SANTA FE INSTITUTE

Update

September / October 2011

Bushmen cave painting depicting elephants and humans, Cederberg, South Africa (Image: Skilpad, www.istockphoto.com)

How the human species came to be both nasty and nice

Our financial markets are citadels of greed. We lobby for business promotions that require the failures of our colleagues. We skip the polls because voting takes too much of our time. We humans are inherently selfish. Right?

Wrong, says SFI Professor Sam Bowles. Heroes rescue strangers from raging rivers. Church congregations organize charity drives. Shoppers help sobbing children find their parents. Soldiers die for their countries. And many citizens pause to vote even when they know a single ballot has a vanishingly small chance of influencing the outcome.

A more optimistic view of human nature is gaining traction because behavioral experiments conducted over two decades with hunter-gatherers, migratory herders, farmers, truck drivers, firemen, and students show that there are relatively few truly selfish *Homo sapiens*. Sam collaborated with SFI External Professors Rob Boyd (UCLA) and Herbert Gintis (Central European University and MIT) and others on many of the studies.

The take home message: "The majority of humans are quite fair when asked to divide what often amounts to about a day's wages between themselves and others," Sam says. "And they punish those they suspect are shorting others, even when it costs the punisher to do so."

Now, drawing on fields from genetics to anthropology and assisted by new computer capabilities and mathematical modeling approaches, Sam and several other SFI-affiliated scientists are taking a close look at how human cooperation could have evolved when natural selection seems to preclude it – and pushing back on the assumption of ubiquitous self interest.

Much of the research is compiled in a new book, *A cooperative species: Human reciprocity and its evolution*, co-authored by Sam and Herb.

Perhaps what's most interesting about the recent spate of scientific results, Sam says, is that the archaeological, genetic, and ethnographic evidence seems to point to a surprising origin of human generosity: war.

The researchers took a careful look at the anthropological and genetic records of prehistoric peoples and, using both computer simulations and evolutionary models, followed their successes and failures through 50,000 years of history. Graves offered evidence of warfare. Genetic evidence provided clues about group sizes, migration rates, and the extent to which group members were related. Sam even hunted with Tanzanian foragers to get a better sense of what cooperation looked like in prehistoric societies.

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RESEARCH NEWS

Language: Our cooperative genes talking

All animals communicate, but of all the species on earth, humans alone have language. How did language evolve, and why only in us?

"Language is your genes talking, getting things they want," says SFI External Professor Mark Pagel, a professor of evolutionary biology at Reading University. It allowed our ancestors to cooperate and prosper like no other species has. But Mark believes language evolved as a response to another distinctively human advancement: social learning.

Other species, even chimps, aren't very good at imitating or learning from others, Mark says. By comparison, humans continually watch and build on the wisdom of others, and good ideas tend to accumulate in groups and in society.

It was not always so. *Homo erectus*, the first upright apes, used the same hand axe design for a million years – "40,000 generations of watching others," he says.

Then, around 200,000 years ago, something happened. *Homo sapiens* became social learners, able

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IN THIS ISSUE

RESEARCH NEWS

Pueblo societies became more stratified as they grew

The origin of political inequality has long been a subject of philosophical investigation, and a new working paper by SFI Science Board member and External Professor Tim Kohler and colleagues suggests that for the Prehispanic Pueblo Indians, political hierarchy could have emerged to develop and regulate public resources for a growing population.

The researchers created a simulation to observe how Pueblo societies might have

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INSIDE SFI

'Science symphony' combines Bach and brain science

Scholars and artists have long recognized the power of music in creating recollections and vivid images within the mind. The brain, in all its complexity, underlies and integrates the emotional and cognitive responses to sound. Thus, familiar music can forever evoke the memories first associated with the piece, along with those associated withrepeated hearings.

In late October SFI and the Santa Fe Symphony are collaborating to produce a unique event exploring the interface between music and science. *Voyages of Discovery III*: Bach On the Brain, will feature selected works of Johann Sebastian Bach interspersed with commentary by neuroscientist Chris Wood and demonstrations of the brain's response to sound and music.

It is the third SFI-SFS "science symphony" in as many years.

"The program explores, in Aldous Huxley's words, 'the vast number of obscure miracles' that music elicits in the brain, and that

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SFI IN THE NEWS

While large companies are thought to promote wealth creation and economic growth, they often are dying and thus cannot serve society's interests, according to a June 10 *Reuters* blog that cites the research of SFI Distinguished Professor Geoffrey West, External Professor Luis Bettencourt, and their collaborators.

Finance models need to get better at predicting how people, and thus markets, behave in the real world, according to a June 13 *Engineering & Technology* magazine article that includes comments from SFI Professor Doyne Farmer.

A July *American Scientist* article credits the past work of SFI External Professor Joe Traub and his former PhD student Spassimir Paskov with bringing about a "dramatic revival of interest" in the quasi-Monte Carlo method of deterministic sampling.

A July 21 *Nature* article reflecting on the 25-year history of high-temperature superconductivity notes the seminal contributions of two SFI Science Board members, David Pines and Philip Anderson.

A July 26 column in the *Santa Fe New Mexican* notes the work of SFI Professor Eric Smith, Omidyar Fellow Rogier Braakman, Science Board Chair Emeritus Harold Morowitz, and their collaborators to put together the puzzle of how life emerged from early Earth's geochemistry.

In a July 27 interview with Smartplanet.com, SFI Postdoctoral Fellow Hyejin Youn describes how social and economic data from cities around the world fit scaling patterns also found in biological organisms.

An oft-used prediction function in economics, exponential discounting, may wildly underestimate the future value of today's investments, especially those relating to environmental health, says a July 27 Bloomberg column that mentions SFI External Professor John Geanakoplos and SFI Professor Doyne Farmer.

New research and a new book by SFI Professor Sam Bowles and External Professor Herbert Gintis suggest that warfare and cooperation go hand in hand in determining success in human evolution, according to an August 1 *New York Times* article.

A controversial 2007 study concluding that traits such as obesity can spread among friends via a "social contagion" process now faces a wave of criticism, most recently from SFI External Professor Cosma Shalizi and Duncan Watts, according to an August 8 *New York Times* article.

Forgiving portions of underwater mortgage loans could reverse the deleveraging process that locks the U.S. in an "economic quagmire," according to an August 8 *USA Today* article quoting SFI External Professor and Yale economist John Geanakoplos.

An August 16 *Santa Fe New Mexican* article describes SFI External Professor Jessica Green's efforts to understand indoor microbe ecology and its relationship to human well being.

The future of human evolution is tied to the accelerating evolution of advancing technology, according to an August 19 NPR.com article citing the work of SFI External Professor Brian Arthur.

An August 29 column in the *Santa Fe New Mexican* by SFI Professor Sam Bowles describes research, much by SFI-affiliated scientists, suggesting that conflict and cooperation co-evolved to become central features of human behavior.

BBC News and several other media described the recent work of SFI Distinguished Professor Geoffrey West, External Professor Jim Brown, and collaborators at MIT who propose a model that predicts maximum tree heights in various environments.

Find these articles and more SFI news — and sign up to receive notifications via Twitter, Facebook, and RSS — at www.santafe.edu.

BUSINESS NETWORK NEWS

'Birds of a feather' meetings launched

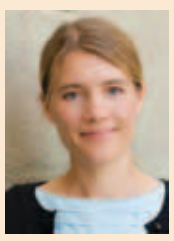
At the suggestion of Chander Chawla and David Hanson, Business Network representatives for National Semiconductor Corporation, SFI's BNet held the first in a series of informal "Birds of a Feather" social gatherings for members in Palo Alto on July 13.

The goal was to explore the desirability of regular informal gatherings at which members can interact, get to know each other's business challenges more deeply, and share possible solutions.

The two will organize future meetings for Bay Area members, and they plan to rotate between Palo Alto, San Francisco, and Santa Clara to maximize opportunity and convenience of participation.

Members are encouraged to invite and bring colleagues from their own companies, as well as guests from other companies who may be interested in the Business Network. Future meetings may be held in Boston, New York, and Washington, D.C. ■

Achievements



Former SFI Omidyar Fellow Jessika Trancik has been awarded a PopTech Science and Public Leadership Fellowship for select "high-potential" scientists who work in "areas of critical importance to the nation and the planet." Jessika, now an assistant professor of engineering at MIT, uses quantitative research methods to compare and optimize alternative energy technologies.

SFI Omidyar Fellow Nathan Collins in August joined the faculty of UC Irvine as an assistant professor of political science. His three-year appointment at SFI included research in physics, biology, and political science. He also published several popular science articles in the online and mainstream news media. ■

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The *SFI Update* is published bimonthly by the Institute to keep its community informed. Please send comments or questions to John German at *jdg@santafe.edu*.

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RESEARCH NEWS

Freeloaders will contribute, eventually

Under the right circumstances even greedy people will tend to cooperate. So finds SFI External Professor Dirk Helbing, a sociologist at the Swiss Federal Institute of Technology Zurich, and colleague Carlos Roca in a *PNAS* study in which they modeled how social cohesion emerges in a greedy group.

"We were interested in the conditions for the evolution of cooperation, when individuals repeat behaviors that pay off, but change their behavior or positions when they are not satisfied," says Dirk.

In their model society, each person has up to eight neighbors. Everyone can choose to participate in a round of the game by contributing one unit of goods. Pool the goods, add a modestly amplifying synergy factor, then split the results evenly among all the neighbors. After each round, every person can choose to stay or move to a new neighborhood. Repeat.

In this setup, cooperating gives you more than what you started with, but being a deadbeat neighbor gives you something for nothing.

Participants could only look at their own past experience, not that of anyone else in the network. This simple structure eliminates punishment, forecasting, speculation, strategic moves to better neighborhoods, or reputation effects – effects typical of more complicated public goods games.

Starting simulations with slightly, moderately, and downright greedy people, the authors found that all networks iterated toward a tendency to cooperate, if individual greediness was allowed to evolve.

However, when people extrapolate future gains from an increase in past performance, their rise in expectations of greater personal returns (in short, increased greediness) can break down social cohesion, Dirk says.

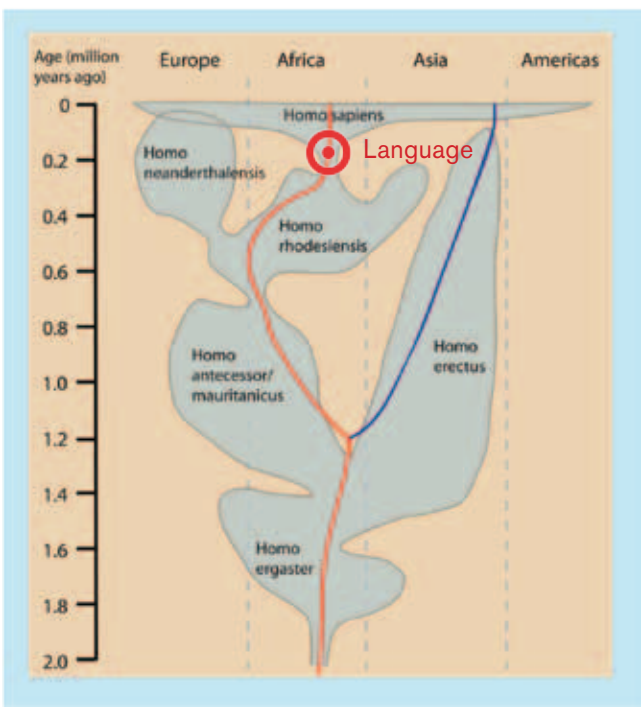
Next, the researchers are planning experiments with actual human participants to see how well their model reflects the real world. ■

> *Genes talking* **continued from page 1**

not only to copy others but also to choose the best idea or behavior from a range of alternatives. As a result, innovation exploded.

Social learning made humans distinct from all other species, but it also created a knotty evolutionary dilemma. Social learning turns out to be a form of "visual theft," says Mark. "If I can learn by watching you, I can steal your best ideas [a better way to catch a fish, or a deadlier spear, for example]. I can make myself more likely to survive, perhaps at your expense, and without putting in the same time and energy as you. So it behooves you to hide your best ideas, lest someone steal them."

Language arose to solve the crisis of visual theft, Mark says. It is a piece of social technology for enhancing the evolutionary benefits of cooperation, giving members of your group access to the vast fund of ideas, wisdom, and innovation.



When social learning and language arose about 200,000 years ago, *Homo sapiens* prospered and occupied nearly every habitat on earth, while others faltered.

But there are 7,000 to 8,000 different languages spoken around the world today for good reason, he says. Speaking different languages slows the flow of wisdom, even the flow of genes, to other groups.

"Our ancestors used language to draw rings around their own cooperative groups, to protect their knowledge from competing groups," he says.

Mark's recent work on cultural evolution has identified the many ways human cultures often behave like biological species, and his work on language evolution shows that language can be modeled as a "culturally transmitted replicator" with properties uncannily similar to genes, adapting to speakers' needs and capable of being transmitted faithfully for tens of thousands of years.

His forthcoming book, *Wired for culture: Origins of the human social mind*, explores how humans' unique set of social, linguistic, and psychological traits are adaptations to living in the social environment of small societal or tribal groups and tracks the human species' propensity for cultural adaptation.

He recently gave a TED Global talk titled "How language transformed humanity," available at www.ted.com. ■

> *Pueblo societies* **continued from page 1**

evolved during the time period from AD 600 to AD 1280, when the first signs of hierarchy appear in the archaeological record for the central Mesa Verde region of Colorado.

They observed that a leaderless society could thrive so long as the group remained small. But once an egalitarian society began to grow, it could no longer force freeloaders to contribute to public goods, which in the real world would have been resources such as defensive walls, reservoirs, and the fruits of communal hunts.

By contrast, groups that paid taxes to a leader who punished freeloaders continued to thrive in the face of population growth. The SFI working paper, "The coevolution of group size and leadership: An agent-based public goods model for prehispanic Pueblo societies," is available at www.santafe.edu.

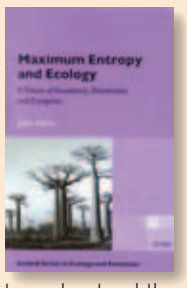
"In general in these Neolithic societies, it's the larger society that's going to be successful and displace the other societies," Tim says. "But you can't just have societies grow larger. They have to grow large in size and act coherently."

The simulation is part of an ongoing study of the Mesa Verde region, and represents Tim's first attempt to investigate the political structure of the Pueblo societies using tools from complex systems research. He believes that these tools have much to offer archaeologists, and discusses their applications in another SFI working paper titled "Complex systems and archaeology."

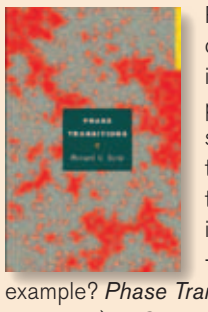
"These simulations give us interaction on a landscape that's instantiated for a particular time and place," he says. "They give us evidence that we can directly compare against the archaeological record for that time and place."

Tim is a Regents Professor of anthropology at Washington State University. ■

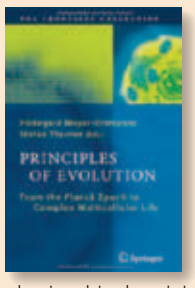
BOOK NEWS



Maximum Entropy and Ecology (Oxford University Press, August 2011), a new graduate textbook by SFI External Professor John Harte (UC Berkeley), provides readers with the concepts and practical tools required to understand the maximum entropy principle and apply it to an understanding of ecological patterns. In explaining how information theory may be applied to modeling ecosystems, Harte eschews mechanistic modeling in favor of a model based on maximum entropy. With a mathematical framework as its basis, his ecological theory is predictive in describing the abundance, distribution, and energetics of many species over a range of habitats.



Physics treats sudden changes in complex chemical or physical systems as phase transitions, but can similar principles reveal the origins and implications of sudden changes in other complex systems – in ecology or society for example? *Phase Transitions* (Princeton University Press) by SFI External Professor Ricard Solé (Universitat Pompeu Fabra) examines dynamical behaviors in a broad range of complex systems. Using a compelling set of examples, from gene networks and ant colonies to human language and the degradation of diverse ecosystems, the book illustrates the power of simple models to unravel phase transitions.



Principles of Evolution: From the Planck Epoch to Complex Multicellular Life (Springer, June 2011), edited by Hildegard Meyer-Ortmanns and SFI External Professor Stefan Thurner (Medical University of Vienna), draws from math, physics, biochemistry, and cell biology to provide a survey of today's understanding of evolution. With self organization as a unifying theme, the book covers the beginnings of the universe, the origin of life and the chances of its arising at all, the role of contingency, and the search for universal features in the plethora of evolutionary phenomena. It includes chapters by SFI External Professors Peter Schuster and Sanjay Jain.

The Origins of Evolutionary Innovations: A Theory of Transformative Change in Living Systems (Yale University Press, 2011), by SFI External Professor Andreas Wagner (University of Zurich), examines four billion years of evolutionary change, ranging from dramatic macroscopic innovations such as the evolution of wings or eyes, to myriad molecular changes that form the basis of macroscopic innovations. The book covers several principles that allow organisms to innovate and proposes the basis of a theory of innovation, integrating recent knowledge about complex molecular phenotypes with more traditional Darwinian thinking. ■

RESEARCH NEWS

Forest fire mathematics suggests less fire suppression leads to smaller fires

Runaway summer forest fires in Arizona and New Mexico this year were no surprise to SFI External Professor John Rundle, a distinguished professor of physics and geology at UC Davis. Large fires are a natural consequence of, oddly enough, over-controlling fires for more than a century, he says.

The evidence is in the mathematics, John says. Fires naturally follow a mathematical rule called a power law, which, simply expressed, means there are lots of small fires and relatively few large fires. The proportion between small and large fires varies from one area to another, though, and this variability is reflected in a single number called the scaling factor.

In northern Mexico, for example, the scaling factor is a big negative number, so there are very few big fires and very many small ones. Just across the border in Southern California, however, the scaling factor is a smaller negative number, tilting the balance toward big fires.

The two regions are similar in almost every respect – weather, plants, topography – except for one: "In northern Mexico they let the fires burn," John says, "and the vegetation doesn't build up." And sparser vegetation makes for smaller fires.

His latest research, published in an article in *Physical Review E* together with his student Mark Yoder and others, shows this dynamic in a beautifully simple model.

"There has been a history from the early days of suppressing all fires," Yoder says. "But our model suggests that by being more creative in the use of our resources, possibly by letting small fires burn early in the season, we may be able to significantly mitigate our fire risk and be much safer." ■

(Image: Ruig, www.istockphoto.com)

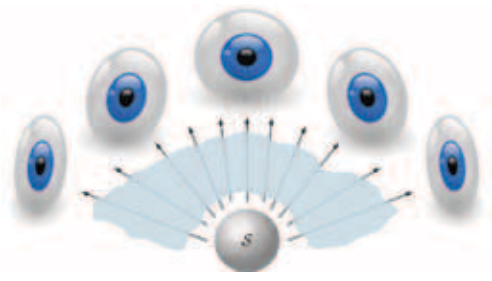
RESEARCH NEWS

Quantum Darwinism: Studying imprints left by a system on its environment

An electron, atom, or other quantum system can be many places at once. It collapses into a single location when an observer pinpoints it, but what happens when an object is not being measured? Can it choose a location on its own, or must it wait for an observer?

SFI External Professor Wojciech Zurek might have an answer.

His Theory of Quantum Darwinism applies natural selection to our quantum universe. It builds on the theory of decoherence, which shows that a quantum particle can no longer be in many places at once not only at the moment it's measured, but also when it interacts with its environment, which can be a de facto observer.



Quantum Darwinism is responsible for objectivity in a quantum world: When there are many copies of the information about the state of a quantum system in the environment – e.g., in the scattered or emitted photons – many observers can find out what the state is indirectly from the fragments of the environment. Their conclusions will agree, and the states they will discover will be the "fittest" states – best in surviving interaction with the environment. (Images: www.webweaver.nu)

(For a particle, common environments are photons and air molecules. Scaling up to a more tangible level, our world persists in its classical state only because large objects can never be fully isolated from their surroundings.)

Quantum Darwinism goes beyond decoherence by studying imprints left by the system on the environment, he says. Drawing from natural selection, where the fittest survive and proliferate, Quantum Darwinism shows that certain states are selected because they survive better than others in a given environment.

Surviving states then proliferate by spreading information about themselves, and we discover them indirectly by intercepting tiny fractions of the environment. This is how consensus about the fittest states – the "objective classical reality" we take for granted – arises in our quantum universe, Wojciech says, and how effectively classical states that exist objectively, immune to measurement, emerge from a quantum substrate.

Recent studies have offered evidence in support of Wojciech's theory. Now, with his newly awarded grant from the John Templeton Foundation, he will examine how quantum information propagates, and how the classical world of our everyday experience emerges from the quantum ingredients.

Wojciech is a Laboratory Fellow with Los Alamos National Laboratory's Theory Division. ■

EDUCATION NEWS

Students sing the 'Complexity Blues' at SFI's 2011 summer schools

This summer's lineup of SFI schools and internships, integrated closely with the Institute's scientific work, wrapped up in August. Here are some highlights:

Research Experiences for Undergrads

Ten undergrads spent 10 weeks at SFI working on projects with SFI faculty. As her project, Emily Lichko, a junior physics major at the University of Michigan, used a combination of phylogenetic trees and agent-based modeling to track how cultural traits are transmitted among generations within a population. She worked with SFI Professor Tanmoy Bhattacharya and Omidyar Fellows Anne Kandler and Laura Fortunato.

Lichko says she was fascinated by the range of subjects to which complexity science can be applied. "Learning how to critically evaluate models from many disciplines is one of the most important things I will bring back," she says. "I am better able to make connections and recognize ideas that are applicable to my own work."

Summaries of all the REU students' projects are available at www.santafe.edu/education/fellowships/undergraduate/reu-2011/

Complex Systems Summer School

Fifty graduate students and postdocs were selected for SFI's three-week crash course in the fundamental concepts of complex systems science.

The research topics chosen by the 2011 CSSS students were as varied as the disciplines they represented. Final presentations ranged from in-depth analyses of their favorite topics using new modeling tools to enthusiastic explorations of questions still to be answered. Videos of the student presentations are available at www.santafe.edu.

Two students, overwhelmed by the volme of information available on a defunct pueblo and the challenge of modeling its complete food web, pulled out their guitars and sang the Complexity Blues. The first few bars went like this:

Wildfires been burnin' baby
Since the day that we arrived
They closed off Atalaya
Yesterday at five

They're waiting for a rainstorm
At Los Alamos National Lab
But we can make our own lightning
In Alfred Hübler's lab

Never seen such robustness
The system cannot fail
Lorenz attract me babe
Complexity's the holy grail

I wanna learn these theories
Until my brain starts to quake
Here at SFI
We work and play until we break…

Complexity and Modeling Program

Games of Capture the Flag and Marco Polo are staples of many summer camp experiences. But the 14 high school students who participated in SFI's Summer Complexity and Modeling Program (CAMP) at the Groton School in Groton, Mass., used these games to model network theory and observe how patterns emerge in chaos.

The two-week program aims to foster transdisciplinary collaboration and inspire students to become complexity scholars. In one research project, CAMPers ventured into the woodlands of Massachusetts to collect data on beaver foraging, then returned to the classroom and used NetLogo to model the data they collected.

"Looking back on the program, we had an incredible group of students who are talented in a variety of disciplines," says Juniper Lovato, CAMP coordinator. "We had a lot of fun!" ■

> *Cooperative species*

continued from page 1

They also modeled mathematically what happens (over many generations) to notional groups with a variety of dispositions. Their results lined up remarkably well with the data: Groups exhibiting two co-existing traits seemed to prevail throughout human history: cooperation within groups and a willingness to collaborate in conflict against outsiders. By contrast, warlike/selfish groups don't fare well. Altruistic/peaceful groups lose too.

So within-group cooperation and aggression toward nonmembers – what the researchers call "parochial altruism" – was a winning strategy if you were a group of prehistoric humans fighting for survival, says Sam.

Thus, he likes to think of war as the midwife of cooperation in human evolution: necessary for cooperation to have evolved and persisted.

So are wars inevitable? Not necessarily, Sam says. "We are a cultural animal, and we've already made huge strides towards greater tolerance and acceptance of people who we once called 'others' or worse," he says. "Our legacy need not be our destiny." ■

War and cooperation evolved hand in hand. (Image: bwilking, www.istockphoto.com)

RESEARCH NEWS

Finding quantities of cultural change

Scott Ortman is on the hunt for hidden regularities in the evolution of human culture.

"Major aspects of the archaeological record are not structured by climate, resources, or warfare," explains Scott, an SFI Omidyar Fellow and anthropologist. "Yet, they still change in regular and patterned ways."

Genes, language, and culture all vary across humanity. Sometimes they are correlated, other times not. This suggests that each evolve through distinct processes, but Scott faces a challenge: While biology and linguistics each have their own methods of measuring change, cultural change is tough to quantify.

His approach is to translate expressions of conceptual metaphors into data suitable for modeling. And he is getting a lot of mileage out of a common feature of the archaeological record: pottery.

Using artifacts from the ancient Mesa Verde culture in Colorado, he is showing how the painted designs on pottery derived from weaving techniques. The evidence implies that the deep-seated analogy "pots are textiles" was a central structuring principle of this famous pottery style.

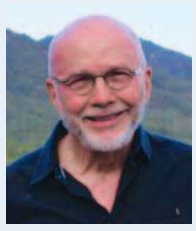
In studying some 60 sites that span 300 years up to AD 1300, Scott found that pottery decoration increased in complexity as the repertoire of weaving techniques expanded, and as potters utilized the imagery of textiles to create designs.

"Most patterns reflect the same motifs, whether they're in woven objects, baskets, or cotton blankets," he says. The conceptual parallels between pottery and weaving appear to have been adopted subconsciously to make implicit statements regarding a widely shared concept. Such parallels suggest the designs insinuated themselves so deeply into the cultural psyche that they were a natural choice. Recognizing such cultural defaults is key in studying cultural change.

"The aspects of culture that are most powerful in structuring human behavior are the ones individuals are least aware of," Scott says. "Archaeologists are actually pretty good at noticing these, but until now, we haven't had a currency for describing them. Conceptual metaphor theory gives us a way of doing so." ■

DONOR PROFILE

Bill Dedmon: Taking refuge in science



Like other corporate refugees living in Taos, Bill Dedmon escaped the business world 10 years ago to be close to the things that matter – skiing and serious hiking. But lately his focus has returned to his intellectual roots in the sciences.

"I've developed an appreciation for a wide variety of topics in science," he says. "That's what turns me on about SFI. I embrace the wide diversity of thought that comes out of it."

A contrarian by nature, Dedmon has always been a dilettante rather than a specialist. Though he was a pre-med major in college, he ultimately chose the MBA program at Harvard, followed by a successful career as an investment banker.

Whether by choice or by chance, his career kept him close to science and technology as the greatest new ideas in business were coming out of applied research through the tech boom years. "It was the leading edge of capitalism in its best form," he says.

A problem Dedmon sees, in both the corporate world and among many not-for-profits, is that leaders are too focused on short-term results, often at the expense of future stability. He supports SFI because its work is far reaching, with little regard for short-term applications.

"People on the basic research side work in sort of a selfless manner," he said. "It is encouraging to me to see young scientists with enthusiasm, even ardor, for what they do." ■

INSIDE SFI

Cognitive ubiquity: The evolution of intelligence

From the formation of the earth from interstellar dust it has taken just under five billion years for matter to be able to speculate about its own origins.

David Krakauer discusses world chess champion Bobby Fischer.

In three Stanislaw Ulam Memorial Lectures over three nights in Santa Fe, SFI Professor David Krakauer explored theories from mathematics, physics, computation, and biology relevant to the emergence of intelligence; recounted the evolution of life on Earth, focusing on the advent of increasingly complex forms of behavior and thought and identifying the common principles of intelligent biological systems; and speculated about the future of biological intelligence in a world of distributed machine intelligence.

SFI's Ulam Lecture series is named for Polish mathematician and Manhattan Project contributor Stanislaw Ulam (1909-1984). The 2011 Ulam Lectures were generously underwritten by the Peters Family Foundation. ■

> *Voyages III* continued from page 1

underlie our musical experience," says Chris, who is SFI's VP for Administration and Director of the Business Network.

Bach On the Brain
Sunday, October 30, at 4 p.m. at the Lensic Performing Arts Center in Santa Fe. For tickets call (505) 983-1414 or (505) 988-1234.

As in past years, *Voyages III* includes an educational component. On Monday, October 31, the symphony and Chris will perform a condensed version of the concert for Santa Fe-area 4th graders. Educational materials are being developed and distributed to local classrooms to accompany the concert and to demonstrate the scientific and mathematical basis of musical experience.

Voyages III is being underwritten by the Sydney & Andrew Davis Foundation. ■

SFI Online

Multimedia and supplementary content available at *www.santafe.edu*

- **Video: SFI's Omidyar Fellows** describe their research and the scientific freedom offered by the three-year Fellowship, www.santafe.edu/stories
- **Video: Omidyar Fellow Anne Kandler** discusses her research in modeling human cultural change and the decline of an endangered language, www.santafe.edu/stories
- **Video: Omidyar Fellow Rogier Braakman** discusses his research to understand chemical networks and their role in the emergence and diversity of life on earth, www.santafe.edu/stories
- **Audio: Omidyar Fellow Nathan Collins** explains some surprising long-term trends in voter behavior during presidential elections, Miller-McCune's "Curiouser & Curiouser" podcast, www.santafe.edu/news
- **Audio: Omidyar Fellow Simon DeDeo** describes SFI research that is revealing a hidden order in animal conflict, Miller-McCune's "Curiouser & Curiouser" podcast, www.santafe.edu/news
- **Audio: Omidyar Fellow Laura Fortunato** explores the evolution of family structure in human culture, Miller-McCune's "Curiouser & Curiouser" podcast, www.santafe.edu/news
- **Video: Science Board member Deborah Gordon** explains how seemingly inept individual ants rival other species in terms of collective intelligence, CBS Sunday Morning, www.santafe.edu/news
- **Video: Distinguished Professor Geoffrey West** describes the surprising mathematics of cities, 2011 TED Global talk, www.santafe.edu/news
- **Video: SFI External Professor Jessica Green** explores microbial diversity, indoor ecology, and human well-being, 2011 TED Global talk and SFI 2011 Community Lecture, www.santafe.edu/news

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