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# REACH

CIFAR

IDEAS TO CHANGE THE WORLD — SPRING 2014



**TESTING THE  
EARTH'S RESILIENCE**  
What can the planet take?

# Connecting Canada's best with the world's best

The fellows and advisors who make up CIFAR (the Canadian Institute for Advanced Research) work on problems as diverse as understanding quantum interactions between particles to mapping the structure of the cosmos to the interplay between political and economic institutions in societies. They probe the way the environment affects our genes, the history of the Earth's climate, the elements necessary for a successful society, and more.

The global research networks that CIFAR creates tackle profound, complex, and world-changing questions. But at our core is a simple idea: We select extraordinary people and create a safe space for them to discuss questions that have the potential to change the world.

The 346 fellows, senior fellows and advisors in our 11 programs come from across Canada and 15 other countries. They gather in the supportive atmosphere of program meetings to share their thinking, discuss untested new ideas, challenge each others' views in a collegial atmosphere, and form new and frequently unexpected collaborations. It sounds deceptively simple. But it's a unique and powerful strategy for advancing knowledge.

The magazine you're holding illustrates the power of CIFAR's vision. For example, on page 24, you can read about our program in Neural Computation and Adaptive Perception (NCAP). The program began 10 years ago with an idea that few people took seriously at the time – that computer programs designed to mimic the neu-

ral networks in our brains could lead to improved artificial intelligence. Today, thanks largely to this program, artificial neural networks are being employed by Google, Facebook and others, and the Internet giants have recruited many CIFAR fellows and their trainees to help them. As *Wired* magazine put it, "Hinton and NCAP have changed the face of the community."

On page 8, three CIFAR fellows in our program in Quantum Information Science discuss the challenges of harnessing quantum mechanics to perform computations that are impossible to carry out using conventional computers. Their research could lead to improved drug design, more secure communications, and even a better understanding of the workings of our universe.

On page 14, you can read about CIFAR's program in Earth System Evolution, a unique collection of outstanding researchers who are looking at how the Earth has adapted to changing conditions over its 4.6 billion years. CIFAR fellows have shown that the Earth's climate manages to adjust up to a point, beyond which dramatic changes can occur, whether it's a "Snowball Earth" in one era, or a global hothouse in another. With the planet facing an uncertain future as a result of global climate change, this work has important implications for humanity.

This is just a small sample of the research that CIFAR is making possible. After you've read this issue, I know you'll agree with me that CIFAR is placing Canada at the very centre of important global conversations. •



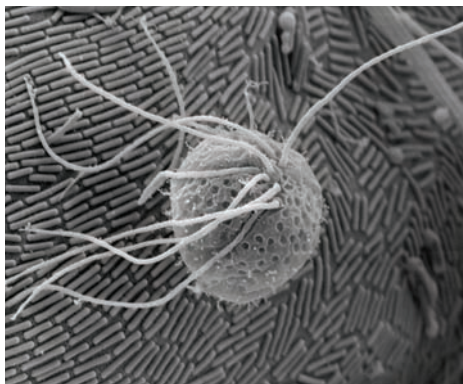
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The strange rules of quantum mechanics could lead to powerful new computers. CIFAR Fellows Raymond Laflamme, John Watrous and Barry Sanders talk about the promise, and the challenges.

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The Earth has survived a lot in its 4.6 billion year history. Understanding that history could help us predict what the effect of human-induced climate change will be.

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## REACH Magazine

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### Managing Editor

Kurt Kleiner

kkleiner@cifar.ca

### Creative Direction

Concrete

www.concrete.ca

### About CIFAR

CIFAR creates knowledge that will transform our world. The Institute brings together outstanding international researchers to work in global networks that address some of the most important questions our world faces today. Our networks help support the growth of research leaders and are catalysts for change in business, government and society. Established in 1982, CIFAR is a Canadian-based, global organization comprised of nearly 350 fellows, scholars and advisors from more than 100 institutions in 16 countries. CIFAR partners with the Government of Canada, provincial governments, individuals, foundations, corporations and research institutions to extend our impact in the world.

### REACH Magazine, CIFAR

180 Dundas Street West, Suite 1400

Toronto, ON M5G 1Z8

### BN / Registration N°

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### Cover

Over the past 30 years the Antarctic has warmed more than any region on Earth. This photo of an Antarctic iceberg was taken by Eric Galbraith, a fellow in CIFAR's program in Earth System Evolution.

# ADVANCES

—  
NEWS HIGHLIGHTS  
FROM OUR  
RESEARCH NETWORKS

## COSMIC INFLATION EVIDENCE DISCOVERED

Scientists have found evidence that instants after the Big Bang the universe expanded in a staggering burst that created ripples in space-time.

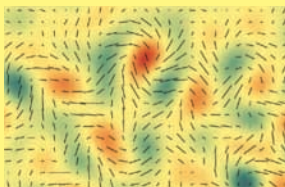
A group of researchers including CIFAR Senior Fellows Barth Netterfield (University of Toronto) and Mark Halpern (University of British Columbia) co-authored papers from a study of the Cosmic Background Radiation, the oldest light in the universe.

The experiment, run out of Harvard University, appears to have detected gravitational waves which were caused by the universe's rapid growth a trillionth of a trillionth of a second after it was born, an expansion physicists call inflation.

"It's a little bit like you've got a wrinkled tarp and you're stretching it out, and all these wrinkles become smaller and

smaller. And then if it ends suddenly, you're left with some residual wrinkles," Halpern says.

Halpern, a member of the Cosmology & Gravity program along with Netterfield, built the detector readout system for the BICEP2 South Pole radio telescope's new cameras, which allowed it to detect these residual wrinkles. Halpern says the data need verification, but renew hope for a theory that aligns our understanding of particle physics and cosmology.



Researchers had feared that the signature of gravitational radiation would be too faint to ever detect. But the new techniques observed a signal which seems to correspond with existing predictions.

## U.S. HONOURS CIFAR MEMBERS

U.S. President Barack Obama awarded medals to two members of CIFAR's community—from the U.S. National Endowment for the Humanities at a ceremony at the White House in the summer of 2013.

Robert Putnam (Harvard University), advisor in the program in Social Interactions, Identity and Well-Being, received the medal for deepening our understanding of community in America. The U.S. National Endowment for the Humanities says that his "writing and research inspire us to improve institutions that make society worth living in, and his insights challenge us to be better citizens."

Former Advisor and Research Council member Natalie Zemon Davis (University of Toronto) received the medal "for her insights into the study of history and her exacting eloquence in bringing the past into focus ... Her works allow us to experience life through our ancestors' eyes and to engage truly with our history."

## DNA UNDERLYING AUTISM

An international research team led by Stephen Scherer (The Hospital for Sick Children), a Senior Fellow in the program on Genetic Networks, used a technique called whole genome sequencing to examine the genetics underlying autism. The work provides a definitive look at the wide-ranging genetic variation associated with the disease, and was published in the *American Journal of Human Genetics*.



Autism spectrum disorder is known to have a genetic basis, but the genetic factors are still poorly understood. The study found genetic risk factors in 50 per cent of the participants, an increase over the 20 per cent who identified using older diagnostic techniques. All together the study identified inherited mutations in four previously unrecognized genes, nine genes that had previously been linked to autism, and eight candidate autism risk genes.

"In the future, results from whole genome sequencing could highlight potential molecular targets for pharmacological intervention, and pave the way for individualized therapy in autism. It could also allow for earlier diagnosis of autism," Scherer said.

### WAR STRENGTHENS SOCIAL BONDS

The experience of war can make a child feel closer to neighbours and schoolmates, but more suspicious of strangers. The results could have implications for nation-building in war-torn countries, according to new research.

The study was led by CIFAR Senior Fellow Joseph Henrich (University of British Columbia) in the Institutions, Organizations & Growth program. His team studied children and adults post-war in the Republic of Georgia and Sierra Leone, using games that tested their willingness to share tokens they could exchange for money or small prizes.

Children who had experienced war during a developmental window between ages seven and 20 were less likely to share their reward equally with people they

didn't know than with those who they considered part of their social group.

The study tested the hypothesis from evolutionary psychology that people embroiled in conflict would work harder toward the welfare of their own group, which could help ensure their own survival. The connections forged among people who endure bloodshed together could help explain how violence leads to more violence, or alternatively, to nation building.

The study was published in the journal *Psychological Science*.

### W. FORD DOOLITTLE WINS NSERC'S HERZBERG AWARD

CIFAR Distinguished Fellow W. Ford Doolittle (Dalhousie University) won the Natural Sciences and Engineering Research Council of Canada's (NSERC) highest honour in February for his research on the building blocks of evolutionary genetics.



Doolittle, an Advisory Committee member in the program in Integrated Microbial Biodiversity and a former director of the Evolutionary Biology program, won the 2014 Gerhard Herzberg Canada Gold Medal for Science and Engineering.

"It's a very nice thing to happen because it justifies my whole life, in a way," Doolittle says.

### DRUG LETS AN ADULT BRAIN LEARN MORE LIKE A CHILD'S

A common mood disorder drug can bring an adult brain closer to musical perfection that's usually only attainable in early childhood, according to a study by CIFAR fellows.

Absolute or perfect pitch, the ability to identify or produce musical notes without the help of a reference, is a skill only children under seven can typically learn. But a paper published in *Frontiers* co-authored by Senior Fellows Takao Hensch (Harvard University) and Janet Werker (University of British Columbia) in the program in Child & Brain Development found the drug valproic acid, used to treat bipolar disorder and epilepsy, restored brain plasticity in healthy adult males.

They didn't develop perfect pitch, but they did absorb much more musical knowledge than those who didn't take the drug, showing it's possible to reopen the pathways that make children's brains sponges for new information.

### CIFAR RESEARCHERS ADVISE CHINESE LEADERS

Three CIFAR senior fellows met with China's Premier in December, advising China's leaders that the country may need institutional reforms to spark innovation and move the economy away from cheap manufacturing.

Institutions, Organizations and Growth program members Torsten Persson (Stockholm University), Daron Acemoglu (Massachusetts Institute of Technology)

and Philippe Aghion (Harvard University) met with Premier Li Keqiang and People's Bank of China governor Zhou Xiaochuan to share economic advice for the country on how to continue growing economically without becoming stagnant or creating a damaging inequality gap.

The economists said China needs new systems for a general pension, social insurance, independent courts and a carbon tax to reduce pollution.

### ● **CARLOS FRENK AND ROGER BLANDFORD EARN CAREER HONOURS**

The Royal Astronomical Society has awarded gold medals to two CIFAR fellows in the Cosmology & Gravity program.

Associate Carlos Frenk (University of Durham) won the Gold Medal for Astronomy in 2014 for his fruitful career studying the formation and structure of the universe. Frenk earned the award, which is the society's highest honour, for research that included supercomputer simulations of the early universe.

Advisory Committee member Roger Blandford, founding director of the Kavli Institute of Particle Astrophysics and Cosmology at Stanford University, earned the Gold Medal in 2013 for his lifetime achievements studying black holes.

### ● **PSYCHOLOGY OF CONFORMITY REVISITED**

Two famous psychology experiments suggested humans are frighteningly willing to conform to authority. But a paper

by Alex Haslam (University of Queensland) in the program on Social Interactions, Identity and Well-Being, challenges that interpretation.

In one famous experiment, by Stanley Milgram of Yale, participants were willing to inflict what they thought were dangerous electric shocks when encouraged to by scientists. In the Stanford Prison Experiment, the study had to be stopped due to abuse after college students were assigned the roles of "guards" and "prisoners."

But Haslam suggests that the participants weren't just thoughtlessly conforming, but actually identified either with the goals of the scientists or with those they felt were part of their group. They consciously chose actions they could justify by ends that they perceived to be right.

"This area of research suggests that it is a mistake to see evil as a slippery slope that people descend without thought or care," Haslam says.

### **WHEN SCARCITY CAUSES TUNNEL VISION**

Eldar Shafir (Princeton) gained widespread attention for his book *Scarcity: Why Having Too Little Means So Much*, co-authored with Sendhil Mullainathan. The senior fellow in the program in Social Interactions, Identity and Well-Being argues that having too little food, money, or time can alter our thinking and lead us to make bad choices.

"We find that people tend to focus on what they feel they don't have enough of. But under scarcity people don't just focus – they 'tunnel,'" Shafir says.

The tunneling can lead to bad choices, such as people being so focused on short-term money problems that they can't bring themselves to worry about long-term consequences. Stress from scarcity can also increase cognitive burdens so much that people make bad decisions in other parts of their lives.



## THE EVOLUTION OF PHOTOSYNTHESIS

John Archibald (Dalhousie University), a senior fellow in the program in Integrated Microbial Biodiversity, led an international team of scientists who decoded the genomes of two important species of photosynthetic algae and published the result in the journal *Nature*.

“Some of the most abundant organisms that evolved photosynthesis in this manner are incredibly important in driving the biogeochemistry of Earth,” Archibald said. “By studying them, we are not only getting insights into the basic biological principles that have governed the evolution of life, but we are also learning about how the climate and atmosphere came to be the way it is.”

The researchers came from 27 institutions in 10 countries. They also included Fellow Claudio Slamovits (Dalhousie), Director Patrick Keeling (University of British Columbia), and Advisor Michael Gray (Dalhousie).

## A PRISTINE TRIPLE GALAXY FROM THE COSMIC DAWN

Researchers have observed a blob-like galaxy from 13 billion years ago that is vigorously birthing new stars.

Richard Ellis (California Institute of Technology), an Advisor to the program in Cosmology & Gravity, and colleagues reported the discovery of a galaxy they named Himiko in *The Astrophysical Journal* in December. Ellis says Himiko originates from the Cosmic Dawn of our Universe,

when the helium and hydrogen produced during the Big Bang started to create the first stars.



Himiko, observed with the Subaru Telescope on Hawaii's Mauna Kea mountain, is in the process of colliding with two other galaxies, and is churning out about 100 solar masses each year. Our own galaxy, the Milky Way, only produces about one per year. “Remarkably, Himiko is forming stars at a ferocious rate,” Ellis says.

## GREENLAND GRAND CANYON

Researchers discovered an enormous canyon in Greenland rivaling the Grand Canyon in size. But it's buried as deep as three kilometers beneath the ice.

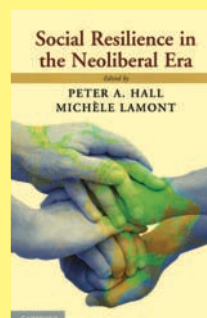
Shawn J. Marshall, a senior fellow in CIFAR's Earth System Evolution program and a glaciologist and climatologist at the University of Calgary, was part of the team that published the discovery in the journal *Science*.

“It's about Grand Canyon in scale, 750 kilometers in length, and it's one of the world's largest canyons,” Marshall says. The team used ice-penetrating radar to see through the ice sheet to the bedrock below. The canyon they discovered there is as deep as 800 meters and as wide as 10 km in places. By comparison, the Grand Canyon is 446 km long and up to 29 km wide and 1,800 meters deep.

## SOCIAL RESILIENCE IN THE NEOLIBERAL ERA

An interdisciplinary group of scholars from CIFAR's program in Successful Societies published a book looking at how societies are dealing with the effects of neoliberalism, including free markets, global trade and user-pay services, along with rising income inequality, job insecurity and the eroding wealth of the middle class.

The book *Social Resilience in the Neoliberal Era* represents 10 years of deep collaboration and analysis. It provides a sweeping assessment of our society, bringing together an unusually wide range of perspectives, from history, political science and economics to psychology, sociology, cultural analysis, epidemiology and more.



“We hope this book opens up new terrain for research into how a movement as powerful as neoliberalism can have so many effects, over so many countries and dimensions of social life,” says Senior Fellow Peter Hall (Harvard University). “We want to open up this concept of social resilience and identify it as a phenomenon so others will also go out and study it and help contribute new thinking to how we make societies more successful.”





### **RICH KIDS GETTING THINNER, BUT NOT POOR KIDS**

Although rising rates of obesity among U.S. adolescents have begun to level off, the benefit is mostly confined to well-off kids, while worse-off adolescents are still getting heavier. Overall obesity rates in 12- to 17-year-olds have plateaued at 17 per cent. But a study by CIFAR Advisor Robert D. Putnam and two colleagues at Harvard University found large disparities. Children in families in the upper third of education and income were becoming more active, less heavy, and better nourished, while children in the bottom third were worse off than ever. Among the obstacles faced by kids at the bottom: fast food and packaged snacks are often cheaper and more easily available than healthier alternatives, and low-income neighbourhoods have fewer parks, sidewalks and safe places to play. "Obesity is a clear example of the growing gap between rich and poor kids in America," Putnam says. "We're becoming a two-class society." He warns that similar data are emerging from the U.K., and wonders whether Canada may not be far behind.

The study was published in the *Proceedings of the National Academy of Sciences*.

### **GLOBAL CALL FINALISTS CHOSEN**

CIFAR issued an invitation for proposals for new programs, and received 262 letters of intent before narrowing them down to seven finalists ranging across many disciplines. All are asking questions of importance to the world.

The Global Call for Ideas marks the first time that CIFAR has expanded its portfolio of research programs through an open call for proposals.

The proposals included a full spectrum of questions bridging the social sciences, medicine, health, the biological and physical sciences, the humanities, policy and engineering. The final selection is expected later this year.

The finalists are:

*Biology, Energy, and Technology.* An initiative to develop solar energy-harvesting science and related technologies by taking inspiration from quantum biology and photobiology.

*BrainLight: Cracking the Sensory Code.* The effort will use optical and computational technologies to decipher the microcircuitry of the human brain with the potential to provide therapies for pain and stroke.

*Brain, Mind, and Consciousness.* A network of neuroscientists, philosophers, ethicists and clinicians that will focus on creating a better understanding of human consciousness.

*Life in a Changing Ocean.* A Canadian-led global initiative to discover and understand the key biological and physical processes in marine ecosystems.

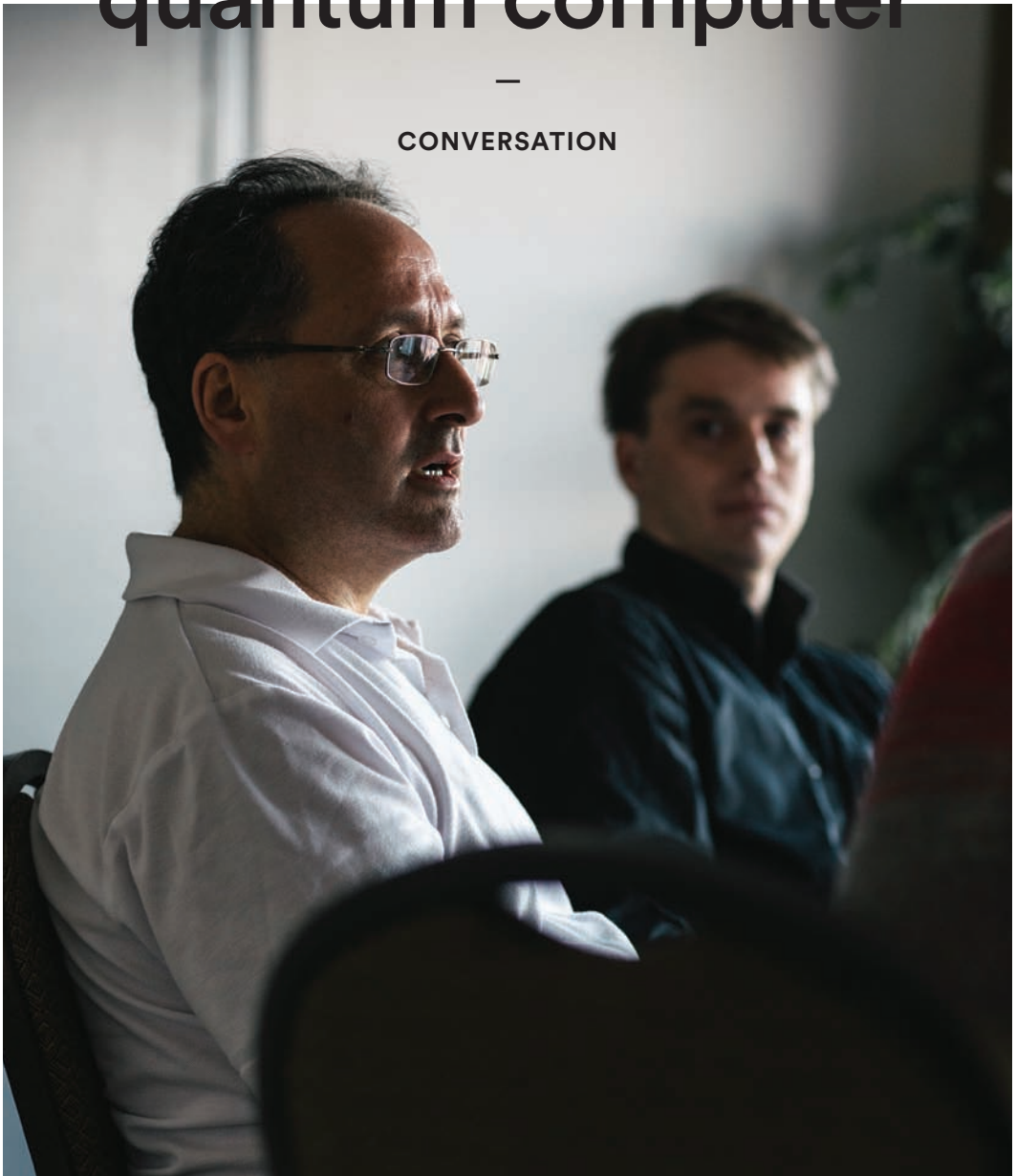
*Making a Molecular Map of the Cell.* An international effort to explore how the molecules responsible for biological processes are formed and interact.

*Microbes and Humans.* An effort to understand the role of the microbial organisms that reside within us in human development and evolution.

*The Planetary Biodiversity Project.* The project will employ DNA barcoding to transform biodiversity science and inform an evidence-based conservation agenda for a sustainable, global bioeconomy. •

# How to build a quantum computer

—  
CONVERSATION





The field of quantum mechanics still seems as mysterious as ever, even 100 years after Niels Bohr first proposed his quantum model of the atom. Quantum theory has given us waves that are also particles; particles that are somehow “entangled” with one another; and particles that are in “superpositions,” both here and there, or up and down.

But these same quantum properties could also hold the key to powerful new computers. With a working quantum computer, hard problems could suddenly become easy—problems like factoring extremely large numbers, or simulating complex molecular interactions.

Our everyday computers using the laws of classical physics work with bits of information that are either on or off. On the other hand quantum bits, or “qubits,” can be in superpositions that represent both on and off at the same time, creating tremendous potential computing power. A quantum computer of just a few hundred qubits could quickly solve some problems that a classical supercomputer would still be working on when the Sun had burned itself out.

But there’s a lot to be done. Practical devices have to be developed, and algorithms that exploit the quantum effects of superposition, entanglement, and quantum interference have to be invented. At a recent meeting of CIFAR’s program in Quantum Information Science in Sherbrooke, REACH sat down with Program Director Raymond Laflamme (University of Waterloo) and Senior Fellows John Watrous (University of Waterloo) and Barry Sanders (University of Calgary) to discuss the future of quantum computing.

#### LEFT

Senior Fellows Barry Sanders  
and John Watrous

**Why are we interested in quantum computing in the first place?**

**Laflamme:** Quantum computing allows us to do things that we cannot do with classical computers. Today's computers use the rules of classical physics to manipulate information. As you go down to the atomic scale, the laws of physics change. What we have found is that the laws of quantum mechanics seem to help us manipulate information in ways that we can't with classical computers. It's not only an incremental change. There's a discontinuity there.

**Watrous:** We have examples of problems for which quantum computers are apparently better than classical computers, according to theoretical models. According to these models one can, in principle, build a quantum computer that will factor numbers efficiently. And it's not known how to do this classically. This and other examples give us reason to think that quantum computers have a lot of potential.

We're talking about problems that if you try to solve them with a classical computer, running the fastest algorithms that we currently have, it would take more time than it will take for the sun to engulf the Earth. Some problems are simply out of reach of classical computers.

**Will these be specialized devices created for special problems? Or is there going to be a kind of general computing device?**

**Sanders:** We're not aiming to invent necessarily a new computer. If we can get things to work, then I think of it like an add-on chip. So we have our computers, and instead of some turbo device we get an add-on chip that will enable us to make some hard problems easy.

**Quantum states are seen as tremendously fragile things that are always on the verge of collapse. But you're talking about building devices that let you create these states and manipulate them.**

**Sanders:** Yeah, that was one of the things about quantum mechanics, the fact that you can ignore it for understanding almost everything in the world. That it might matter if you want to understand atoms, molecules, nuclei, but we could ignore it at the higher level. But this is where we're pushing the boundaries. We can engineer systems so that quantum mechanics does matter on a larger scale, and we can exploit it.

**What kind of a timeline are we looking at for working quantum computers?**

**Watrous:** We're coming up on 2014, which is the 20th anniversary of [Peter] Shor's algorithm, which shows how a quantum computer could be used to efficiently factor numbers. And this was a question that people were asking then – how long is it going to be before you can build a quantum computer? And people always used to say, well, 20 years.

**Sanders:** It's always 20 years.

**Watrous:** Right. But we've learned an enormous amount about the nature of the problem. We're up against a pretty big challenge, but we're optimistic.

**Laflamme:** If you think of a large-scale quantum computer, the timeline is still fuzzy. But today we have small devices where quantum effects are important, which can be used practically today. Advances in quantum metrology and quantum sensing have given us devices that allow us to create images of a single electron, for instance, and could someday be used for things like creating detailed images of proteins or other molecules of interest.

**Sanders:** I agree with Ray, that along the way there are all these benefits that come along. There's the quantum metrology stuff, there's the side benefits to nanotechnology, etc.

**Where does Canada fit into all this?**

**Laflamme:** We have people who are really, really strong. Something which is unique to the CIFAR program is the combination of physics and computer science. There's some great stuff that has come out of the program because of that.

**What are the big questions you're interested in?**

**Watrous:** I'm interested in the mathematics of quantum information. There are many unanswered questions, questions about entanglement, for example. Entanglement is very poorly understood in large systems. The types of correlations that can arise from entangled states, for example, is a huge mystery, and there are mathematical challenges to try to understand these things.

I'm also interested in questions related to





Program Director Raymond Laflamme:  
"Quantum computing allows us to do things  
we cannot do with classical computers."



computational complexity, which tries to understand the limitations on the power of quantum computers.

### **Barry, what about you?**

**Sanders:** I'm interested in [physicist Richard] Feynman's original question that motivated the idea of quantum computing, the question of whether nature can be simulated. You know the movie *The Matrix*? If you haven't seen it I'm sorry if I'm giving anything away...

**Watrous:** It's been around a long time. You don't have to worry about spoilers.

**Sanders:** So then the idea is, do we live in the world or do we live in the matrix? And suppose there is a matrix – is the computer that runs it classical or quantum?

But the serious question is whether nature is simulatable. This is the question that really drives me, is whether the universe as we know it is equivalent in some sense to quantum computing or not. And then all the technology and stuff is what I need to do to earn my money to be able to think about it.

### **How about you, Ray?**

**Laflamme:** So I'm interested in knowing can we, and how can we, control quantum systems. If you look at the history of humankind and you look at technological evolution, from fire 20,000 years ago, or steam 200 years ago, or electricity a hundred years ago, you can see a pattern that starts with people being curious about something.

We're curious about some things, and then by kind of pushing our brain we learn how to understand these phenomena of nature and kind of see how they work. And once we understand them, then we have a path of how to control them.

Quantum mechanics is at least a hundred years old. About that time we started to realize that there was this new phenomenon of nature. It took time to build a theory, and we've learned a little bit about controlling some small part of the quantum world, but we haven't learned how to control the superpositions of many states, and this is the essence of quantum computing and quantum information science. Controlling is the important part. That's why I do what I do.

**Watrous:** You have a much more romantic answer than me. I just want to prove theorems.

**Laflamme:** And that's the fun part of interacting with you.

**Watrous:** Well, you are among the people who have proved one of the foundational theorems of quantum computing, which is the threshold theorem. I mean this is a fundamentally important result, which helps us to have confidence or at least hope in being able to build a quantum computer.

**Laflamme:** Yeah, so, I had help. •





An Arctic iceberg.  
Photo by CIFAR Fellow Eric Galbraith



# Poking the system

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## THE HISTORY OF EARTH'S CLIMATE

Over the eons, Earth has veered wildly from frozen to baked, from teeming with life to nearly devoid of it. It has survived impact with asteroids, the slamming together of tectonic plates, spewing volcanoes and ruinous ocean acidification.

Today, the planet is sustaining one of the swiftest and most extreme changes in atmospheric composition in its 4.6-billion-year history, due to human-produced greenhouse gases. Scientists are racing to determine the consequences, and whether we could be approaching another catastrophic switch, one with grave consequences for life on the planet.

Researchers are taking a number of approaches, from collecting better information about the current climate to creating better models of atmospheric interactions. But for a group of CIFAR scientists, the key is to better understand the Earth's past. The CIFAR team is interrogating the planet's ancient physical archive to see how it responded to similar events in the past.

“The rock record is out there waiting to be read,” says Jerry Mitrovica, Director of CIFAR’s Earth System Evolution program and a geophysicist at Harvard. “The Earth contains all the natural experiments you want.”

“When we look at the Earth’s history, we’re struck with the amazing resilience of the planet,” says Lee Kump, Associate Director of the program and a geoscientist at Penn State. “For 3.5 billion years, there’s been life somehow, despite monstrous impacts that could have had the potential to sterilize the Earth. Despite the horrible insults, the planet recovers.”

The Earth features a dynamic, shifting interplay among the living and non-living, fluid and solid, visible and invisible, all of which work together to keep the planet inhabited against the odds. That means the Earth system bends over backwards trying to remain stable and then, when it can’t, it changes tack, actively helping a new era come into being by enhancing the very assaults it faces. That’s called a positive feedback loop.

It means that disturbances don’t have to increase, they only have to persist, pushing the planetary system past a point it can fight. Then, change can happen abruptly.

## Snowball Earth

James Zachos, a senior fellow at CIFAR and professor of earth and planetary sciences at the University of California, Santa Cruz, points to a classic example of abrupt change: the rapid development of the Antarctic ice sheets 34 million years ago. Carbon dioxide levels in the atmosphere were falling steadily; at one point a bit of the continent’s snow didn’t melt, and ice formed and bounced heat back up into the atmosphere. This helped more ice to form and, voila, Antarctica’s vast ice sheets came into existence in less than 40,000 years – the blink of an eye, geologically speaking.

A similar, if less straightforward, planetary phenomenon was Snowball Earth, thought to have developed about 850 million years ago. During that period, the planet was covered in ice for tens of millions of years. Living creatures were confined to remote nooks such as glacial beds and deep-water vents heated from the inner Earth, or, perhaps, were cryogenically preserved.

CIFAR Senior Fellow Daniel Schrag of Harvard and Associate Paul Hoffman of the

University of Victoria have been central to the development of the Snowball Earth idea. As in the formation of Antarctica’s ice sheets, more and more white ice reflected heat away from the planet’s surface, causing runaway global cooling. The continents were clustered near the tropics at that time, and this helped draw more and more carbon out of the atmosphere, as rocks weathered into the ocean, cooling things down even more.

While the Earth was locked into a deep freeze, carbon dioxide that spewed from volcanoes steadily increased in the atmosphere, eventually triggering a paroxysm of warming and melting. This, in turn, led to an explosion of new multi-cellular life forms over millions of years.

## A hothouse, and then some

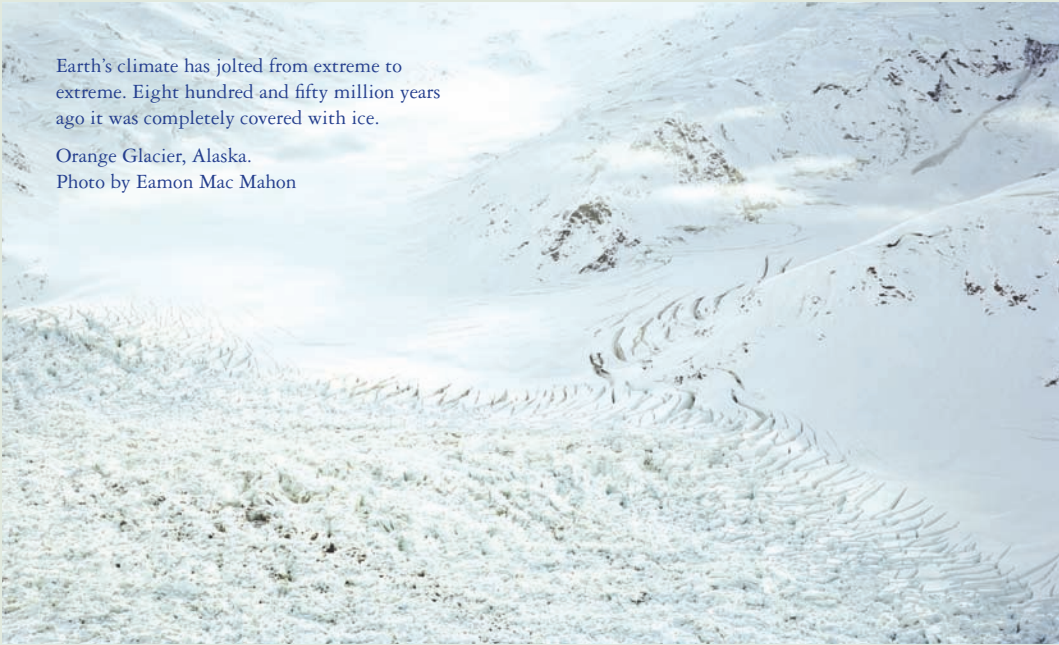
A similar pastiche of planetary assaults was at play during the Paleocene-Eocene Thermal Maximum (PETM). This period of exceptional, rapid warming occurred about 55 million years ago, not long after the dinosaurs became extinct. Scientists are fascinated by the period, which is considered a possible parallel to the current perilous state of the climate and ocean systems.

Zachos, one of the world’s leaders on this enigmatic period, gave a talk about it at a CIFAR meeting and Kump dove in as a result.

When the PETM began, the planet was already a hothouse by today’s standards. But it got far, far hotter – as much as 9 degrees Celsius on average – after a massive infusion of carbon-based gas hit the atmosphere. This was such a huge spike, it was equivalent to the burning of all the modern planet’s remaining stores of oil, gas and coal. PETM scientists discovered that the atmosphere was heavily laden with carbon-based gas by looking at the isotopes of elements, such as carbon, in the fossils.

At the same time, the Arctic Ocean heated up enough to resemble a salty bathtub with a layer of fresh water on the top, thronged with freshwater ferns. Even the deep ocean heated up by 4 or 5 degrees C, a phenomenon scientists hadn’t believed possible until CIFAR researchers and others discovered it. Many life forms became extinct and new ones came into being.

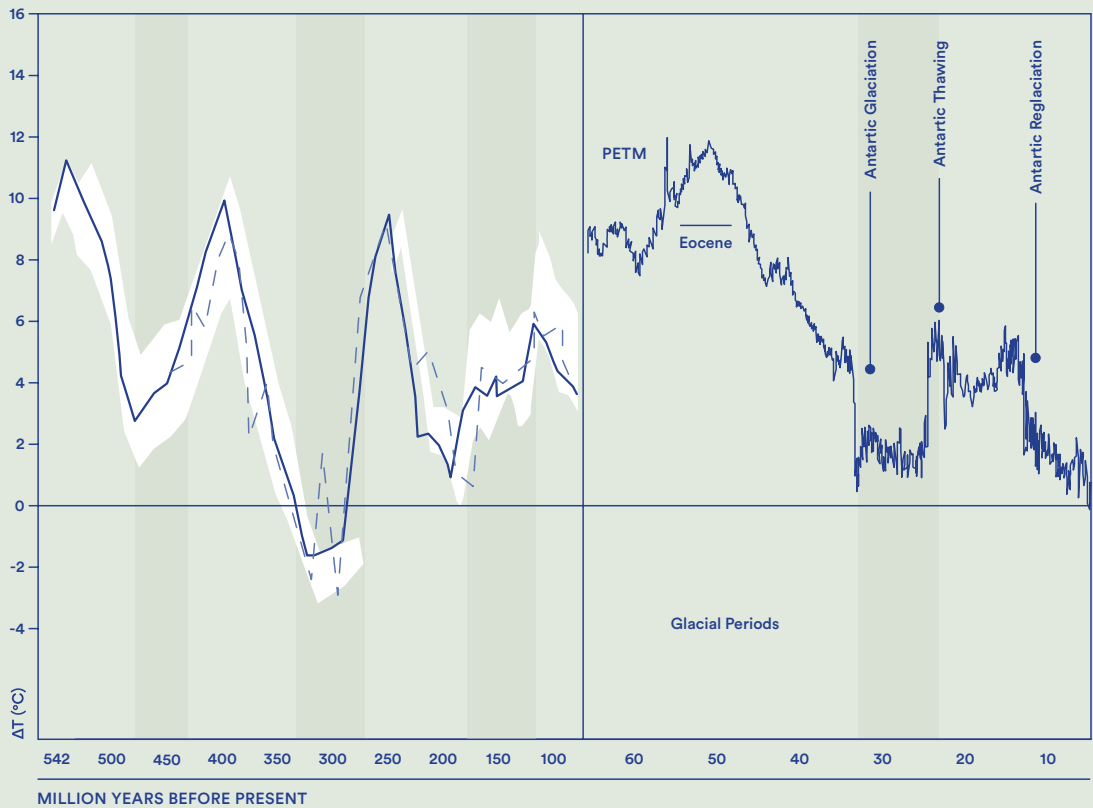
But the shocker was a finding by Zachos, Kump and another CIFAR Senior Fellow, Katherine Freeman, a geoscientist at Pennsylvania State. The three conducted research on a

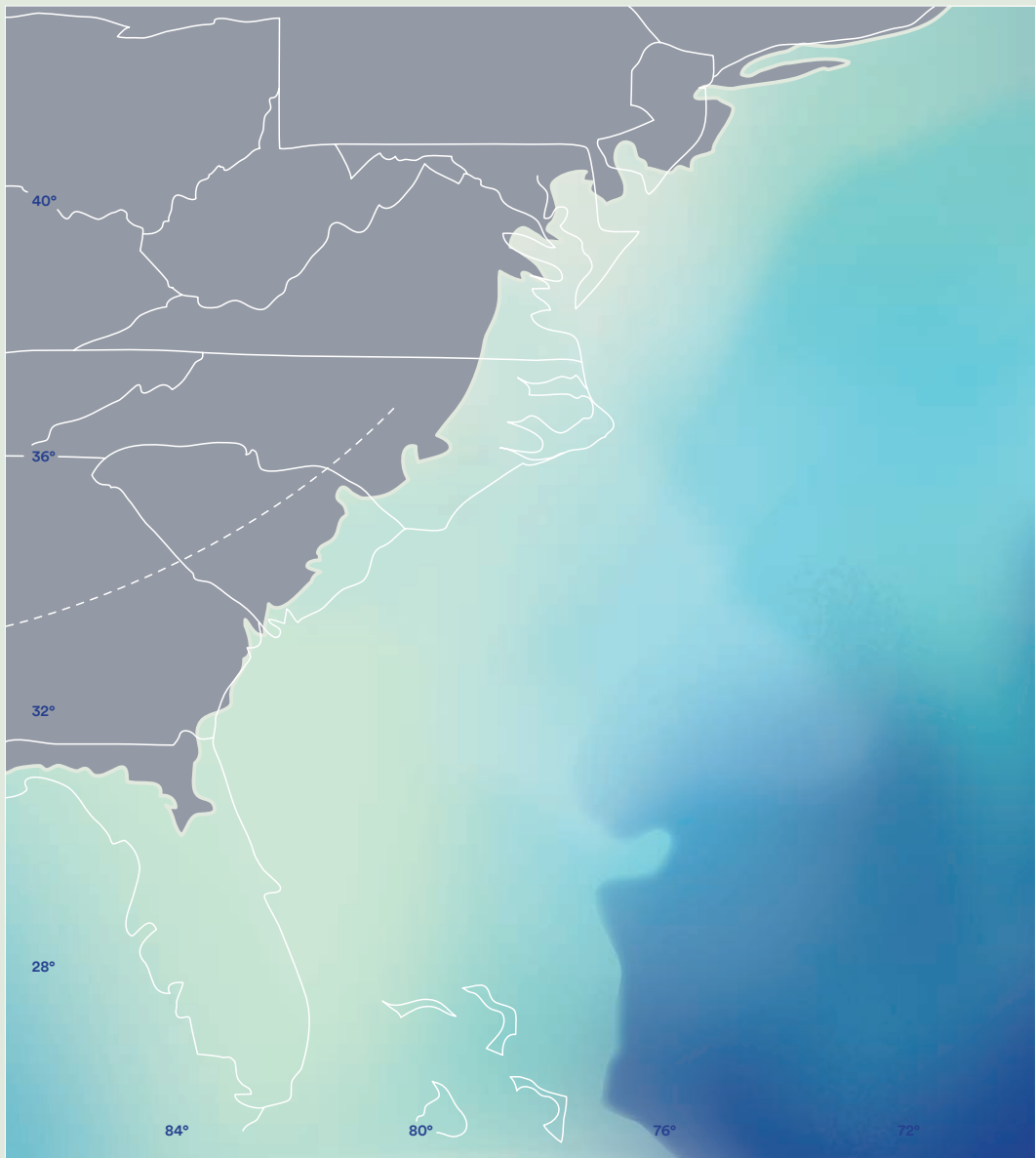


TEMPERATURE OF PLANET EARTH

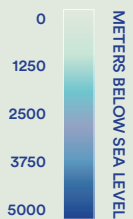
This record of changing Earth temperatures shows how climate has changed suddenly and dramatically in the past.

Credit:  
Adapted from Glen Fergus under the Creative Commons BY-SA 3.0 license.





A reconstruction of the shoreline of the Eastern United States about 3 million years ago, which shows much of today's shoreline underwater. CIFAR fellows discovered that pressure from Earth's underlying mantle has forced the shoreline upward, which requires conclusions about past sea level rise to be reconsidered. (Adapted from Rowley et al., Science 340, 1560)





beautifully preserved chunk of the PETM record they found on Svalbard, an archipelago in Norway. They already knew that an enormous amount of carbon-based gas had hit the atmosphere during the PETM, but they didn't know how fast it went in. In Svalbard, they discovered that it had entered the atmosphere at a rate of somewhere between 0.3 and 1.7 trillion kilograms a year.

That's fast. And Earth responded to it catastrophically. But today's rate is far faster. In 2008, for example, humans pumped 9.9 trillion kilograms of carbon into the atmosphere, anywhere from five to 33 times the rate during the PETM.

## Jersey shore

While some of CIFAR's detective work focuses on individual episodes from long ago, other investigations have uncovered deeply concealed planetary patterns or tendencies that run through Earth's history.

Mitrovica recounts the story of collaborating with two other CIFAR senior fellows: Alessandro Forte, a geophysicist at Université du Québec à Montréal, and David Rowley, a geologist and paleogeographer at the University of Chicago. Like a crack team of crime-scene investigators, they pooled their specialties to solve a particularly puzzling case.

They were trying to discover why three-million-year-old beaches along the east coast of the United States are now 50 to 80 metres above present sea level. These ancient beaches were there when the Earth was 2 to 3 degrees C warmer than today. Other scientists had seen the beaches' elevation as proof that the polar ice sheets had melted away in the face of the warming.

But when Rowley, Forte and Mitrovica put their heads together, they realized that those earlier arguments didn't take into account the flow of the mantle (the solid, but shifting region between the Earth's crust and its core), nor the tectonic plates the mantle carries with it. As Mitrovica pointed out, this flow doesn't just move tectonic plates across Earth's surface horizontally (leading to the familiar ideas of continental drift); it also moves them vertically. These massive forces can drag continents down with them, working like the heavy anchor of a ship, or push them up – even at locations far

away from well known plate boundaries such as the San Andreas Fault. And they could drastically change the elevation of ancient shorelines, like those along the east coast of the U.S.

Rowley and Forte had another key piece of the puzzle. Their recent work had focused on the Farallon tectonic plate, which had been subducted, or absorbed, under North America until about 30 million years ago. They knew that this plate now sat deep below the east coast of the United States, 1,000 kilometres below Earth's crust – and that, even at that depth, it was still influencing the elevation of the continent. This meant the earlier thinking – that the sea level had risen up to 80 metres from the collapse of polar ice – was incorrect.

"Forte, Rowley and I said, 'In this case, it's the land going down and up, not the sea going up and down,'" says Mitrovica.

The finding has rewritten textbooks on sea change, a key concern in today's rapidly warming world, and it means scientists examining ancient sea levels for clues about ice volumes must now take into account what has happened over time in the deep Earth.

But we can't take this as cause for optimism, says Mitrovica. "When we look at other times when the Earth was warmer than today, there is clear evidence that major sectors of the Greenland and West Antarctic ice sheets melted and sea level rose close to 10 metres higher than what we see today. This is just getting started."

## Acidic oceans

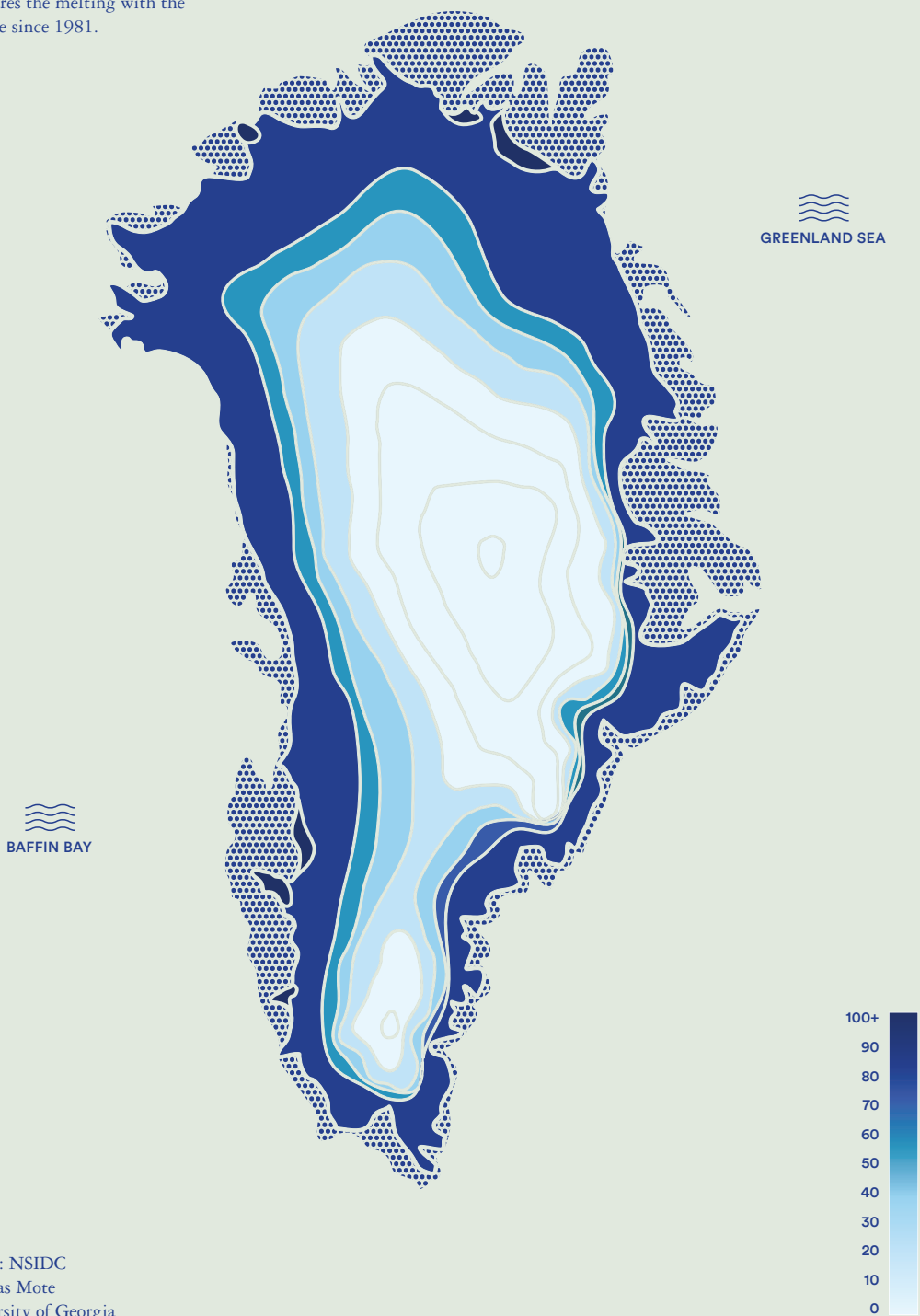
An equally radical find stemmed from digging into the geological record to explore Earth's fundamental ability to support life. This was driven by curiosity and solved by some canny sleuthing on the part of a large international, interdisciplinary team that included Zachos and Kump.

"If I had followed my heart and passion, I would have been a policeman or a detective," confesses Kump. "I always read detective stories and was interested in solving mysteries."

The question at hand: How have high carbon levels in the atmosphere affected the pH of the ocean over the past 300 million years, and how have these shifts in pH affected patterns of extinction?

It's a key consideration today as the ocean absorbs part of the air's carbon load, sparking a

Researchers are concerned about rapid melting of Greenland's ice sheets. The chart at the left shows cumulative days of melting for across Greenland in 2013. The chart at the right compares the melting with the average since 1981.



chemical reaction that creates carbonic acid in the water and makes it more acidic. Just in the past couple of hundred years, the ocean surface waters have become 30 per cent more acidic than they were before people began burning fossils for energy. Today, the ocean is more acidic than it's been for 55 million years – since the PETM – and it is poised to become far more so this century if fossil-fuel burning continues.

This landmark ocean acidification study found that high carbon loads in the atmosphere have acidified the ocean a handful of times in the planet's billions of years, but the effect on species – whether they survived, or died en masse – was linked to how quickly that happened. The quicker the acidification, the greater the number of extinctions.

So the team looked at the pace of carbon emission. They found that during the end-Permian mass extinction 252 million years ago, carbon entered the atmosphere swiftly, likely from volcanic activity. That extinction is the biggest of Earth's five mass extinctions, and is known as the "Great Dying" because 95 per cent of species became extinct.

But the rate of carbon release into the atmosphere today is even quicker, the team discovered – anywhere from 10 to 100 times quicker. That is the fastest of any time in the history of

the Earth as far as scientists can read it, and has worrying implications.

"Clearly the rise in greenhouse gases that we are currently experiencing is much faster than what we believe was the rate of change for past events," says Zachos.

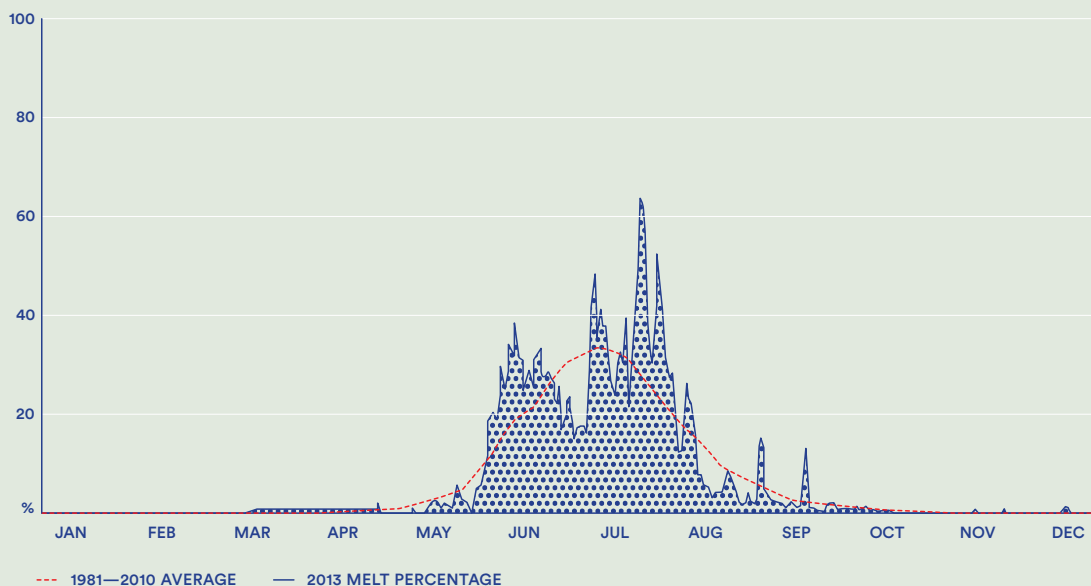
## Understanding the oceans

While the chemistry of the ocean is critical to the fate of life on Earth, much of it is still not fully understood. CIFAR Fellow Eric Galbraith, a professor of earth and planetary sciences at McGill University in Montreal, is trying to change that. Galbraith is working with another CIFAR Fellow, Markus Kienast of Dalhousie University, and Daniele Bianchi, a post-doctoral fellow at McGill whose work is also funded by CIFAR.

Together, they have begun to revolutionize the way scientists understand the chemistry of the modern and recent ocean, sometimes literally excavating forgotten data out of other scientists' file drawers and hard drives and crunching the numbers in new ways.

### GREENLAND MELT EXTENT 2013

NSIDC / Thomas Mote, University of Georgia







Last year, they published the first global analysis of the ocean's nitrogen cycle over the past 30,000 years, based on an analysis of the rare, stable isotope, nitrogen-15. They found that the cycle runs faster in a warmer ocean that is spiked with more low-oxygen zones, a phenomenon that increasingly characterizes the modern ocean.

In another paper, Bianchi and Galbraith showed that animals migrating vertically through the water every day play a significant role in changing the chemistry of the whole ocean, particularly when it comes to oxygen. Before their study, scientists had assumed that bacteria controlled marine chemistry.

This finding has raised new questions about the health of the ocean. In the past few decades alone, humans have taken vast volumes of migrating creatures out of the ocean. The implications for ocean chemistry are not yet clear.

## A catastrophic future?

The emerging picture of Earth's past, which is coming into focus through the research of the fellows in CIFAR's program in Earth System

Evolution, is inevitably linked to concerns about its future. Senior Fellow Shawn Marshall, a glaciologist and climatologist at the University of Calgary, has been tracking the ongoing dramatic melt of Greenland's ice sheets. In 2012 alone, the sheets lost 630 billion tonnes of ice, shattering all records. That's eight times the amount of ice the Alps lost in more than a century, from 1900 to 2010.

It's worrisome. But Greenland's ice could be rebuilt by snowfall if the climate cooled again, Marshall says. He's more concerned about the hidden pulse of heat nestled ominously in the depths of the North Atlantic Ocean. That pulse, soaked up by the ocean from the atmosphere, is inexorably making its way toward Antarctica.

If it is enough to warm the water surrounding that continent by as little as 1 or 2 degrees C, then it could destabilize the ice shelves, Marshall says, causing them to fracture and topple into the sea. And once they're gone, they're gone. If the shelves disappear, there is little to stop the massive ice sheets behind them from flowing into the ocean. This worst case scenario would lead to a sea level rise of perhaps 60 metres, changing the face of the Earth yet again.

"When you poke the system, the system will run with it," he says. "And the amount of poking we're doing now is definitely something that worries many of us." •

### LEFT

CIFAR fellows are working to understand how climate change has affected ocean chemistry in the past and present, and what the changes could mean for life on Earth.

Photo by Mikael Eriksson.



STORY — Kurt Kleiner  
PHOTOGRAPHY — Josh Valcarcel

# Deep thinking

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## MAKING MACHINES BETTER LEARNERS

The journey towards creating artificial intelligence has been slower and more difficult than early pioneers predicted. Modern computers are truly impressive in many ways. But they don't hold a candle to the human brain when it comes to picking a face out of a crowd, understanding a pun, composing a symphony, or any of hundreds of things humans do.

But a new approach pioneered by CIFAR fellows is shaking up the world of artificial intelligence. Over the past decade the fellows have championed a technique called deep learning and made it one of the hottest areas in artificial intelligence.

If you use the voice recognition feature on an Android phone you already benefit from deep learning networks, which improved voice recognition by 25 per cent over the best existing techniques. A similar improvement in image recognition led Google to implement deep learning techniques on their Google+ service last year.

In fact, the Internet giants are happily snatching up CIFAR fellows to work on their artificial intelligence efforts. Last year Google recruited Geoffrey Hinton, until recently director of

CIFAR's program in Neural Computation & Adaptive Perception (NCAP), to work in its artificial intelligence laboratory. Shortly after, Facebook followed suit, hiring Senior Fellow Yann LeCun to set up a new artificial intelligence laboratory for them. And since 2011 Senior Fellow Andrew Ng has been at Google, where he developed the Google Brain neural network.

"NCAP was crucial," says Hinton. "The fundamental idea of CIFAR, which is to get the best people and put them in contact where they can exchange ideas, worked really well."

The digital giants are interested in deep learning because the technique promises to allow their computers to sift through millions of photos and videos and describe them as accurately as any human could; or to understand natural language beyond the level of simple keyword searching; or, perhaps, to make better predictions about which ads we're likely to click on.

"The interest of large companies in artificial intelligence is really focused today on deep learning," says LeCun. "And deep learning was basically a CIFAR-funded conspiracy."



## PAGE 24

Former NCAP Director Geoff Hinton is working with Google after helping to spark a resurgence in deep learning networks.

## LEFT

NCAP Co-Director and Senior Fellow Yann LeCun recently went to work setting up an artificial intelligence lab for Facebook.

## From Pong to neurons

From the most primitive game of Pong to the most sophisticated supercomputer climate model, conventional computer programs consist of precisely-written, step-by-step instructions that have to be carried out exactly as written. Although these programs can be fantastically complex, they consist of steps written down by a human programmer who had to figure out just what he wanted the program to do and how he wanted it done.

But as early as the 1950s, some computer scientists became interested in another direction. They began to experiment with artificial neural networks, loosely modelled on the workings of the human brain. Rather than being programmed, these networks were trained, learning from experience to arrive at the right answer. (*See figure opposite.*)

It seemed like a good idea. Consider all of the ways a picture of a cat can look. It can be in different colours, taken from different angles, by itself or in the frame with other objects or animals, etc. The neural network between our ears does a great job of picking out cats. But how do you write an algorithm describing a step-by-step process of recognizing a cat?

The promise of neural networks was that you wouldn't have to. You could simply show the neural network a lot of pictures of cats and let it learn what they looked like.

There was a lot of interest, but there were also a lot of problems. For one thing, the networks weren't always easy to train. You had to collect a lot of data and label it – picture a team of grad students getting together hundreds or thousands of photos and making sure the ones labeled “cat” really had a cat, and the ones labeled “not cat”

really didn't. Then after you'd trained the network, you had to use even more examples to make sure the network worked on photos it hadn't been trained on.

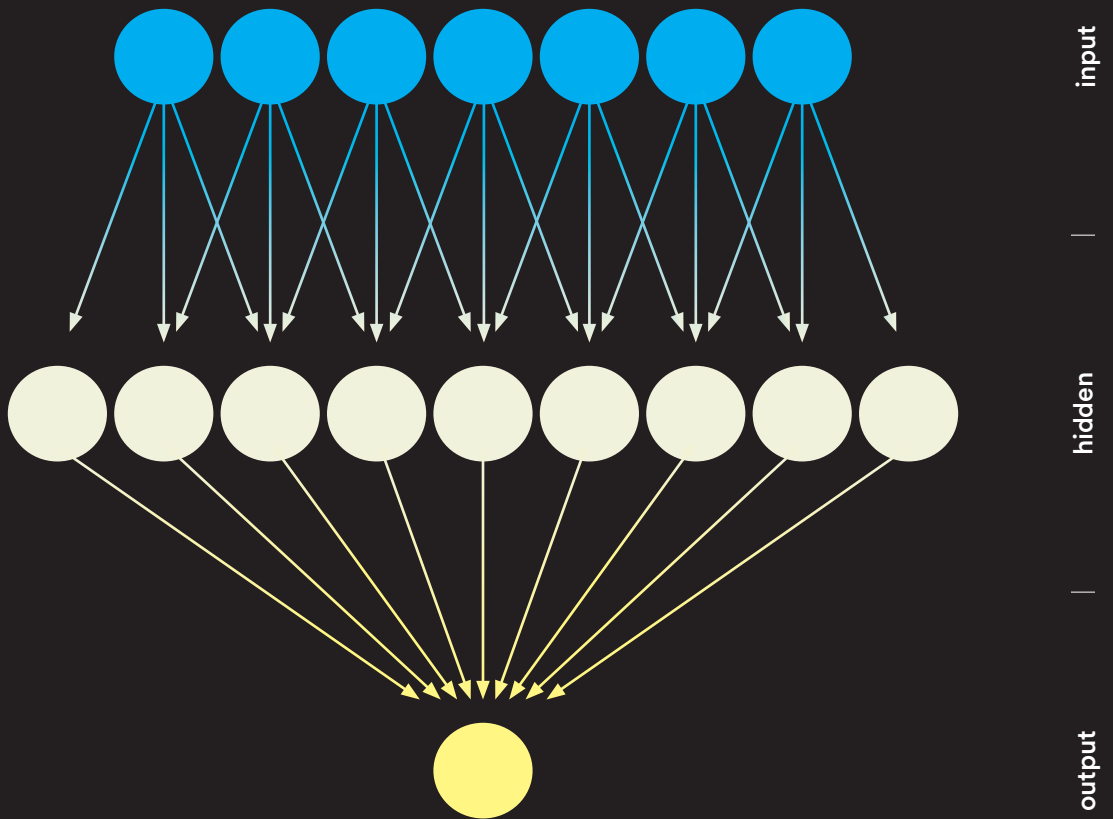
Neural nets could be tough to train for other reasons. When they failed to work it could be hard to figure out why. Or they would seem to work, only to reveal later that they had been “over-trained” – they might have only learned to recognize some other common feature, like a random pattern of pixels that the particular collection of cat photos accidentally had in common.

After a surge of research in the 1980s, interest in neural nets had largely fallen away by the 1990s, to be replaced by other forms of machine learning. In fact, one respected journal was said to have stopped considering any paper with the term “neural network” in the title.

## Obviously wrong

But Hinton didn't give up on neural nets. He says it made sense to look towards the workings of the human brain to figure out better ways of achieving machine learning. After all, if we want to teach computers to perceive things the way we do, why not use a model that has been shaped by evolution to do just that? He wasn't put off by the consensus of the field – he grew up as an atheist in a Christian school, and was used to trusting his own beliefs.

“When people said it's irrelevant how the brain works, they were just utterly and obviously wrong,” Hinton says.



## HOW NEURAL NETWORKS WORK

An artificial neural network is typically made up of three or more layers of neurons. You feed a signal (say a pattern of pixels depicting a cat) into an input layer. The signal causes the neurons in the input layer to fire in a particular pattern, and this signal is passed on to the next hidden layer. The process can continue through a number of hidden layers, which finally pass on their signals to an output layer. The goal is to get the network to learn to recognize the features in an image that are necessary to label it a picture of a “cat.”

Getting that to happen is the trick. You start by weighting each artificial neuron differently, so different inputs cause different neurons to fire at different times. By giving the network feedback on whether it was successful, and using the information to re-adjust the weights and the connections to other neurons, you can eventually train the system to recognize whatever you want, in this case a picture of a cat.



**“When people said  
it’s irrelevant how  
the brain works, they  
were just utterly and  
obviously wrong.”**



CIFAR’s NCAP fellows at a meeting  
in San Francisco last year.



NCAP Co-Director and Senior Fellow  
Yoshua Bengio.

In 2004 Hinton and a number of other researchers including Senior Fellow Yoshua Bengio (McGill) formed CIFAR's NCAP program and immediately began discussing how to make neural networks work better.

"It was a matter of time, but we had to convince the community that it was worth the effort to work on this," LeCun says.

The community finally began to sit up and take notice in 2006 when Hinton and colleagues published a paper called "A fast learning algorithm for deep belief nets" in the journal *Neural Computation*. The paper described a new way to design better "deep" neural networks – that is, neural networks with three or more "hidden" layers between the input layer and the output layer.

The new technique trained one layer of the network at a time. Neurons in the first layer would learn to represent some feature of the data, for instance to distinguish a horizontal line. When the first layer had learned something, the data would be passed on to the next layer, which would learn to represent some other feature of the data – perhaps combining two or more shapes to learn to recognize an eyebrow. The next layer might contain a neuron that recognized the combination of an eyebrow and an eye. Essentially, each higher layer of the network would learn to operate at a higher and higher level of abstraction. (See figure page 30.)

## Even more cats

Possibly even more exciting was that Hinton's paper showed that these networks didn't need to be supervised. You could set them loose on an unlabeled collection of images, and they could learn to recognize relevant features for themselves. After the initial learning was done you could come along and fine tune the process and add labels, telling the network that this image was a car, this one an airplane, etc.

"If you think about how babies learn," says LeCun, "they learn by themselves the notion of objects, the properties of objects, without being told specifically what those objects are. It's only later that we give names to the objects. So most of the learning takes place in an unsupervised manner."

In fact, last year Andrew Ng made news with a Google network that did this on a giant scale. Working with colleague Jeff Dean and the Google "brain team," he created a deep learning network composed of 16,000 computer proces-

sors, and fed it 10 million images extracted at random from the Internet, with no labels. The network taught itself to recognize human faces, human bodies – and yes, cats.

Hinton's 2006 paper created a groundswell of interest in neural networks, and researchers began working on them again.

Hinton says that part of the recent success of neural networks comes from the huge advances in both computing power and availability of data. Neural nets that were too complex to be practical on older, slower processors hummed along perfectly on modern work stations. And bigger computer memories and the Internet made it much easier to get big data sets to train the networks on.

"The main issue was that there wasn't enough data and the computers weren't fast enough," Hinton says. "As soon as we got 1,000 times the data and computers a million times as fast, neural networks started beating everything else."

## What lies ahead

The NCAP program was created with the dual interest of figuring out how neurons can be used in computation, and how computers can be made to perceive patterns. In many ways, Hinton says, vision is a perfect problem for machine learning. We actually know a lot about how the brain processes vision, compared, for instance, to how it processes language.

As he continues his research, he sees two major challenges. First, he wants to push forward on unsupervised learning. Second, he has to tackle the problem of how to make neural networks work at larger and larger scales.

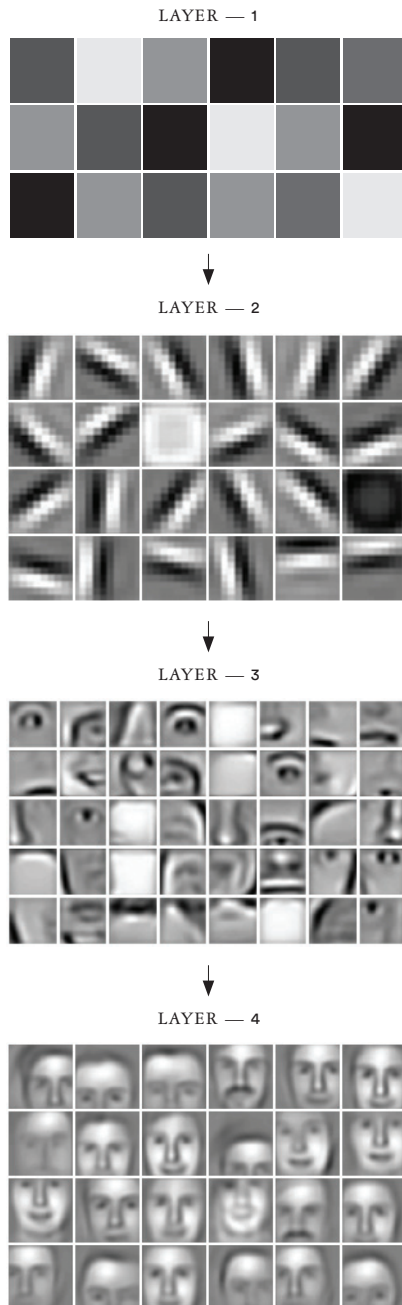
First is the unsupervised learning problem. Although Hinton's 2006 paper gained a lot of attention because of the promise of unsupervised learning, once researchers dusted off the old neural nets and started running them on modern computers with big data sets, they realized that the old techniques worked well enough. Most of the neural net applications in use now were actually trained with labeled data. Nevertheless, supervised learning still has limitations.

"What we really want is something that will be like a person and will just understand the world. And there, unsupervised learning will be crucial," Hinton says.

"For example, we'd like to be able to understand every video on Youtube. It would be nice if you could say, find me a video of a cat trying

## FACIAL RECOGNITION

How a neural net recognizes a face: The image is fed into the neural network, and the first layer learns to identify light and dark pixels. The second layer begins to recognize basic patterns such as edges and horizontal and vertical lines. The third layer compiles these into parts of faces such as eyes and eyebrows, and the final layer learns to recognize complete faces.



to jump on a shelf and falling. A person would understand exactly what you were saying. Right now, maybe machine learning methods could say there's probably a cat in this video. They might even be able to say there's a shelf. But the idea of a cat trying to jump on a shelf and failing, they don't understand that. My prediction is that over the next five years, we'll be able to understand that."

The other problem is how to make neural networks "scale" — that is, how to make them work efficiently as they get bigger and bigger. Right now, Hinton says, the computing power you need is roughly the square of the speed increase you want. In other words, twice as much speed requires four times the computing power; 10 times the speed requires 100 times the computing power.

Hinton will split his time between the University of Toronto and Google, spending four months of the year at the corporation's headquarters in Mountain View, as well as working in its Toronto office. He says he's looking forward to the resources Google has — especially the data — as well as the researchers.

"They've got really smart people there, and they've got very interesting problems there. It's quite nice when you do something for it to be in a billion Android phones."

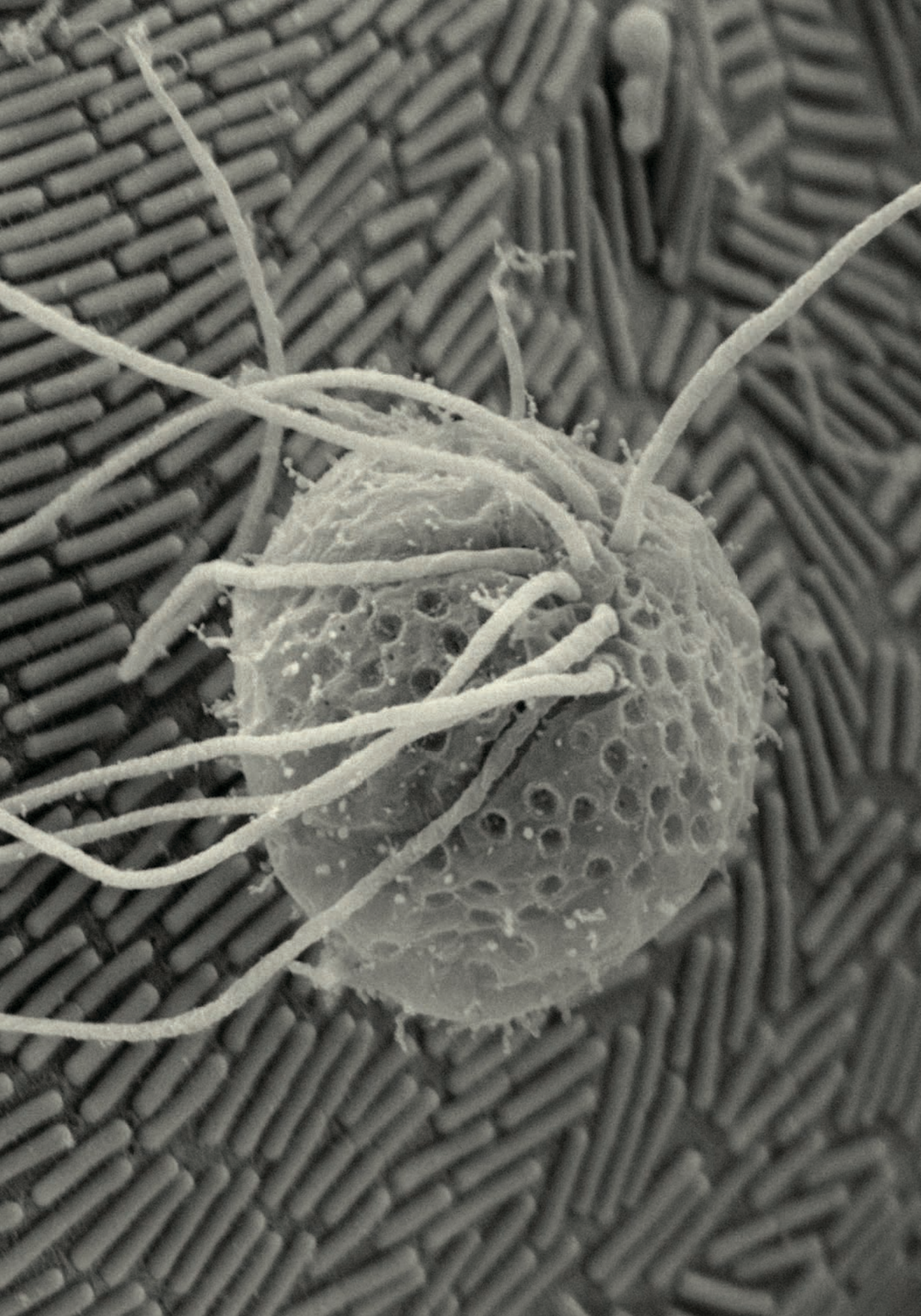
At Facebook, LeCun will have a similar situation. He'll continue to teach at NYU, and will be able to set up the Facebook artificial intelligence lab practically across the street from his campus office. "The nice thing about Facebook is that if you come up with a better way of understanding natural language, or image recognition, it's not like you have to create a whole business around it. It's just a matter of setting it up for 1.3 billion users."

Although Hinton has stepped down as director of NCAP, LeCun and Bengio have stepped up as co-directors of the program. LeCun says the program will continue to explore improvements in deep learning networks.

"There's no question in my mind that the problem of learning representations of the world will have to be solved by an AI system we build. Deep learning is the only answer we have to that problem now," he says. •









# The art of science

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## SMALL BUT PERFECTLY FORMED

Peer at the world closely enough, and things can start to look a little strange.

Patrick Keeling, a CIFAR senior fellow and director of the program in Integrated Microbial Biodiversity, is an expert at looking closely. He's especially interested in protists — a hugely diverse group of mostly single-celled organisms that have cell nuclei, but that aren't animals, fungi, or plants.

In this beautifully detailed photo made using a scanning electron microscope, we see a protist called *Saccinobaculus*. The name comes from a Huron word for “snake in a bag,” and refers to an organelle inside the protist (not visible here) that thrashes around like a snake and allows the protist to move. The little dents on its body work like little mouths through which it takes in nutrients.

Now look again at the background. *Saccino-*

*baculus* is actually resting against a much larger protist called *Barbulanympha*, which is so much bigger that it looks like a wall. Even stranger, the mosaic pattern of rod shapes is actually made up of many individual bacteria on the body of the large protist.

Several years ago, Keeling and his colleagues began to place their scientific photographs in large gilt frames and hang them in the hallway outside the lab. They've since had exhibits at the Beaty Biodiversity Museum and the Carl Sagan Society for the Promotion of Science at the University of British Columbia.

“We would like to do a show in a normal public art gallery one day, as an outreach activity,” Keeling says. “I think it could be really compelling if you keep the art show format and pretend the content is not scientific.” •



# Creating a world where all children can succeed

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FROM CELL TO SOCIETY

STORY — **Lindsay Jolivet**  
PHOTOGRAPHY — **Karen Whyllie**



On February 6, the auditorium at MaRS Discovery District filled with community leaders, pediatricians, researchers and engaged citizens, all there to hear some of the world's leading experts discuss how early childhood experiences get under our skin.

*From Cell to Society: Creating a world where all children can succeed* brought together powerful thinkers for a CIFAR symposium dedicated to the late Clyde Hertzman, a longstanding CIFAR researcher who made critical contributions to the study of early childhood development.

CIFAR President and Lawson Foundation Fellow Alan Bernstein gave the opening remarks, saying we owe much of our understanding of early childhood to the efforts of researchers in CIFAR's programs over many years, including Hertzman and Founding President Fraser Mustard.

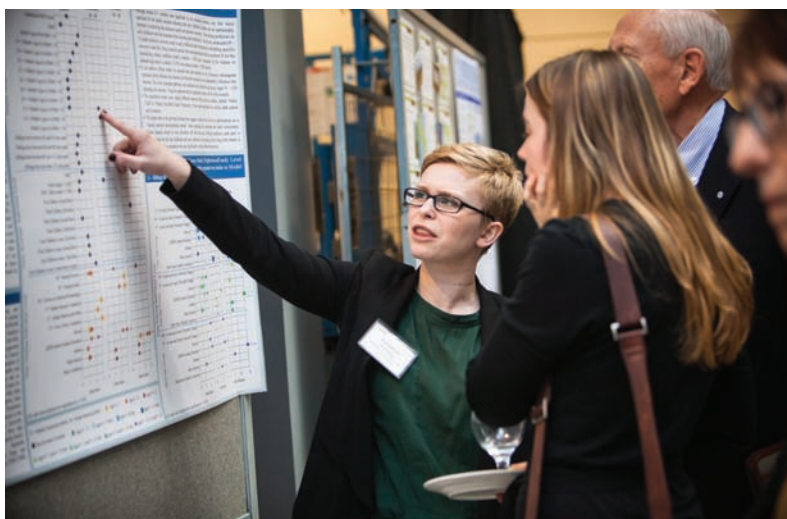
"Policies such as all-day kindergarten can be traced directly back to Fraser's campaign and Clyde's research," he said.

Over the course of the day, experts from Canada, the United States and the United Kingdom participated in panels exploring three levels of concern related to early childhood development: the cellular, the experiential and the societal. CIFAR Co-Director and Weston Fellow Marla Sokolowski (University of Toronto) began the

CIFAR Advisory Committee Chair Sir Michael Rutter spoke about the biological embedding of experience. He was one of more than a dozen speakers at the symposium honoring the late Clyde Hertzman.

day with an overview of the most pressing challenges facing epigenetics research, drawing examples from current work by CIFAR's Child & Brain Development program. The program's focus is to understand the critical periods in brain development, the windows when genes listen most to experience. According to Sokolowski, with a deeper understanding of brain plasticity, researchers will be better able to answer another pertinent question: How can we make a difference so that all children can reach their potential?

Sir Michael Marmot (University College of London) told the audience that while the statistics on childhood morbidity and poverty are sometimes grim, there are communities worldwide that are listening to the evidence, and change is possible. Drawing on his World Health Organization report on the social determinants







#### ABOVE

Michèle Lamont, co-director of CIFAR's program in Successful Societies.

#### LEFT AND BELOW

The program included speakers, a poster session, and a reception.

of health, *Closing the Gap in a Generation*, Sir Marmot said cities and nations need to start implementing proven strategies.

"We have the knowledge to close the gap in a generation. We have the means to close the gap in a generation. What we now need is the *will* to close the gap in a generation," Marmot said.

The keynote speech by Tom Boyce (University of California, San Francisco), co-director of the Child & Brain Development program, was a stirring tribute to Clyde and a galvanizing commentary on one of Clyde's key messages: "It doesn't have to be this way."

"He would have said that it doesn't have to be that children from disadvantaged communities sustain higher levels of toxic stress, and virtually every form of human malady and premature mortality," Boyce said.

Boyce explained that there are ways to prevent the millions of child deaths each year from disease and to reduce the negative effects of poverty, including giving greater rewards to those who care for young children and providing more supports for parents.

Boyce said that by connecting leaders, scientists and policymakers to Clyde's profound insights, we can carry his vision forward and build a better, healthier world for children everywhere. •



## CIFAR Knowledge Circle

CIFAR thanks members of the Knowledge Circle, its community of major supporters. The list below recognizes gifts made to CIFAR between July 1, 2012, and December 31, 2013, and current multi-year commitments to CIFAR of \$10,000 or more.

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# Canadarm

## HISTORY NOTE

The Canadarm2 robotic arm aboard the International Space Station is recognized around the world as a symbol of Canadian technological ingenuity. What's not widely known is that CIFAR played a role in getting it up there.

In 1985 the U.S. announced that it would build a space station and that it wanted international partners. CIFAR founder and then-President Fraser Mustard saw an opportunity for Canada, and put together a committee chaired by retired University of Toronto President Jim Ham to look at the question and make recommendations.

The committee concluded that Canada should take the lead in creating an automated service centre for the ISS, one that used robots to test, service and repair satellites and other spacecraft. Mustard himself was deeply interested in robotics – in fact, CIFAR's first program was in Artificial Intelligence & Robotics in Society.

The recommendation especially made sense because the Canadian company SPAR Aerospace had built the first Canadarm that flew aboard the US space shuttles. Creating a robotic service centre for the space station would give Canada an opportunity to leverage this technological lead.

Mustard and Ham made the case in December of 1985 to the House of Commons Standing Committee on External Affairs and Defence. They also pressed the case that Canada should consolidate all of its space-based efforts into one agency.

A year later the government announced the formation of the Canadian Space Agency. And in April 2001 Canadarm2 was carried into orbit by the space shuttle and deployed by the first Canadarm, with help from astronaut Chris Hadfield, who became the first Canadian to walk in space.

The Canadarm2 was used to build the space station, and now forms part of a suite of systems owned and operated by the Canadian Space Agency on the station. These include the Mobile Base System moveable work station and the Dextre maintenance robot. •



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Creating a world where all children can succeed.

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180 Dundas Street West, Suite 1400

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