



# Update

December 2008/January 2009



## RESEARCH NEWS

### Secrets of collective decision making



(Image: ©iStockphoto.com/Dejan Sarman)

How does a swarm of bees select a new spot for a hive? How do schools of fish decide which way to swim next?

John Miller, SFI Professor and Professor of Economics and Social Sciences at Carnegie Mellon University, is organizing a January 8-11 workshop, "Collective Decision Making: From Neurons to Societies," with social insect specialists Nigel Franks (University of Bristol) and Tom Seeley (Cornell University).

The meeting will bring together some 20 experts to find common theories among their fields of microbiology, immunology, social insect behavior, neuroscience, political science, and engineering.

With bees, scouts find and communicate sites, and hive members act as a "super-organism" in reaching a choice without a central authority. By understanding how such decentralized systems make decisions, the researchers hope to gain insight into

how societies form, how they function, and how they break down. Common themes, as well as decision-making differences, may shed light on complex adaptive systems such as stock markets and voting. They also may offer strategies to improve how human organizations make decisions.

As John puts it, "Bees find new homes, and political systems find new presidents. Maybe they aren't all that different." ■

## RESEARCH NEWS

### Ancestral tongues: Understanding language migration

Human languages spread as glaciers retreated from their latest maximum some 20,000 years ago. Explorations of the descent and global flow of such languages formed one component of a mid-November workshop held at SFI.

The workshop, "The Human Impact of the Last Glacial Maximum," convened a dozen linguists, archaeologists, and geneticists to survey what has been learned in recent years about how humanity recovered from the last glacial maximum (LGM).

It was organized by SFI Distinguished Fellow and Trustee Murray Gell-Mann, SFI External Professor Henry Wright (University of Michi-

gan), and visiting researcher Ilia Peiros.

"We're looking for evidence of the wide expansion of one language's descendants that we think happened between 15 and 20 thousand years ago," explains Murray.

During the LGM, people likely survived in pockets of friendly environments, or refugia, and later spread their cultures and languages when conditions favored expansion.

"We have preliminary indications that one particular tongue was ancestral to many languages throughout the Old World – and subsequently the New World," he says. "What genetic and cultural markers accompa-

nied that language set's expansion? Can we detect them in the archaeological or genetic record?"

Bantu languages emerged in West Africa nearly 4,000 years ago, and spread across the continent, accompanied by familiarity with certain metals and food plants. Indo-European languages swept most of Europe nearly 6,000 years ago, rolling wagon, wheel, and axle across the steppes. In Australia, where people first arrived 50,000 years ago, the aboriginal languages may have descended from one spoken around 10,000 to 12,000 years ago.

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## RESEARCH NEWS

### NSF grant continues SFI scaling work

Institute President and Distinguished Professor Geoffrey West has received a National Science Foundation grant of \$225,000 over three years to continue SFI's work in biological scaling.

The grant renewal builds on research that began at SFI more than a decade ago to find principles that explain the mathematical regularities discovered in the metabolic processes of all organisms.

In 1999 Geoffrey and his colleagues, SFI External Professors Jim Brown (University of New Mexico) and Brian Enquist (University of Arizona), showed that the most efficient way to supply blood to any size animal was to have capillaries, the finest possible vessels in the circulatory system, be the terminal units of what mathematicians call a fractal network.

They also showed that because of this arrangement, the relation between energy

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## INSIDE SFI

### SFI accepts \$7.5 million Omidyar challenge gift

With a gift from eBay Founder Pierre Omidyar, an SFI Trustee, the Institute has announced the Omidyar Challenge, a \$7.5 million three-year effort that establishes the Omidyar Fellows Program at SFI.

The program aims to attract creative and curious scholars from the social, physical, and natural sciences to spend two to three years as postdoctoral fellows at SFI, delving into the major questions facing science and society.

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## LIT BITS

Nonadditive entropy reconciles the area law in quantum systems with classical thermodynamics; Caruso, F.; **Tsallis, Constantino [SFI External Professor]**; *Physical Review E* 78 (2 pt 1), August 2008, pp. 41-46

The non-random walk of stock prices: The long-term correlation between signs and sizes; La Spada, G.; **Farmer, Doyme [SFI Professor]**; **Lillo, Fabrizio [SFI External Professor]**; *European Physical Journal B* 64 (3-4), August 2008, pp. 607-614

SynBlast: Assisting the analysis of conserved synteny information; Lehmann, J.; **Stadler, Peter [SFI External Professor]**; Prohaska, S.J.; *BMC Bioinformatics* 9, August 24, 2008, pp. 1-14

Analysis of the Karmarkar-Karp differencing algorithm; Boettcher, S.; **Mertens, Stephan [SFI External Professor]**; *European Physical Journal B* 65 (1), September 2008, pp. 131-140

Leverage cycles and the anxious economy; Fostel, A.; **Geanakoplos, John [SFI External Professor]**; *American Economic Review* 98 (4), September 2008, pp. 1211-1244

Strictly and asymptotically scale invariant probabilistic models of  $N$  correlated binary random variables having  $q$ -Gaussians as  $N \rightarrow \infty$  limiting distributions; Rodriguez, A.; Schwammle, V.; **Tsallis, Constantino [SFI External Professor]**; *Journal of Statistical Mechanics-Theory and Experiment*, September 2008, pp. 51-70

Developmental autonomy and somatic niche construction promotes robust cell fate decisions; Bershad, A.K.; **Fuentes, Miguel [SFI Postdoctoral Fellow]**; **Krakauer, David [SFI Professor]**; *Journal of Theoretical Biology* 254 (2), September 21, 2008, pp. 408-416

Large-scale reconstruction and phylogenetic analysis of metabolic environments; **Borenstein, Elhanan [SFI Postdoctoral Fellow]**; Kupiec, M.; **Feldman, Marcus [SFI External Professor]**; Ruppin, E.; *Proceedings of the National Academy of Sciences of the United States of America* 105 (38), September 23, 2008, pp. 14482-14487

Generation of hierarchically correlated multivariate symbolic sequences with an application to the assessment of bootstrap confidence in phylogenetic analysis; Tumminello, M.; **Lillo, Fabrizio [SFI External Professor]**; Mantegna, R.N.; *European Physical Journal B* 65 (3), October 2008, pp.333-340

Reconstructing macroeconomics: A perspective from statistical physics and combinatorial stochastic processes; Aoki, M.; Yoshikawa, H.; **Foley, Duncan [SFI External Professor]**; *Journal of Economic Behavior & Organization* 68 (1), October 2008, pp. 319-325

Statistical properties of thermodynamically predicted RNA secondary structures in viral genomes; Spano, M.; **Lillo, Fabrizio [SFI External Professor]**; Micciche, S.; Mantegna, R.N.; *European Physical Journal B* 65 (3), October 2008, pp. 323-331

Evolutionary emergence of responsive and unresponsive personalities; Wolf, M.; **van Doorn, Sander [SFI Postdoctoral Fellow]**; Weissing, F.J.; *Proceedings of the National Academy of Sciences of the United States of America* 105 (41), October 14, 2008, pp. 15825-15830

Energy uptake and allocation during ontogeny; **Hou, Chen [SFI Postdoctoral Fellow]**; Zuo, W.Y.; Moses, M.E.; **Woodruff, Woody [SFI External Professor]**; **Brown, Jim [SFI External Professor]**; **West, Geoffrey [SFI President and Distinguished Professor]**; *Science* 322 (5902), October 31, 2008, pp. 736-739

## > Omidyar challenge continued from page 1

The gift will enhance the Institute's existing postdoctoral fellows program and help support SFI's research infrastructure. The "challenge" part of the gift is a requirement that SFI raise a dollar-for-dollar match.

"We are very pleased Pierre has made such a generous contribution toward ensuring the vibrancy of SFI research," says Bill Miller, SFI Chairman of the Board and Chairman of Legg Mason Capital Management. "We are committed to raising the matching funds and meeting his challenge."

For more than two decades the Institute's postdoc program has helped advance SFI's unique multidisciplinary research and spread SFI's approach to academic institutions around the world.

The new program will provide postdoctoral fellows with more opportunities and a greater level of support and training at SFI, says SFI Professor Jon Wilkins, who has coordinated the postdoctoral program for several years.

The first Omidyar Fellows will join the Institute in Fall 2009. More information can be found at [www.santafe.edu/education/fellowships-postdoctoral.php](http://www.santafe.edu/education/fellowships-postdoctoral.php).

The Omidyar gift brings SFI two-thirds of the way toward meeting the \$50 million goal of its 25th anniversary campaign, says Shannon Larsen, SFI Executive Director of Development and Corporate Relations. ■

## PEOPLE

### Wayne Cote to leave SFI

Institute Events Manager Wayne Cote has announced that he plans to leave SFI at the end of January to become Far East regional events manager for the St. Regis Hotel group.

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## RESEARCH NEWS

### Newman cartograms help describe 2008 election results

Election maps created by SFI External Professor Mark Newman (University of Michigan) were part of the presidential election-night coverage on several major news networks including ABC and BBC. Later Mark was interviewed about the work on NPR's All Things Considered.

The maps, called cartograms, are similar to the red-and-blue state maps commonly used during election coverage to show nationwide voting patterns. But the standard state-by-state maps don't tell the whole voting story because they depict voting results in terms of geographic area.

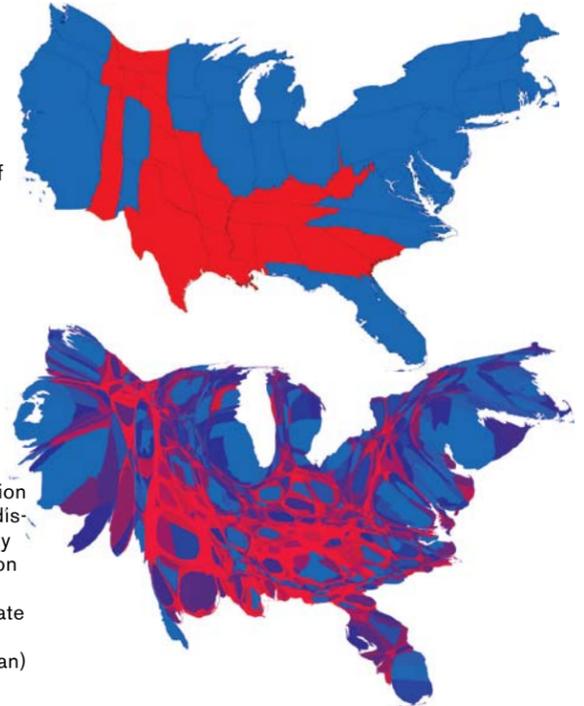
For the last few presidential elections Mark and collaborators have created special cartograms – maps in which the sizes of states are visually rescaled to incorporate population distribution, electoral college votes, county-by-county voting percentages, or other more telling patterns.

Mark's says his website ([www.umich.edu/~mejn/election/2008](http://www.umich.edu/~mejn/election/2008)), which contains a variety of election cartograms, received more than half a million hits the week of the election. The site also offers the technical details of how the cartograms were created.

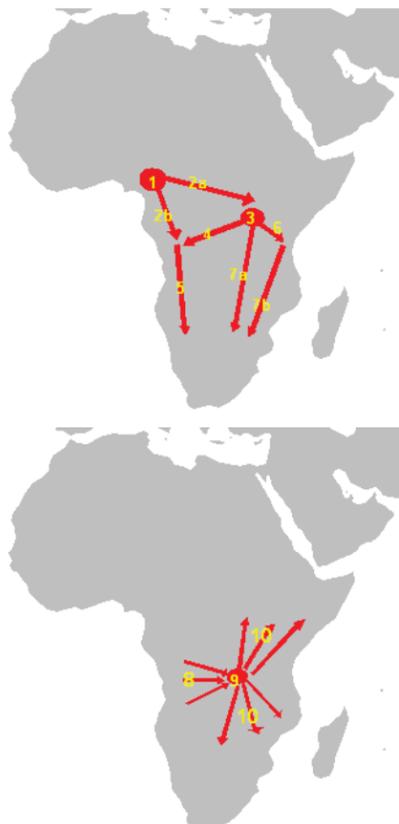
The original cartogram work was done in collaboration with former SFI Postdoctoral Fellow Michael Gastner and former SFI Graduate Fellow Cosma Shalizi. ■

Cartograms of 2008 presidential election results by (top) electoral college vote distribution and (bottom) county-by-county voting weight as a function of population distribution, with shades representing weighting of voting toward one candidate or the other.

(Images: Mark Newman)



A sketch of Bantu's spread from West Africa across the continent from its origins in 3000-1500 B.C. (1), through first migrations of Eastern Bantu (2a) and Western Bantu (2b) circa 1500 B.C., to the Urewe nucleus of Eastern Bantu (3) in approximately 1000 - 500 B.C., its southward and eastward advance (4-8) to the Congo nucleus (9) at approximately 500 B.C. - 0, and the last phase (10) in approximately 0 - A.D. 1000. (Image: Wikimedia Commons)



## > Language migration continued from page 1

In what Murray calls a bottleneck, "many languages may be spoken at a given time, but one somehow projects itself strongly into the future through its progeny."

## RESEARCH NEWS

### Answer to cyber threats: immunity

The greatest threat to computer systems is no longer the mischievous techie but adversarial nations and organized computer criminals.

To protect against such threats, computer security systems need to be far more sophisticated than they are today, says SFI External Professor Stephanie Forrest, Professor and Chair of Computer Science at the University of New Mexico. Like the human immune system, tomorrow's systems need to automatically detect threats, defeat them, and protect against them in the future.

Stephanie is co-director of a five-year, multi-university research initiative grant from the U.S. Air Force to develop such systems. She and her collaborators will meet at SFI January 6-9 to discuss "Self-Regenerative Approaches to

Computer Security."

"Computer systems are vulnerable to attack because they're all genetically identical," she says. When a virus infects one Windows computer, it can easily go on to infect millions of others. Human populations are more robust than computers because human immune systems vary, so you may be naturally immune to a bug that lays your spouse low.

The workshop will explore ways software can be systematically varied to create analogous protection for computer systems. Also to be considered are techniques by which computer systems can heal themselves when a virus does manage to break through their defenses. ■

## RESEARCH NEWS

### Better networks for better insights

Networks, which have helped illuminate a variety of complex relationships from gene regulation to terrorist interactions to ecological food webs, are flexible, powerful, and widely applicable scientific tools.

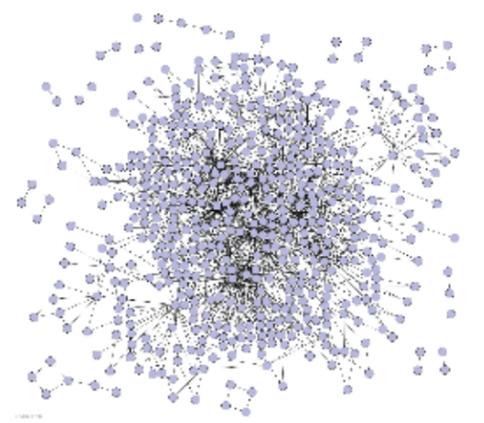
But their full power can only be realized with a better understanding of networks themselves, says SFI Postdoctoral Fellow Aaron Clauset.

"Most people in the field believe that networks are much more complex than our simple models give them credit for," he says.

Improved future models will be more complex and will use data more directly to test the theories, he says. Machine learning techniques are pointing the way.

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Interactions that make up the metabolism of the *Treponema pallidum* bacterium, which causes syphilis, are so complicated that researchers need better tools to understand them.



## SFI IN THE NEWS

An October 31 segment on KOAT TV's evening newscast featured several northern New Mexico middle school students participating in the SFI education outreach program Project GUTS – Growing Up Thinking Scientifically. Project GUTS coordinator Irene Lee was interviewed. She characterized the program as getting students to apply complex systems thinking to their experiences. [www.koat.com/video/17861656/index.html](http://www.koat.com/video/17861656/index.html)

A post to the PBS *Online NewsHour's* Business Desk includes an audio interview with SFI Professor Sam Bowles, following this introduction from editor Paul Solman: "Recently we interviewed one of America's true maverick economists and longtime students of inequality, Sam Bowles...for a story on inequality in New Mexico (part of the *NewsHour's* Spotlight Cities series). We only used a small piece of the Bowles interview in our story. But I thought it was a fascinating case for the negative economic consequences of inequality and have thus posted

a longer portion of the interview here, edited exclusively for the readers of this page. I hope you find it as provocative as I did." [www.pbs.org/newshour/businessdesk/2008/11/](http://www.pbs.org/newshour/businessdesk/2008/11/)

An essay in the November 20 *Nature* by SFI Professor Sam Bowles suggests that parochialism and altruism may have acted synergistically to advance the evolutionary advantage of human groups. He described computer simulations developed by himself and his collaborators. "We allowed groups of agents, tolerant or parochial, altruistic or selfish, to interact over thousands of generations under conditions likely to have been experienced by our Late Pleistocene and early Holocene ancestors...In millions of simulated evolutionary histories, the populations emerging after thousands of generations of selection tend to be either tolerant and selfish, with little warfare, or parochial and altruistic, with frequent and lethal encounters with other groups." Results were

compared with historical evidence of environmental stress, resource competition, and warfare. The conclusion: "In ancestral humans, evolutionary pressures favoured cooperative institutions among group members as well as conflict with other groups. These were complemented by individual dispositions of solidarity and generosity towards one's own, and suspicion and hostility towards others." [www.nature.com](http://www.nature.com)

A new documentary that features SFI External Professors Steven Strogatz (Cornell University), Duncan Watts (Columbia University), and several SFI-affiliated scientists explores network theory's implications in a number of fields. The segment leads with a test of the landmark "six degrees of separation" experiment. The documentary has already aired on Australian TV and is expected to air on the BBC, Discovery Channel Canada, and the Science Channel in the U.S. [www.abc.net.au/tv/documentaries/interactive/futuremakers/ep4](http://www.abc.net.au/tv/documentaries/interactive/futuremakers/ep4)

A November 18 opinion piece in the *Philadelphia Inquirer* by economic sociologist Brooke Harrington (Max Planck Institute for the Study of Societies) cites SFI research in describing the need for new approaches to analyze the current financial crisis: "The system is so complex that it overwhelms even the financial professionals and policy experts who are paid to understand it...This suggests a very different strategy for addressing the crisis. Instead of using the tools that created the mess, or declaring open season on top executives, we should be applying complex systems analysis. The science of complex systems has been around for decades, but only recently has it been applied to financial markets. Research centers such as the Santa Fe Institute in New Mexico pioneered the use of complex systems models to explain biological phenomena, such as aging and gene expression..." [http://www.philly.com/inquirer/opinion/20081118\\_With\\_current\\_crisis\\_a\\_monster\\_emerged.html](http://www.philly.com/inquirer/opinion/20081118_With_current_crisis_a_monster_emerged.html)

## RESEARCH NEWS

### Are dynamics of brain response like niche construction?

Niche construction – the complex process by which a population of organisms modifies its surroundings to make the environment more suitable, all the while being influenced by that environment – has reshaped scientists' view of evolution.

In a January 5-6 working group at SFI, "Neuro-cognitive Niche Construction," a half-dozen participants from neurobiology, neurology, evolutionary biology, and other fields will apply similar thinking to scientists' understanding of brain behavior.

Organizers include SFI External Professor Marc Feldman (Stanford University), SFI Research Fellow Jessica Flack, SFI Professor David Krakauer, and Miriam Reiner, head of the Haptics Lab at the T2 Technion TouchLab in Haifa, Israel.

"Our idea is that the brain's response to information affects the dynamics of other parts of the brain, and this looks to us a lot like niche construction," says Marc.

In other words, when the brain responds to a stimulus, the neurological response may not be registered in just the part of the brain directly involved. Other parts of the brain are changed in complex ways, and that may alter how it responds the next time it encounters the same or other stimuli.



(Image: ©iStockphoto.com/Kiyoshi Takahase)

The working group, the first meeting Marc is aware of on the topic, includes a group of researchers affiliated with the TouchLab that is using immersive virtual environments to study human neurological response (<http://edu.technion.ac.il/projects/hapttech/index.html>).

The meeting's objective, he says, is to develop a research agenda that would combine empirical observation with theory and begin to formulate a model for neuro-cognitive feedback.

"The empiricists will describe the results of their experiments, and we'll see if there are simplifications of their descriptions that can be turned into a model," he says.

In their 2003 book *Niche Construction* (Princeton University Press), Marc and co-authors described evolutionary processes in terms of niche construction. ■

with Ingeo™, a compostable plastic derived from domestic plants rather than petroleum products. Plates and bowls are made from recycled, compostable sugar cane pulp, otherwise discarded or burned. Napkins are made of 100 percent recycled paper.

And reusable metal utensils and stoneware are now used for luncheon service.

"In just a few weeks we have made a huge impact in the reduction of trash we generate," Ginny says.

There still is more the Institute can do, and several additional steps are being planned, she says.

But, she says, official measures can take the Institute only so far. The key to future plans is thinking green in every aspect of daily work life, and she's asking for the support of all members of SFI's community. ■

## INSIDE SFI

### Walking the walk: Greening effort makes SFI's work more sustainable

The Institute is getting greener as part of an effort spearheaded by Ginny Greninger, Manager of the Office of SFI's President, and Ronda K. Butler-Villa, Publications, Facilities, and Personnel Director, to adopt practices and habits that allow SFI's people to work more sustainably.

SFI faculty and staff have already begun to notice the changes, says Ginny, with efforts under way in recycling and reuse, proper waste disposal (batteries, light bulbs, etc.), transportation, use of recyclable or eco-friendly products in construction and maintenance, and utilities (90 percent of the Institute's metered electricity is generated by wind power from PNM, for example).

"You'll notice a difference in the kitchen, too," says Ginny, "with the discontinuation of use of paper plates, cups, and plastic utensils."

Cold and hot beverage cups are now made

## INSIDE SFI

### SFI undergoes FY09 belt tightening

The worldwide economic downturn is prompting the Institute to do some preemptive belt tightening for 2009.

SFI is bracing for possible decreases in funding during the coming months as a result of the economic crisis, says Institute Vice President Chris Wood. Historically, in times of hardship, funding for basic research has been sacrificed in favor of projects and research that will produce immediate results, so it is possible public and private funding could contract.

"SFI's existing donors and sponsors have reiterated their commitment to SFI, but finding new sources of funding in 2009 could be very difficult," says Chris. "We are adopting prudent plans to prepare for this possibility."

Among the belt-tightening measures are a 10 percent cut to the Institute's 2009 budget,

hiring and salary freezes, and postponement of major capital expenditures.

The goal is to continue the current level of SFI scientific activity while making measured reductions that do not reduce the productivity or impact of SFI science.

SFI President Geoffrey West recently emphasized to faculty and staff that the tough times may come with opportunity, including a renewed appreciation for the Institute's work.

"As a result of the economic crisis and the clear manifestations of climate change, we are seeing increased interest in SFI research," he says. In particular, he says, business, government agencies, and philanthropists are now "thinking big" and trying to attain a complex systems perspective of these global challenges. ■

## RESEARCH NEWS

### Universals in ancient worldviews

A society's complexity is reflected in its concept of the world and its spiritual beliefs. Comparing worldviews, or "cosmologies," across cultures may offer glimpses into universal human traits that constrain individual cultures.

"We are not *Homo sapiens, per se*, as other *Homo* species did some form of thinking," says SFI External Professor and archaeologist George Gumerman of the School for Advanced Research, Archeology, and Anthropology. "We're *Homo spiritualis*. All societies we know had a belief system. So what's the adaptive value of that worldview?"

To explore this notion, he joined SFI Distinguished Fellow and Trustee Murray Gell-Mann to organize "Cosmology and Society in the Ancient Amerindian World," a late October meeting of 11 researchers in several fields including astronomy, linguistics, physics, archaeology, and folklore. Participants explored human universals in prehistory societies of the

southeastern and southwestern United States and Mesoamerica.

Cultures in all three areas see the world as tiered, for example, with levels above and below Earth. All have a figure that dwells to the nether worlds. All see the coyote as a trickster spirit. But, in a cosmological difference linked to subsistence methods, hunter-gatherer societies place greater spiritual value on the individual than do their agricultural counterparts.

The group aims to gather its collective knowledge online and ultimately see whether its members can predict the cosmology at stages of cultural evolution.

"It's such a melange maybe we will never get universals," says George. "But maybe we will." ■

This Late Classic Mayan plate depicts the sacrificial death and resurrection of a maize god, a cyclic belief shared by other societies. (Image: Justin Kerr)



# SFI public lecture explores the road to happiness

To achieve happiness, people must do two things: predict how they will feel in a variety of possible futures, and act to bring about the best future and avoid the worst.

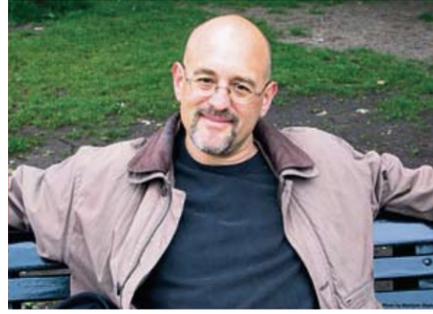
Although knowing what to want seems simple, research in psychology and behavioral economics shows that people not only have trouble predicting the future, they have trouble predicting how much they will like it when they get there, according to Daniel Gilbert, author of *Stumbling on Happiness* (Vintage Press, 2007).

In a November 17 SFI public lecture in Santa Fe, Gilbert described to a standing-room-only

crowd what science has to teach us about why we have so much trouble making ourselves happy. More about Gilbert's work can be found at [www.wjh.harvard.edu/~dtg/gilbert.htm](http://www.wjh.harvard.edu/~dtg/gilbert.htm)

Gilbert is the Harvard College Professor of Psychology at Harvard University and Director of Harvard's Hedonic Psychology Lab. His research with University of Virginia psychology professor Tim Wilson, author of *Strangers to Ourselves: Discovering the Adaptive Unconscious* (Harvard University Press, 2004), investigates how and how well people make predictions about the emotional impact of future events.

The event, the final lecture in the 2008 SFI public lecture series, was supported by Wayne and Barbara Coleman. ■



Daniel Gilbert

## > Better networks continued from page 2

Aaron and SFI Professor Cris Moore organized a December 3-5 workshop, "Statistical Inference for Complex Networks," to identify the big problems that might yield to these new methods.

Workshop participants were experts drawn from machine learning, physics, and several other domains who are doing interesting and productive work with networks, particularly from a methodological perspective, he says.

"Studying networks has been a lot like the story of the three blind men and the elephant – one studied the tail, one the ears, one the trunk, and none could agree on what kind of animal it was," he says. "To really understand the complexity of networks, we need new approaches that look at the whole animal." ■

## PEOPLE

# Laurie Innes' paintings shown in local exhibits

Oil paintings by SFI staff member Laurie Innes, Assistant to SFI Distinguished Fellow and Trustee Murray Gell-Mann, have been on exhibit in recent weeks in Santa Fe.

"Beauty and the Demon," a 12-in. by 9-in. oil on canvas, was on display October 31-November 22 at the Owings-Dewey North Gallery as part of its shrine group show, themed Explorations in the Garden of Good & Evil.



The annual benefit show is a chance for local contemporary artists to show their works in a high-profile gallery. Many use the opportunity to experiment, make a statement, or honor something dear to them, says Laurie. This year's show benefited the Santa Fe Rape Crisis and Trauma Treatment Center.



Laurie created "Beauty and the Demon" specifically for the show. The oriental still life is typical of her paintings, which often feature brief, early era poetry pieces painted into the work.

A self-taught painter who began at an early age, Laurie says her current collection of work reflects the interest she has always had in Chinese and Japanese painting, drawing, prints, calligraphy, and poetry.

She has been invited to exhibit two drawings at the Community Gallery in the Civic Center during the holiday season. In January she will have a one-person show at the Main Branch of the Santa Fe Library; on display will be nearly 40 works, paintings, and drawings. ■

Laurie Innes, "Beauty and the Demon," oil on canvas

## > Scaling grant continued from page 1

usage and mass will follow a power law, helping to explain, among other things, why all mammals have the same number of heartbeats in a lifetime no matter their size, or why humans sleep eight hours a day while a mouse sleeps 18 and an elephant three.

The work also suggests, Geoffrey says, that a quantitative theory describing how organisms age and die is possible.

Subsequent work has extended the theoretical framework for biological scaling and found hundreds of examples of regularities at multiple scales, not only in the biological world but in social organizations as well. Cities and large corporations, for example, can be thought of as organisms exhibiting regularities that mirror those found in biology.

Geoffrey and colleagues will continue to examine the implications of a power law for metabolic rate, apply scaling models to tumor growth and vascularization, and further define biological network characteristics. ■



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