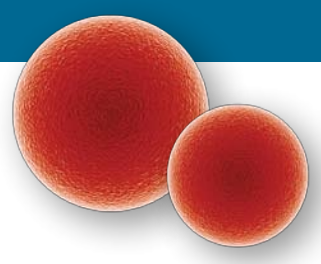
SANTA FE INSTITUTE

Update

June / July 2008

RESEARCH NEWS

Little cell, big job



Life requires particular chemical reactions, and to make them happen, the chemicals need to be highly concentrated. Such concentrations won't occur if the compounds are awash in a great sea.

Thus, to create life, first there has to be a little compartment. In other words, a cell.

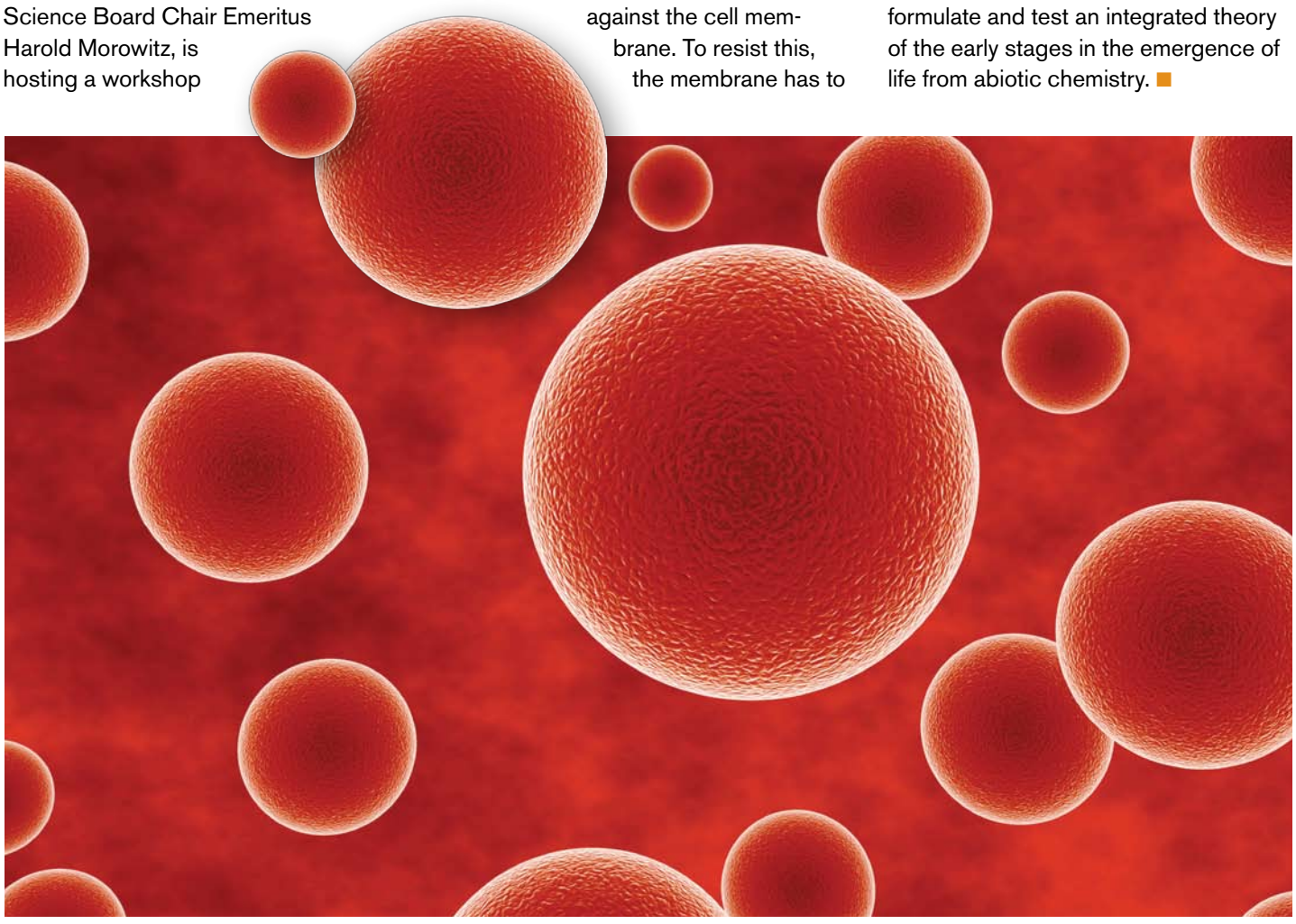
"A cell is a big complicated thing that does all this stuff," says SFI Professor Eric Smith who, along with SFI Science Board Chair Emeritus Harold Morowitz, is hosting a workshop June 16-19 to ask how cells could have come about.

First a cell somehow has to form. Ideally, it will self assemble from raw materials. But how can such a complicated structure possibly create itself?

The next problem a cell faces is as soon as it concentrates a compound, it's liable to explode. Concentration creates osmotic pressure that pushes against the cell membrane. To resist this, the membrane has to be either toughened or reinforced.

At the same time, the membrane has to be porous, welcoming some things in and shutting others out.

The workshop is the third in a series of annual meetings that are part of a five-year NSF Frontiers in Integrative Biological Research (FIBR) grant led by SFI. The project brings scientists from many disciplines and institutions together to formulate and test an integrated theory of the early stages in the emergence of life from abiotic chemistry. ■



Were primitive cells the containers in which life's chemistry emerged? (Image: ©iStockphoto.com/David Marchal)

RESEARCH NEWS

Ancient ecosystems organized much like today's

The more things evolve, the more they stay the same.

So concludes a multidisciplinary study – the first to reconstruct detailed food webs of ancient ecosystems – showing that networks of feeding relationships among marine species that lived hundreds of millions of years ago are very similar to the food webs of today. The work was led by SFI Research Fellow Jennifer Dunne.

The study's results, published in the open-access journal *PLoS Biology* (April 2008), suggest that deep principles underlie the structure of ecological relationships, explaining,

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Editor's note: The *Update* will not be published in July. The next issue will be August 2008.

IN THIS ISSUE

RESEARCH NEWS

Eco analogy for market success

Financial strategies compete with one another, adapt, live and die, and spread or go extinct. To SFI Professor Doyne Farmer's ear, that sounds a lot like what species do. He believes that the principles driving financial markets can be better understood if they are viewed as evolving ecosystems.

To that end, SFI is sponsoring a workshop, "First Steps Towards Understanding Market Ecologies," July 28-Aug. 1 that will bring together economists, physicists, ecologists, and biologists to explore how to use the ecosystem analogy to get concrete financial results.

Financial strategies, in Doyne's analogy, correspond to biological species. The capital invested using a particular strategy represents the population level of that species.

Darwinian evolution relies on three essential properties: reproductive descent, variation, and natural selection. Financial strategies exhibit all three, says Doyne.

When one investor imitates another investor's strategy, the strategy reproduces. The new investor may tweak the strategy a bit in applying it, providing variation. Finally, strategies compete with one another, and the survivors over the long run are those that make the most money: survival of the fittest.

Doyne's collaborators in Taiwan have gathered data on how individual investors bought and sold assets over the last 15 years. One of his

> more on page 4

LIT BITS

The symmetric group defies strong Fourier sampling; **Moore, Cris [SFI Professor]**; Russell, A.; Schulman, L.J.; *SIAM Journal on Computing* 37 (6), 2007, pp. 1842-1864

The power of choice in growing trees; **D'Souza, Raissa [SFI External Professor]**; Krapivsky, P.L.; **Moore, Cris [SFI Professor]**; *European Physical Journal* B 59 (4), October 2007, pp. 535-543

A Polynesian motif on the Y chromosome: Population structure in remote Oceania; **Cox**, **Murray [SFI Postdoctoral Fellow]**; Redd, A.J.; Karafet, T.M.; Ponder, C.A.; **Lansing, J. Stephen [SFI Professor]**; Sudoyo, H.; Hammer, M.F.; *Human Biology* 79 (5), October 2007, pp. 525-535

The regulatory network of *E. coli* metabolism as a Boolean dynamical system exhibits both homeostasis and flexibility of response; Samal, A.; **Jain, Sanjay [SFI External Professor]**; *BMC Systems Biology* 2, Feb. 29, 2008, pp. 1-18

Metabolic photofragmentation kinetics for a minimal protocell: Rate-limiting factors, efficiency, and implications for evolution; Knutson, C.; Benko, G.; Rocheleau, T.; Mouffouk, F.; Maselko, J.; Chen, L.; Shreve, A.P.; **Rasmussen, Steen [SFI External Professor]**; *Artificial Life* 14 (2), Spring 2008, pp. 189-201

Scaling laws of strategic behavior and size heterogeneity in agent dynamics; Vaglica, G.; **Lillo, Fabrizio [SFI External Professor]**; Moro, E.; Mantegna, R.N.; *Physical Review* E 77 (3 pt 2), March 2008, pp. 1253-1258

Essential amino acids, from LUCA to LUCY; Shinivasan, V.; **Morowitz, Harold [SFI Science Board Chair Emeritus]; Smith, Eric [SFI Professor]**; *Complexity* 13 (4), March-April 2008, pp. 8-9

Transparent and catalytic carbon nanotube films; **Trancik, Jessika [SFI Postdoctoral Fellow]**; Barton, S.C.; Hone, J.; *Nano Letters* 8 (4), April 2008, pp. 982-987

Modeling in biological chemistry: From biochemical kinetics to systems biology (review); **Schuster, Peter [SFI External Professor]**; *Monatshefte fur Chemie* 139 (4), April 2008, pp. 427-446

Gene duplications, robustness, and evolutionary innovations; **Wagner, Andreas [SFI External Professor]**; *Bioessays* 30 (4), April 2008, pp. 367-373

Compilation and network analyses of Cambrian food webs; **Dunne, Jennifer [SFI Research Fellow]**; Williams, R.J.; Martinez, N.D.; **Erwin, Doug [SFI Resident Faculty]**; *PLoS Biology* 6 (4), April 2008, pp. 693-708

Rise of the digital machine; **Pagel, Mark [SFI External Professor]**; *Nature* 452 (7188), April 10, 2008, p. 699

Nets, puzzles, and postmen: An exploration of mathematical connections, by P.M. Higgins; **Mertens, Stephan [SFI External Professor]**; *Science* 320 (5873), April 11, 2008, p. 181

BUSINESS NETWORK NEWS

London primer explores complexity

Speakers at a May 8 SFI Business Network Complexity Primer in London spoke about how complex systems are defined, how their properties are measured, what controls their dynamics, and to what extent people can influence them.

As the speakers described systems ranging from the quantum to the economic, it became clear that – despite the recurrence of familiar SFI themes such as nonlinearity, self-organization, and emergence – complexity has many meanings.

"There's no unique definition," said Karoline Wiesner of Bristol University. Instead, different complex systems share some properties but differ in other ways.

Common properties mean that tools for analysis can be transferred between systems. SFI Science Board Member Lord (Robert) May of the University of Oxford and SFI External Professor Stefan Thurner of the Medical University of Vienna spoke about network analyses as applied to disease epidemics and the Internet. SFI External Professor Peter Schuster of the University of Vienna described phase shifts in the dynamics of mutation and showed how this has already led to antiviral therapies. And SFI President and Distinguished Professor Geoffrey West explained how thinking about animal growth and metabolism had led him and his colleagues towards their current work on cities. ■

CREDITS

Editorial staff
John German
Ginger Richardson
Della Ulibarri

Contributors
Julie Rehmeyer
Pat Lowe
Matthew Blakeslee
John Whitfield

Design and production
Michael Vittitow

The SFI *Update* is published monthly by the Institute to keep our community informed about current work and activities. Please send comments to Ginger Richardson at *grr@santafe.edu.*

RESEARCH NEWS

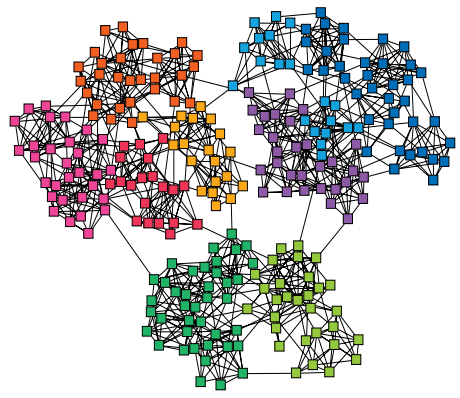
Extracting the hierarchical structure of networks

In a May 1 *Nature* paper, "Hierarchical structure and the prediction of missing links in networks," three SFI researchers show that many real-world networks can be understood as a hierarchy of modules, where nodes cluster together to form modules, which themselves cluster into larger modules. Such arrangements are similar to the organization of sports players into teams, teams into conferences, and conferences into leagues.

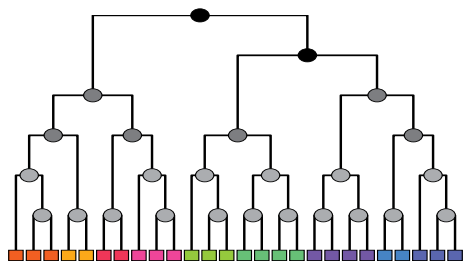
This hierarchical organization, they show, can simultaneously explain patterns previously discovered in networks in biology, technology, and sociology, such as the surprising heterogeneity in the number of connections some nodes have, or the prevalence of triangles in a network diagram. Their discovery suggests that hierarchy may, in fact, be a fundamental organizational principle for complex networks.

In the paper SFI Postdoctoral Fellow Aaron Clauset, SFI Professor Cris Moore, and SFI External Professor Mark Newman (University of Michigan) propose a direct but flexible model of hierarchical structure, which they apply to networks using the tools of statistical physics and machine learning.

To demonstrate the practical utility of their model, they analyzed networks from three disparate fields: the metabolic network of the bacteria that causes syphilis, a network of associations between terrorists, and a food web of grassland species. Even when only half of the connections in these networks were shown to their



A hierarchical network with structure on many scales (above) and corresponding hierarchical random graph (below) in which shades of the internal nodes represent probabilities of connectedness.



algorithm, the researchers found that hierarchical structure can predict missing connections with an accuracy of up to 80 percent.

"Many networks, particularly those in the biological sciences, are not well understood," says Aaron. "But hierarchy offers a way to understand their large-scale organization and, from this, predict what interactions we might have missed." ■

RESEARCH NEWS

To tinker or not to tinker: Principles of repurposing

The swim bladders of fish became lungs. An academic data-sharing protocol became the world wide web.

Nothing comes from nothing. The new always springs from the old, though the path to novelty and innovation is often circuitous and unpredictable, steeped in serendipity, and bedeviled by awkward constraints.

Understanding what kinds of systems are best at having their parts and functions modified to meet new challenges, and why, is the central question of a workshop, "Principles of Repurposing," to convene at SFI July 14-16.

The workshop's 20-odd participants hail from economics, psychology, physics, several branches of the humanities, the biological sciences, engineering, and information technology. According to SFI Professor Jon Wilkins, who co-organized the workshop with SFI Postdoctoral Fellow Jessika Trancik, the group will focus on repurposing in technology, biology, and cognition.

"Our hope," says Jon, "is to be able to come up with a list of candidate [features or principles of system design] that can help people decide when it's best to tinker with an existing system and when it's best to go back to the drawing board."

Such principles would be equally of interest to forward-looking disciplines such as software design and genetic engineering and to backward-looking disciplines such as evolutionary biology and linguistics, he says. ■

Public lectures: Art meets science

A series of public lectures this summer, "Crossing Over: Where Art and Science Meet," will explore beauty and expression in science, as well as fundamental principles and regularity in art.

Con/cantation: Chaotic Variations, June 2, 7:30 p.m., James A. Little Theater (1060 Cerrillos Road): In an interactive performance piece combining mathematics and dance, University of Colorado Computer Science Professor Liz Bradley and Hunter College Dance Professor David Capps present a dialogue between computer and dancer. The piece involves one live dancer and three screens showing avatars performing variations of a movement theme created via a computer-generated chaos algorithm. Co-sponsored by the National Dance Institute of New Mexico.

Art, Optics, and Human Vision, July 16, 7:30 p.m., James A. Little Theater: University of Arizona Professor of Optical Sciences Charles Falco, working with painter David Hockney, has examined optical evidence found in a number of paintings demonstrating that artists as early as 15th century oil painting pioneer Jan van Eyck used optical projections as aids for producing portions of their images. The work sheds light on how more recent artists have created some of their iconic images. This lecture is underwritten by the Gerald Peters Gallery.

The Geometry of Consonance: Music and Mathematics, Aug. 13, 7:30 p.m., James A. Little Theater: Musical chords live in geometrical spaces called "orbifolds" that contain unusual twists and strange singularities, analogous to the black holes of general relativity. Dmitri Tymoczko of Princeton University's Department of Music provides an accessible, multimedia introduction to this new way of thinking about music.

For more information: www.santafe.edu/events/abstract/1225. ■

SFI IN THE NEWS

SFI External Professor Stefan Thurner (Medical University of Vienna) and other researchers say in the April 14 issue of *Europhysics Letters* that our individual opinions both influence and are influenced by our surroundings. The researchers have modeled the opinion formation process in societies and found that, depending on two criteria – how strongly individuals are influenced by each other and how many connections individuals have – a society's overall state can exhibit either large segregated patches of consensus, or areas with closely intermingled opinions. www.physorg.com/news127385810.html

A quantum gate could lead to "automatically secure" networks, said SFI External Professor Seth Lloyd (MIT) in an April 15 *Personal Computer World* article. www.pcw.co.uk/personal-computer-world/news/2214301/first-step-towards-quantum

SFI Professor Doyne Farmer is quoted in the April 17 *New York Times* obituary of Edward Lorenz, a meteorologist who gave rise to chaos theory. "The paper he wrote in 1963 is a masterpiece of clarity of exposition about why weather is unpredictable," said Doyne, referring to work suggesting that even a small difference in a single weather variable might lead to major changes in weather forecasting. Lorenz died April 16 in Cambridge, Mass., at the age of 90. www.nytimes.com/2008/04/17/us/17lorenz.html

The May 2 issue of *Science* notes that SFI External Professor W. Brian Arthur (Palo Alto Research Center) and Yakov Sinai (Princeton University) are the inaugural winners of the Lagrange Prize for research on the science of complexity. They each receive $118K from the Italian CRT Foundation. www.fondazionecrt.it/fondazioneEng

The May 15 *Birmingham Post* (UK) features British painter Andrew Tift, who has had two portraits acquired by the Smithsonian – portraits of Pulitzer Prize-winning author Cormac McCarthy and Nobel Prize-winning physicist Murray Gell-Mann. Both were painted three years ago when Tift was visiting Santa Fe. "I went out there in 2003 and drove around New Mexico, and through a friend of a friend found myself at the Santa Fe Institute, which is where I met McCarthy and Gell-Mann," said Tift. "I didn't really know who they were at the time and how significant they were." www.birminghampost.net/life-leisure-birmingham-guide/birmingham-culture/birmingham-art/2008/05/13/american-honour-for-walsall-artist-andrew-tift-65233-20902487

The May 16 *Santa Fe New Mexican* included a story about recent research led by Jennifer Dunne comparing modern and Cambrian food webs (see page 1). The story was paired with an article on a new Triassic dinosaur exhibit at the New Mexico Museum of Natural History and Science. www.santafenewmexican.com/HealthandScience/Ancient-ecosystems-a-lesson-in-today-s-extinctions

Natural selection takes place at all levels – gene, individual, and population – simultaneously, and what happens at each scale resonates through the web of life in ways we're just beginning to comprehend, according to SFI External Professor Maya Paczuski (University of Calgary), who talked with *Wired.com* blogger Brandon Keim about the expansion of evolutionary theory to include complexity and emergence. http://blog.wired.com/wiredscience/2008/04/the-complexity.html

RESEARCH NEWS

How a brain is like a computer

To make a spectacular diving catch, an outfielder's brain takes sensory input and from it organizes a precise series of muscle movements.

A three-day working group at SFI May 19-21, "Principles of Biological Computation," sought to explore how the brain processes information and translates it into action, and how these functions are like, and unlike, those performed by a computer.

Organizers were Garrett Kenyon and Ilya Nemenman (both of Los Alamos National Laboratory), SFI External Professor Melanie Mitchell (Portland State University), and Institute Vice President Chris Wood.

(Image: ©iStockphoto.com/Vasiliy Yakobchuk)

"Both the brain and a computer have memory, both have input and output, and both process information," says Melanie. "One of the most important discoveries of computer science was that, by combining simple logic operations, any computation can be carried out by the computer's CPU. But how does the brain carry out complex computations without, as far as we know, having a CPU?"

The working group brought together molecular and cellular biologists, computer scientists, cognitive scientists, and neuroscientists to explore whether there are abstract general principles of biological computation, independent of systems or implementations.

"This identification of commonalities among systems can help us understand how they work in ways we didn't understand before," says Melanie. "And, by focusing on the 'information processing' view of these systems, we might see new ways to program them." By developing drugs that prevent information processing errors, for example, doctors might discover ways to correct brain disorders, she says.

Melanie plans to present this work in September during a weeklong SFI Business Network meeting titled "Understanding Complex Systems: The Future of Interactive, Immersive Visualization." ■

PEOPLE

Lucia Jacobs: 'This place is like catnip'

For Lucia Jacobs, an evolutionary biologist at UC Berkeley's Department of Psychology, a six-month sabbatical at SFI has been a welcome exploration of data's meaning.

"I'm an idea person, so this place is like catnip," she says. "I come from a field that is very empirically driven. SFI has given me space to step back from the data and bounce questions of theory off people who are used to thinking at that level."

Lucia's research focus is memory and spatial representation – how cognitive beings' brains evolved to create representations of the external world and how these adaptations resulted in complex thought. Her papers are as likely to focus on dogs or squirrels as on humans.

"Most psychologists want to understand the human brain," she says. "I'm interested in the mind, but I don't really care if it's a person or a mouse or a robot. I want to know how slightly different minds solve the same problem."

This comparative approach, she thinks, could be the shortest route to a general principle of spatial representation. "We might then peer into the minds of ants and spiders and humans and find that the same algorithm is working in all of them," she says.

Lucia Jacobs

While at SFI Lucia has spent her time talking with the Institute's resident faculty members, exploring the interrelationships among cognition, neuroscience, behavior, and evolution.

Discussions with SFI Professor Sam Bowles about his work in models of wealth, for example, have surfaced some interesting parallels between species in food storage and sharing, such as for squirrels and humans, she says.

"It's a typical SFI conversation," she says. "We don't have answers, but asking the questions has given me lots to think about." ■

> *Ancient ecosystems*
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perhaps, the persistence of these structures across deep time.

Food webs depict the feeding interactions among species within habitats – like food chains, only more complex. The scientists studied the food webs of Cambrian sea creatures whose unusually well-preserved fossils are found in half-billion-year-old shales in regions of Canada and China.

Feeding interactions were inferred primarily from where species lived and what body parts they possessed; grasping claws and toothy mouthparts, for example, were among clues that one organism was a formidable predator of trilobites, consistent with bite marks found on some fossils.

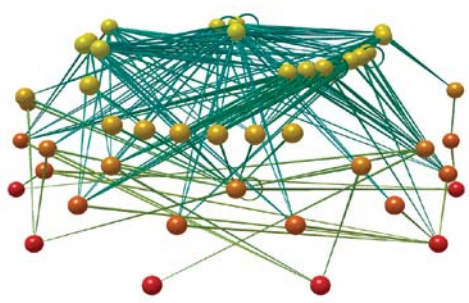
To compare the organization of Cambrian and recent ecosystems, the team used methods for studying network structure, including new approaches for analyzing uncertainty in the fossil data. They found that while the species are completely different, the Cambrian food webs share many similarities with modern webs, such as how many species are expected to be omnivores or cannibals, and the distribution of how many types of prey each species has.

"In general, it doesn't seem to matter what species, or environment, or evolutionary history you've got," says Jennifer. "You see many of the same sorts of patterns. What we don't know is why food webs from different habitats and across deep time share so many regularities."

It could be that species-level evolution leads to stable community-level patterns, for example by limiting through selective pressures the number of predators any species can have. Or the patterns may reflect fundamental physical constraints on how resources flow through ecological networks, she says.

The discovery of enduring regularities could help researchers understand the history and evolution of life and could provide insights for modern ecology.

Jennifer, an ecologist, is co-director of the Pacific Ecoinformatics and Computational Ecology (PEaCE) Lab in Berkeley. Among the study's co-authors are SFI Professor Doug Erwin and Richard Williams of Microsoft Research in Cambridge, UK. Doug is curator of the Smithsonian Institution's Department of Paleobiology.



Food web of the Burgess shale from the Middle Cambrian. Spheres represent species or groups of species; the links between them show feeding relationships. Image produced with Network3D software written by R. J. Williams.

The May 2 issue of *Science* covered the research in its "News of the Week" section. ■

INSIDE SFI

Summer school SFI style: Education programs offer complexity training

More than 100 young scientists ranging from undergraduates to postdocs are becoming better acquainted with the study of complex systems through SFI's summer education programs.

Education & Outreach Director Ginger Richardson says the Institute's motives are both altruistic and self-serving. "Not only do we have an obligation to support science education for the good of society," she says, "our students also become part of an important social network as they go on in their careers and serve as ambassadors for the Institute and for complexity science."

The 2008 lineup includes:

Research Experiences for Undergraduates – Nearly 100 applicants vied for seven spots in this year's program, says REU coordinator Lee Goodwin. The 10-week, all-expenses-paid residency for science and social science majors began June 1. Participants live at St. John's College and spend their days at SFI. Each REU student pairs up with an SFI professor to pursue a custom project for the summer.

Complex Systems Summer Schools (CSSS) – SFI's signature summer schools for graduate students and postdoctoral fellows pursuing interdisciplinary research, now in three countries, provide intensive four-week introductions to complex behavior in mathematical, physical, living, and social systems. Partial support is provided by the NSF and (for the Beijing school) the Chinese Academy of Sciences.

Fifty-five students were selected from hundreds of applicants for the 20th year of **CSSS Santa Fe**, being held June 1-28, according to school director and SFI External Professor Dan Rockmore (Dartmouth). "This is the next class of complex systems researchers," he says. "For many this is their introduction to the field as well as an introduction to collaborative research."

CSSS Beijing, now in its fifth year, will be held June 30-July 25. Fifty-one participants have been selected. Co-directors are David Feldman (College of the Atlantic) and Chen Xiao-song (Institute for Theoretical Physics, Chinese Academy of Sciences).

SFI is offering CSSS in Latin America for the first time this December. The two-week **Bariloche School** will focus on the foundations of complex systems with emphasis on the research frontiers in the field, says SFI Postdoctoral Fellow Miguel Fuentes, school co-director with former SFI International Fellow Pablo Marquet (Pontificia Universidad Católica de Chile). The 30 participants will represent mathematics, biology, and physics.

Graduate Workshop in Computational Social Science Modeling and Complexity – The late-June workshop brings together 11 advanced graduate students and a small faculty for an intensive two-week study of computational social science modeling and complexity. Its primary goal is to assist graduate students pursuing research that includes computational modeling. ■

IMPACT

SFI honors eleven local students, one teacher

At a May 1 awards ceremony at SFI, the Institute honored 11 high school seniors and one teacher for outstanding performance in science and mathematics as part of its annual Prize for Scientific Excellence.

Students from area high schools are selected for the award by a committee of the schools' science and math teachers. The teacher is selected by an SFI committee based on nominations submitted by school administrators.

The prize was co-sponsored this year by the Santa Fe Alliance for Science. The winning students and their schools were: Veronica Weser, Academy for Technology and the Classics; Robert Migliori, Capital High School; Margaret Rose Leitner, Desert Academy; Alexander Blair, Monte del Sol Charter School; Sarah Cantor, New Mexico Academy for Sciences and Mathematics; Marie Atterbury, St. Michael's High School; Daniel Pedro, Santa Fe Indian School; Ellie Powell, Santa Fe High School; Ben Goldsmith, Santa Fe Prep; Max Bennett, Santa Fe Waldorf High School; and Clifford Richardson, SER/SFPS Career Academy.

The winning teacher was Carlos Santiestevan of the New Mexico Academy for Sciences and Mathematics.

SFI's Prize for Scientific Excellence was established in 1996 at the suggestion of SFI Distinguised Fellow and Trustee Murray Gell-Mann. The teacher's award was begun in 2005. ■

> *Market success*

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goals for the meeting is to strategize with colleagues about how to use this information.

"It's a fantastic data set," he says. "We're very eager to use it to understand fundamental properties of the financial system through this evolutionary picture."

The workshop is supported by the NSF as part of an SFI award, "Financial Markets as an Empirical Laboratory to Study an Evolving Ecology of Human Decision Making." It also is part of a larger initiative on financial risk funded in part by SFI Board of Trustees Chair Bill Miller of Legg Mason Capital Management.

SANTA FE INSTITUTE

1399 Hyde Park Road
Santa Fe, New Mexico 87501
T 505.984.8800
F 505.982.0565
www.santafe.edu