted that “adding diversity back in is much easier than it would be in the natural world.”

The dominance of Google, eBay, and others shows that “online niches are often winner-take all,” notes Virgil Griffith of the California Institute of Technology and SFI. But Griffith claimed that “promiscuous interoperability” can promote diversity by allowing people to use data for new purposes. “When all-powerful monocultures make data available, diversity flourishes,” Griffith claimed. “The users diversify the monoculture, not the other way around.”

DIVERSE PERSPECTIVES

In finance, diversification reduces risk by spreading money among assets that respond differently during market moves. But during the 1998 international financial crisis, Long-Term Capital Management suffered enormous losses when its ostensibly diversified investments began to react similarly as other investors desperately sold the same assets (see “Risk in Financial Markets” in this issue). “Diversity collapses are really the source of inefficiencies in markets,” asserted Michael Mauboussin, Chief Investment Strategist at Legg Mason Capital Management and an SFI trustee.



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Mauboussin reviewed three theories for how markets become efficient, meaning that prices reflect value. The first, in which all investors behave rationally, is unrealistic. A second explanation, which requires only that some investors exploit—and thereby remove—arbitrage opportunities, “has failed us in critical junctures,” he asserted.

Mauboussin contrasted these models with a view of “markets as a complex adaptive system, where prices essentially emerge from the interaction of many agents.” In this view, also called “the wisdom of crowds,” three conditions assure efficiency: diversity among investors, an aggregation mechanism, and financial incentives. Of these assumptions, he said, “the most likely to be violated is diversity,” which may decline imperceptibly until it suddenly collapses.

Scott Page of the University of Michigan and SFI, has compiled many ways that diverse groups outperform individuals. In expert judgment, for example, as in diversified portfolios, the average judgment of a group is always better. “This is not a feel-good statement, this is a mathematical theorem,” Page said. For problem solving, having multiple strategies can help a group evade roadblocks that hamper any one approach.

“In human systems,” Page said, “the thing that really works against cognitive diversity is selection.” The increasingly global marketplace of ideas selects the current “best practices” at the expense of other approaches. “If the world is flat, we cannot count on the right amount of diversity existing,” Page said.

Page warned that merely recognizing the advantages of cognitive diversity might not be enough to preserve it. “Diversity’s benefits may be public goods that are not in any one’s interest to maintain.”

One way to maintain diversity is through time-varying selective pressures that prevent one idea from dominating. However, Page showed a simple model in which such churn did not prevent uniformity. He suggested that maintaining diversity also requires diverse selective processes or richer networks, so that the criteria for picking winners varies.

The broad range of speakers at this symposium shows that the Santa Fe Institute is in no danger of diversity collapse, although similar principles apply in very different fields. Still, in the world outside, increasing interconnectedness seriously threatens diversity in both human organizations and ecosystems. ◀

Don Monroe (www.donmonroe.info) writes on biology, physics and technology from Berkeley Heights, New Jersey. Prior to 2003, he spent 18 years in basic and applied research at Bell Laboratories.

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