REACH

CIFAR

IDEAS TO CHANGE THE WORLD — SPRING 2016

THE MYSTERY OF CONSCIOUSNESS

Exploring the question of human consciousness

– P.15

President's message

Promoting excellence now and in the future

The breadth and the depth of research being carried out by CIFAR fellows is truly impressive – from the action of tiny particles in fractions of a second, to the behaviour of the universe over billions of years. From the effects of stress on a child, to the development of entire societies and the institutions that make them work.

Fascinating as CIFAR research is, it's not undertaken merely out of curiosity. When we're deciding on what programs to bring together, we ask ourselves a few simple questions. Is the question important? Can answering it make a real and enduring difference? Will CIFAR's involvement make a difference?

Only when we can answer yes to all of these questions do we decide to put together a program of research. It's an approach that has led to amazing successes. You'll read about a few of them in this issue of *Reach* magazine, in which we highlight some of our many pre-eminent researchers and the important work they are doing.

In our cover feature, you'll read about how researchers in our Azrieli Program in Brain, Mind & Consciousness are using the latest tools of science and philosophy to tackle the puzzling questions raised by consciousness – what is it, exactly? What is it good for? Where does it come from, and how do we recognize if someone or something has it? Those questions are interesting in themselves, but they also have important implications for our understanding of basic human psychology, cognitive function and mental health. It's exactly the sort of research problem that CIFAR's interdisciplinary approach is intended to solve.

You'll also see how the fellows in our Integrated Microbial Biodiversity program are tackling fundamental questions about the incredible diversity of microbial life in the oceans that have major implications for the health of coral reefs, the oceans and our world's climate. And you'll read about Joe Henrich's new book *The Secret of Our Success*, which suggests that it's not our overall intelligence, but our ability to learn from one another, that has led to human success.

Finally, I want to point out the conversation among three of our fellows – Megan Gunnar, Charles Nelson and Michael Kobor. They discuss what research has taught us about the importance of early experience to the well-being of children, what questions still need answered, and how our research findings can be translated into policy and practice that actually help vulnerable children.

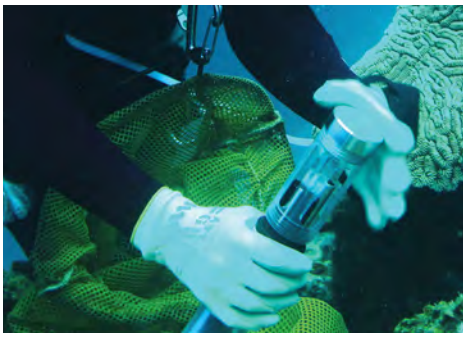
The conversation is especially interesting because the issues it raises will be addressed in November by the CIFAR Forum on the Well-Being of the World's Children in London, England. In the forum, CIFAR will bring together more than a hundred researchers, practitioners, organizations and other stakeholders to discuss what research questions need to be answered to help us help children. It's a massive effort by CIFAR to tap into the expertise of an entire community, and it's one we think will play an important role in setting new research directions.

I'd also like to take the opportunity to mention that we are launching the CIFAR Azrieli Global Scholars program. This new program will provide young researchers with opportunities to develop the cross-disciplinary and cross-sector knowledge, skills and perspectives they need to become research leaders within academia and agents of change beyond academia. The program is just launching, but please go to cifar.ca to read about it and other developments at CIFAR.

I hope you enjoy this issue of *Reach* magazine. It tells some of our stories, but there are many more than we can fit into its pages. I'd encourage you to go to our new IdeasExchange website, cifar.ca/ideasexchange, to keep up on all of our news. •

Alan Bernstein, President & CEO

15



23

33

41

Reach Magazine

Spring 2016—Volume 15, Issue 1

Managing Editor
Kurt Kleiner
kkleiner@cifar.ca

Reach Magazine, CIFAR
180 Dundas Street West, Suite 1400
Toronto, ON M5G 1Z8

Creative Direction
Concrete
www.concrete.ca

BN / Registration N°
11921 9251 RR0001

Produced by CIFAR Marketing & Communications

About CIFAR
CIFAR creates knowledge that is transforming our world. The Institute brings together outstanding researchers to work in global networks that address some of the most important questions our world faces today. Our research is focused on improving human health, transforming technology, building strong societies and sustaining the Earth. 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 is generously supported by the governments of Canada, British Columbia, Alberta, Ontario and Quebec, Canadian and international partners, as well as individuals, foundations and corporations.

Cover illustration by Adam Simpson.

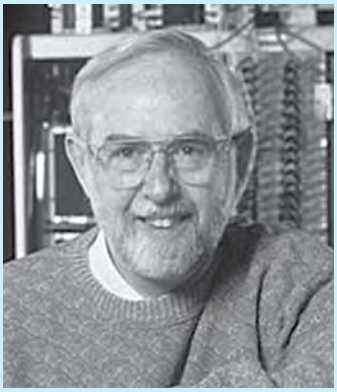
Advances
News highlights from our research networks

ARTHUR McDONALD RECEIVES THE NOBEL PRIZE

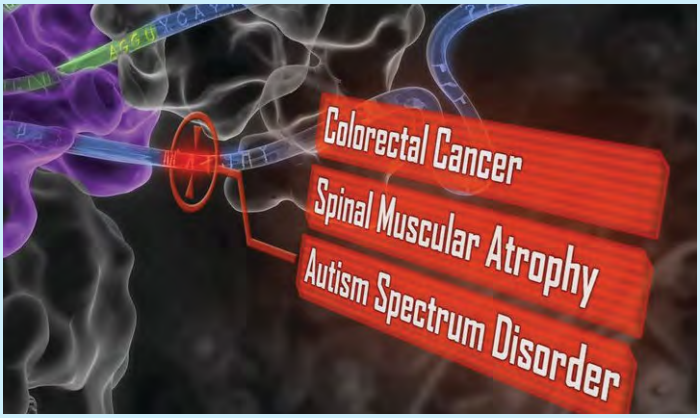
Arthur B. McDonald (Queen's University), associate fellow in CIFAR's Cosmology & Gravity program, received the 2015 Nobel Prize in Physics for his discovery that neutrinos change identities, a finding which shows that these subatomic particles have mass. He shares the prize with Takaaki Kajita of Japan.

McDonald led a research group, including Senior Fellow Mark Chen (Queen's University), at the Sudbury Neutrino Observatory (SNO), studying neutrinos formed through nuclear reactions in the sun. As these tiny particles travelled to Earth, two-thirds of them seemed to be disappearing. McDonald's group discovered that SNO was in fact capturing the neutrinos, but that the missing ones had actually changed 'identities' during their trip from the sun – changing from one to another of three different types of neutrino. Not only did the discovery explain the missing neutrinos, it also implied that neutrinos actually have mass. This finding challenged the Standard Model of particle physics, changing our understanding of one of the most abundant particles in the universe.

McDonald has been involved with CIFAR for 18 years, previously as the Cosmology & Gravity program's advisory committee chair and as a member of the Research Council.



Arthur B. McDonald won the Nobel Prize.



Deep Genomics combines deep learning with genome science. Photo: Image courtesy of *Science*

CIFAR FELLOW LAUNCHES DEEP GENOMICS

Senior Fellow Brendan Frey (University of Toronto) launched a startup company, Deep Genomics, which will develop technology to predict how changes in our genome affect human biology and health.

The company is using technology based on an artificial intelligence approach called deep learning, which CIFAR fellows in the Learning in Machines & Brains program have pioneered. Frey, who is appointed to this program and also to CIFAR's program in Genetic Networks, has combined deep learning with new technologies for reading and writing DNA code in living

organisms. One of the company's goals is to understand how mutations in our genomes affect susceptibility to disease.

Deep Genomics' first product, called SPIDEX, provides information about how hundreds of millions of DNA mutations may alter splicing in the cell, a process that is crucial for normal development. Aberrent splicing is behind many diseases and disorders, including cancers and autism spectrum disorder, so SPIDEX has immediate and practical importance for genetic testing and pharmaceutical development. The science validating the SPIDEX tool has been described in the journal *Science*.

ARTIFICIAL PHOTOSYNTHESIS CREATES FUEL FROM SUNLIGHT AND WATER

Inspired by photosynthesis in plants, scientists have built two systems that use sunlight and water to produce fuel – butanol and methane, respectively.

Materials scientist Peidong Yang (University of California, Berkeley), a senior fellow in CIFAR's program in Bio-inspired Solar Energy, has been developing the concept behind these systems with his collaborators for more than a decade.

The first system produces chemicals such as butanol by using semi-conducting nanowires to harvest sunlight and turn it into electrons, then feeding the electrons to bacteria that produce acetate and feeding the acetate in turn to synthetically engineered *E. coli*. Butanol can be used in a standard vehicle without modifying the engine, and when burned it releases less carbon dioxide into the atmosphere than standard gasoline does. However, it is currently expensive and difficult to produce.

In the second system, sunlight and nickel sulfide nanoparticles split the hydrogen from water (H_2O). Then a microbe called *Methanosarcina barkeri* takes in the hydrogen and carbon dioxide (CO_2) and produces methane (CH_4). Renewable methane is useful – methane is the main component of natural gas. But Yang hopes to improve the approach and produce even more complex chemical compounds in the future.

GENETIC SWITCH CONTROLS STRESS-INDUCED INFERTILITY

Chronic stress has long been known to reduce fertility. CIFAR Fellow Daniela Kaufer (University of California, Berkeley) and her colleagues have un-covered the molecular mechanism that causes the infertility. They have also identified a potential target for treatment. The research was conducted in rats.

Kaufer, who is in CIFAR's Child & Brain Development program, worked with UC Berkeley colleagues Anna Geraghty, Sandra Muroy, Lance Kriegsfeld and George Bentley. Their findings show the important role of a neural peptide that controls a number of functions related to fertility.The peptide, called RFRP3, is expressed at high levels prior to puberty, and falls when sexual development begins. The researchers induced stress in female rats by restricting their movements, resulting in high levels of RFRP3 expression, and then letting them recover. Even long after recovery, the rats' RFRP3 levels remained high, and they were less likely to mate, less likely to become pregnant if they did mate, and more likely to lose some embryos if they did become pregnant. The researchers could also reverse the effect by injecting a genetically engineered virus to turn off the gene that produces RFRP3.

Daniela Kaufer explores the link between stress and infertility.

Kaufer says the findings could point to a treatment for stress-induced infertility in humans. The gene and the RFRP3 peptide could be useful targets for a drug.

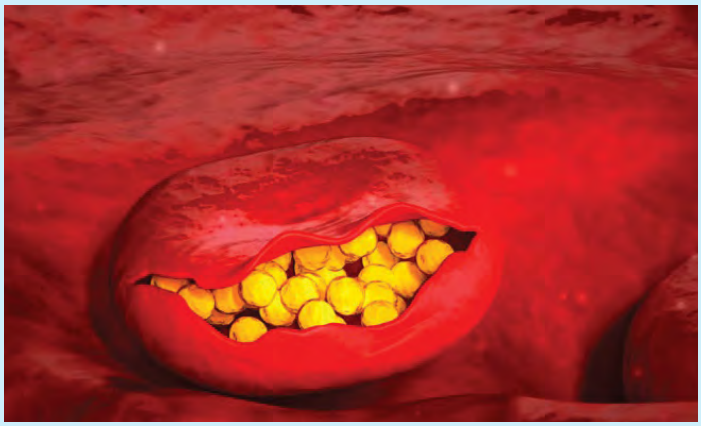
FAST RADIO BURST HINTS AT ITS SOURCE

Scientists have detected a burst of radio waves from six billion light years away, one of a handful they've discovered in the past decade – and this time they have clues about its source.

CIFAR Global Scholar Alumnus Kiyoshi Masui (University of British Columbia) is the lead author of a paper, published in *Nature*, that details the remarkable findings. Masui worked with a team including Ue-Li Pen (University of Toronto), a senior fellow in CIFAR's Cosmology & Gravity program; and Jonathan Sievers (University of KwaZulu-Natal). They analyzed 700 hours of archival data from the National Science Foundation's Green Bank Telescope.

They discovered the burst and found that the region of space it came from was highly magnetized, suggesting that the burst could be related to a recently exploded star – a supernova – or to the gas cloud inside of a nebula forming new stars. Another possibility is that it came from the dense inner regions of its host galaxy.

The finding advances our limited knowledge of fast radio bursts (FRBs), which last only a split second but carry more energy than our sun emits over a few months. Scientists have puzzled over FRBs since they were discovered 10 years ago.



Malaria parasites bursting from red blood cells. Photo: Shutterstock

FROM SYMBIONT TO PARASITE

The group of parasites that cause malaria and toxoplasmosis were once algae, living in symbiosis with other organisms. Researchers have found that these ancestors, called apicomplexans, had all the genetic tools they needed to evolve from symbiont to parasite – from friend to foe – all along.

Apicomplexans use spores to latch onto cells in the host, then reproduce once inside. This may seem like quintessential parasite behaviour, but it isn't, according to Senior Fellow Patrick Keeling (University of British Columbia). They don't harm the host; the two live together in a mutually beneficial relationship.

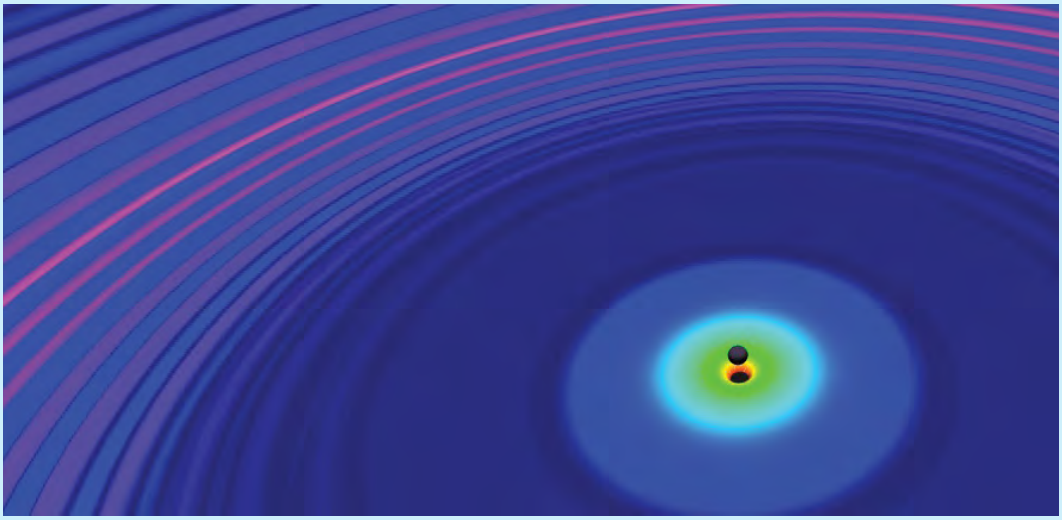
Keeling and his team sequenced parts of the genomes of several benign apicomplexan relatives and compared them with the parasite. They found that all of the genes linked with parasitism exist in the friendlier relatives too, and it was a fairly small and subtle change that gave rise to the parasite.

"The whole system existed long before parasitism. It just got co-opted into being used for parasitism," says Keeling, director of CIFAR's program in Integrated Microbial Biodiversity. The results, which contradict existing textbook theories about the origin of parasitism, were published in *Proceedings of the National Academy of Sciences (PNAS)*.

PARENTS PROTECT YOUNGER CHILDREN, BUT NOT TEENS, FROM STRESS

A parent's presence helps younger children reduce or prevent the activation of the powerful stress hormone cortisol in difficult situations, according to research by Megan R. Gunnar (University of Minnesota), an associate fellow in CIFAR's Child & Brain Development program. However, by the time children are teenagers, the presence of a parent has little or no influence.

The parental role as a buffer against stress hormones is important; it helps kids when they are in stressful situations such as going to a new school or performing in public. Until now, it was unclear how far into childhood the effect would last.



Work by CIFAR fellows helped detect gravitational waves for the first time.

Photo: Courtesy of SXS/CITA/SciNet

Gunnar's team used a stressful public speaking test on two groups of children, aged nine to 10 and aged 15 to 16. The children prepared with the help of either a parent or a stranger. In the younger children, cortisol levels in the saliva were not elevated when they prepared with their parent, although these kids still said they were anxious while they gave their speeches. For the older group, the parents were no more helpful than the strangers for relieving stress.

It's possible that for teens, peers play a more important buffer role than parents do. If so, that would have implications for teenagers who fail to establish close peer relationships.

Megan Gunnar.

GROUP MEMBERSHIPS BOOST SELF-ESTEEM MORE THAN FRIENDS ALONE

Belonging to multiple groups that are important to you boosts self-esteem much more than having friends alone, new research has found.

The researchers worked with groups of school children, the elderly and formerly homeless people in the UK, China and Australia, and found that those who belonged to many groups, whatever their nature, consistently had higher self-esteem. However, this was apparent only when people felt that the groups in question contributed to their sense of who they were – that is, when they were a basis for social identity.

CIFAR Fellows Nyla Branscombe (University of Kansas), Alexander Haslam and Catherine Haslam (both University of Queensland) collaborated with lead author Jolanda Jetten on the research, which compared people's group memberships with the number of friends they had. They found that even a large network of friends did not predict self-esteem, but belonging to multiple groups did. The authors argue that groups provide benefits that interpersonal ties alone do not, such as meaning, connection, support and a sense of control over one's life.

This new study could signal a shift away from thinking about self-esteem as something that comes solely from inside of us. Research on groups is a major theme in CIFAR's Social Interactions, Identity & Well-Being program. The paper was published in *PLOS ONE*.

GRAVITATIONAL WAVES DETECTED

Physicists have detected gravitational waves left over from the collision of two black holes more than a billion years ago, and confirmed a prediction made by Albert Einstein as part of his general theory of relativity.

CIFAR Fellow Harald Pfeiffer (University of Toronto) was part of an international team

called the Laser Interferometer Gravitational-wave Observatory (LIGO) Scientific Collaboration. LIGO detected gravitational waves, which are ripples in the fabric of spacetime that happen when massive objects accelerate in the universe.

Many decades of theory and indirect evidence supported the existence of gravitational waves, most notably through a technique called pulsar-timing used by CIFAR fellows in the program in Cosmology & Gravity, but this is the first direct observation. The researchers concluded the source of the gravitational waves was two black holes orbiting each other and pulling together until they collided and merged into one.

"It is absolutely stunning to see two groundbreaking discoveries at once," says Pfeiffer, "Not only were gravitational waves that were passing through Earth measured for the very first time, but also, the origin of these waves are astronomical objects that have hitherto never been observed."

VISION STARTS WITH A TURBO CHEMICAL REACTION IN THE EYES

CIFAR researchers have discovered that the first molecular reaction in vision generation happens much faster than any previously known biological process.

The first steps of vision take place in specialized cells in our eyes called photoreceptors. The pigment in these photoreceptors is called rhodopsin. When light hits rhodopsin it causes a reaction that changes the shape of the protein, enabling the rhodopsin to interact with other proteins and initiating the visual-signalling cascade that ultimately sends an electrical signal to the brain.

Teams led by CIFAR Senior Fellows R. J. Dwayne Miller (University of Toronto and Max Planck Institute for the Structure and Dynamics of Matter) and Oliver Ernst (University of Toronto) used an advanced type of spectroscopy to study retinal isomerization within bovine rhodopsin. They found that the process takes place in 30 femtoseconds – 30 millionths of a billionth of a second. This appears to represent a molecular speed limit. Previously, the best measurement suggested that it took place in 200 femtoseconds.

A better understanding of these functions could be helpful in creating drugs for conditions such as vision loss, heart failure and epilepsy.

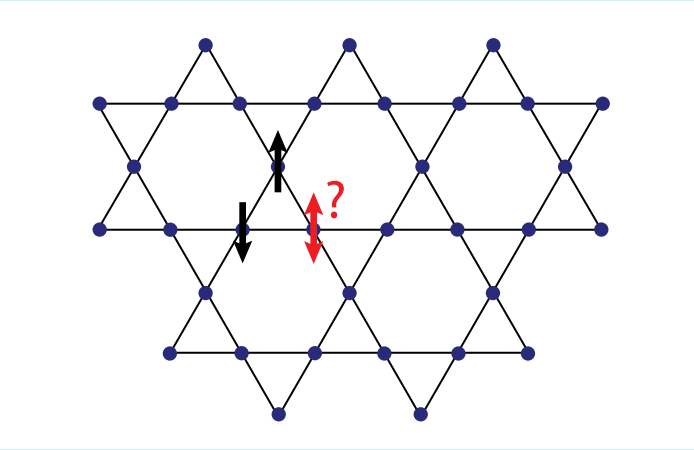
Miller and Ernst co-direct CIFAR's program in Molecular Architecture of Life. The research was published in *Nature Chemistry.*

PATIENCE AND PERSISTENCE LEAD TO EVIDENCE OF A QUANTUM SPIN LIQUID

Physicists have reported the first evidence that a state of matter called a 'spin liquid' exists at a temperature near absolute zero. The findings may advance a new field of study in modern physics and contribute to our understanding of other states, such as superconductivity.

CIFAR Senior Fellow Takashi Imai (McMaster University) and his student Mingxuan Fu published their findings in *Science*.

Spin is the property of an electron that determines its magnetic behaviour. In certain materials at low temperatures, spins tend to align. But theorists have debated for decades whether particular triangular arrangements of electrons could ever prevent the spins from aligning themselves in a stable order. In the proposed fluctuation that would result, spins would alternately attract and repel each other in a 'love triangle,' where no arrangement can satisfy all of the electrons. This is called a spin liquid because of its shifting nature.



Electrons aligned in a 'love triangle' can't align their spins. Photo: Courtesy of Takashi Ima

The challenge was to determine if the spin liquid state existed near absolute zero, the lowest theoretically possible temperature, or if at that temperature it 'froze' into a fixed pattern of spin orientations. To investigate, the researchers used a sample of a copper material called herbertsmithite and nuclear magnetic resonance. What they found was 'smoking-gun' evidence that the spin liquid state exists at this temperature.

KASPI WINS HERZBERG MEDAL

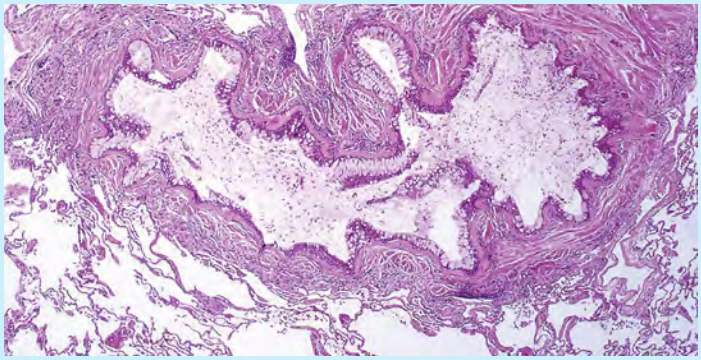
Victoria Kaspi, the CIFAR R. Howard Webster Foundation Fellow, has received Canada's top award in the physical sciences for her far-reaching research on neutron stars.

The Natural Sciences and Engineering Research Council of Canada (NSERC) awarded her the Gerhard Herzberg Canada Gold Medal for Science and Engineering. Kaspi's study of neutron stars – the remnants of enormous stars which have exploded and then collapsed – has increased our understanding of how stars live and die, as well as our understanding of how matter behaves in the extreme conditions of space.

Victoria Kaspi.

"I am profoundly thrilled and humbled to receive the NSERC Herzberg Gold Medal. It is truly overwhelming to think that I am in the same category as some of its previous recipients," Kaspi says. She is the first woman to receive the $1 million research grant.

Kaspi, a fellow in CIFAR's Cosmology & Gravity program for the past 14 years, is the sixth CIFAR researcher to win the Herzberg medal in recent years. Previous recipients were Distinguished Fellow Geoffrey Hinton, Senior Fellow Gilles Brassard, Nobel laureate John C. Polanyi, Program Director J. Richard Bond and Advisor W. Ford Doolittle.



The lung inflammation caused by asthma, shown here, is linked to lack of gut bacteria. Photo: Yale Rosen

MISSING BACTERIA LINKED TO ASTHMA

Children who lack four specific types of gut bacteria at three months of age are much more likely to go on to develop asthma.

Brett Finlay, co-director of CIFAR's new Humans & the Microbiome program and a microbiologist at the University of British Columbia, has published this research with colleagues in *Science Translational Medicine*.

The researchers analyzed the microbes found in the feces of 319 three-month-old babies, 22 of whom would go on to develop asthma by the age of three years. Four specific types of bacteria were missing from the feces of those 22 – *Faecalibacterium*, *Lachnospira*, *Veillonella* and *Rothia*, or FLVR for short.

One or more of the FLVR bacteria may assist in the development of a healthy immune response that protects against asthma – a disease that usually results from an allergic reaction. Most of the children who developed asthma went on to acquire the FLVR bacteria later, suggesting that it needs to be present at a very young age to confer protection.

Finlay and his colleagues also infected germ-free mice with the microbiome from the feces of the 22 children who had later developed asthma. Then they exposed some of the mice to the FLVR bacteria. The mice who did not receive the FLVR bacteria developed asthma-like symptoms, while those who received the bacteria did not.

The work suggests that in the future, treatment with probiotics could protect children at risk of asthma.

ESSENTIAL GENES IN CANCER MAPPED

Scientists have uncovered the set of genes that are needed to keep cells alive. In the process, they have found genes that are important in several types of cancer.

CIFAR fellows Jason Moffat and Frederick P. Roth (both University of Toronto) and their collaborators used the gene editing technology CRISPR to turn off 18,000 genes in human cancer cells one at a time to determine which genes are essential for cells to survive. They found that about 10 per cent of human genes are responsible for keeping cells (cancerous and otherwise) alive and growing.

Performing this experiment on tumours from retinal cancer, brain cancer, ovarian cancer and two types of colorectal cancer, the researchers also found the different and specific sets of genes that allow each type of cancer cell to grow. This has clear implications for drug development. It suggests that drugs could target and knock out the specific genes that drive ovarian cancer growth, for example, stopping the cancer with minimal damage to healthy cells.

The CRISPR technology that facilitated the research has, in the past few years, made it significantly faster to edit genomes.

Moffat is a senior fellow in CIFAR's Genetic Networks program, which Roth co-directs. The findings, published in *Cell*, bring us closer to understanding the purpose of each gene in the human genome.

MACHINE LEARNS TO READ, WRITE AND INVENT 'HANDWRITTEN' CHARACTERS

A new computer model learns to recognize and create handwritten characters just as well as people, and can even invent new characters that look correct to the human eye.

Ruslan Salakhutdinov (University of Toronto), a fellow in CIFAR's program in Learning in Machines & Brains, co-authored a paper describing the research, along with Joshua Tenenbaum (Massachusetts Institute of Technology) and lead author Brenden Lake (New York University). The paper was published in *Science*.

The computer model learned to recognize 1,600 types of handwritten characters in 50 alphabets, including Latin, Greek and Sanskrit. To build it, the researchers used a new framework called Bayesian program learning, which imitates the way people learn – quickly, with few examples and with a flair for creativity.

Bayesian program learning incorporates prior knowledge into the learning of new concepts. Building on that knowledge, it learns to recognize new concepts about writing in other languages, to generate new examples and to develop hypotheses about how characters look. The approach drastically reduces the number of examples needed to learn a handwritten character.

The researchers also tested the model's knowledge by comparing its outputs to people's, and asking judges to tell them apart. Three-quarters of the judges had trouble telling the difference between the computer-generated characters and the human-drawn ones.

Artificial intelligence allowed a computer program to quickly learn handwriting, and even invent characters itself. Photo: Courtesy of *Science*

Childhood well-being

How can research help children overcome adversity and live up to their potential?

PHOTOGRAPHY BY ALANA PATERSON

Top (left to right): Charles Nelson, Michael Kobor and Megan Gunnar.

In November, CIFAR will hold a Forum on the Well-Being of the World's Children, bringing together researchers, institutions and other stakeholders to explore how new research can improve the lives of children.

CIFAR's Child & Brain Development program has been at the forefront of examining the long-term developmental effects of early adversity, and in tracing how early experiences get 'under the skin' in the form of changes to the way genes are expressed.

Reach *sat down with three researchers from the program: Senior Fellows Charles Nelson (Harvard University), Michael Kobor (University of British Columbia) and Associate Fellow Megan Gunnar (University of Minnesota) to discuss what we know, and what we still need to learn.*

Let's start by talking about what research tells us about the importance of the early environment on children and well-being.

MEGAN GUNNAR: The underlying basics are that babies, young children, need the support of caregivers that are responding to their needs, that are feeding them, keeping them warm and responding socially to them.

We have known for a very long time that adverse early life care is really bad for kids. What we are adding now is a material understanding of how it affects bodies and brains. The idea that kids are resilient, they will bounce back, is true to some extent. But the evidence is overwhelming that if we want a healthy population, we need to protect and support our young.

CHARLES NELSON: I think another issue on the genetic side is that many people are still caught up in the old nature-nurture issue. So how do you move them off of that position to explain that you don't have to change the structure of DNA to change how this stuff gets written out?

MICHAEL KOBOR: And how do we then go from having this knowledge that there's a little chemical tag that gets attached to your DNA if you're living in adversity? But how do we bring it to the public and to policy-makers in a way that doesn't freak people out, that's responsible, and that ultimately leads to a change in behaviour?

What have you learned about timing and sensitive periods that have come out of the group and the work that you're doing on child well-being?

MK: What we've learned is that there are critical periods, and they're to some degree malleable in this narrow window of time. The regulatory part of the genome is very malleable and is changing all through development. What I certainly have learned in the context of this group is that changes happen in response to a variety of prenatal postnatal, and early-life environments.

Chuck, can you talk about your experience in Romania and what that taught you about critical periods?

CN: Early on we learned that around the age of two was a critical period for multiple domains – language, cognition, things like that. And now what we're starting to observe is that as the kids get to mid-adolescence, we're not sure we see those critical periods anymore.

MG: My question about puberty is, does it reshuffle the deck? We're a very long-lived species. The environments that we're born into may not be the environments we're in at the time we're giving birth. And it would seem to make sense that we evolve some mechanisms to be able to resample the environment and then reprogram our biological systems to accommodate our updated environment.

If I'm right, what puberty is doing is opening up the development program. It allows it to sort of recalibrate. But if life is still full of horrible things at that time, you'd expect sort of a double whammy.

MK: To me, one of the fascinating questions that I think we're starting to explore is this issue of short-term versus long-term adaptation. To what extent do responses to short-term threats lead to much more long-term adaptation changes?

CN: Let me ask a question about this, using a metaphor: so if you're driving a car on an icy road and you start to turn in the direction of a skid, you make a short-term adaptation. But if you overcorrect, you may go off the road. And so I wonder how far you can deviate for the short term before the short term becomes a long term?

MG: If I'm an adult and a stressor occurs to me, I make these adaptations. I show a deficit for a period of time and I bounce back. I haven't been changing developmentally very much over that period.

But if I'm a young child, I'm continuing to develop, and I'm developing in the context of

Michael Kobor.

the adaptation I made to survive. Because other things are dependent on earlier adaptations, it's potentially going to have a longer-term effect.

What is the research question that's most engaging to you now?

CN: I say individual differences. Why do I have a kid who's been in an institution since birth and who's 16 and has a normal IQ – now the kid has serious mental health issues, but the IQ is fair. But then we have other kids who have IQs of 60, but they're lovely kids. So how do you explain those individual trajectories, mechanistically, not superficially?

MK: I would echo what Chuck says. We have been fascinated by what we can learn from group differences as opposed to individual differences. And how some of the mean differences can be used potentially at the policy phase. But individual differences can teach us much more about the mechanism and the stratification of kids as it relates to resiliency.

MG: Yeah, I'm really interested in understanding the mechanisms that might open up opportunities to reorganize. Hormones regulate genes and shape neurodevelopment, so I am interested in how puberty and its hormones or pregnancy and its hormones open up opportunities to reorganize the nervous system. But other things, like intense exercise, might also open up neurobiological programs. If so, perhaps we can use this information to increase the chance that our interventions will actually take effect. I'm very excited and interested by these questions.

CN: This has implications for personalized medicine. For all three of us, in some ways it's a matter of precision medicine – it's a matter of, can you target interventions?

That's why I was intrigued by your statement that the group differences might inform policy, but the individual differences may inform understanding mechanisms. Can you just talk a little bit about that?

MK: On a population basis we might find we can associate epigenetic changes with particular environments. But that doesn't really help the individual kid; it doesn't inform interventions that might or might not work for each individual kid. When we can zoom in on a view of the individual child, I think then we can start moving toward medical intervention.

MG: I call it the cowlick theory of development. Every kid has their own cowlick, and your job as an educator and a parent is to figure out how to craft the environment that will allow them to shine, to have the greatest hairdo they can have.

So it's really beyond simply precision medicine to precision environment, precision education.

MG: It's figuring out what to do with individual children …

CN: Yeah, rather than one size fits all.

MG: … to create the best environment for them to develop the skills and talents that they have. And Mike Rutter has definitely shown this in the kids that he was looking at, that were adopted from Romania – that the families where the kids did the best were the ones that identified particular strengths of those children. They dealt with the issues they needed to fix, but they identified something that child did well and

helped that child develop that capacity to the fullest, so that there was something that they were very special and wonderful about, whether it be acting or riding horses or whatever.

CN: Let me pose a question to these two. We have a great deal of knowledge. But how would we expedite the rollout of interventions or programs to change the course of development for the better?

MG: I think that's the hardest thing we haven't managed to do. Personally, I think that's what we ought to be talking about at every single meeting – is what does this mean in terms of improving what is done?

MK: And at least I've started thinking about – we've just recently published a paper in the *Canadian Journal of Public Policy* – how could what we know about social epigenetics in child development affect public policy? And it's a hard nut to crack.

MG: Closing that gap is tough.

MK: To what extent do we need to know more before we say, okay, enough is enough? I had a meeting last year actually, and there was a fellow who was one of the people who was pushing this idea that we don't need any more research, we need action. And I disagree.

MG: Well, part of that is true. We know that you should be nice to little kids. We don't need any more research to tell us that. But under conditions where there's a lot of adversity and we can only do so much, can we use our knowledge to figure out what things to do first and how? That's the real challenge.

CN: It's less here, but in the US, as social and financial disparities increase, the amount of effort to reach out and deal with the huge disparity is getting harder and harder. Good relationships are a big deal, but how do you improve them in a family that has so many burdens? And on a global scale, many children are being raised in poverty, or with the effects of war or resettlement.

MG: The trick, I think, is using our understanding to improve what we do to prevent or shift or change negative outcomes. And we haven't gotten very far on that. •

ARTICLE Dan Falk

ILLUSTRATIONS Adam Simpson

The mystery of consciousness

—

Philosophers have struggled for centuries to understand what consciousness is and where it comes from. New scientific tools for studying the brain could finally help answer the question.

According to legend, someone once asked Louis Armstrong to define jazz. He replied, "Man, if you have to ask what jazz is, you'll never know." For years, the puzzle of consciousness seemed equally intractable. As with jazz, there was never any problem recognizing consciousness when confronted with it – in fact, consciousness seems like the most fundamental aspect of our experience. You wake up – boom! – you're conscious.

But try for a precise definition and you run into trouble. Does consciousness simply mean being awake? Maybe not; most of us have had the experience of driving somewhere and arriving at our destination with little or no conscious memory of the trip. And then there's sleep. We lose consciousness when we doze off, yet we're aware of dreams. Are we conscious then? We're not even sure if consciousness is all or nothing, or if we can talk meaningfully about levels of consciousness.

And, maybe most perplexing of all: How does consciousness come about in the first place? How do sensory impressions create not just a neural signal for, say, the colour red, but also a sensation of 'redness'? Why do we have a feeling that it's 'like' something to be ourselves, alive in the world?

Until recently, it wasn't even clear that consciousness could be a fruitful topic for scientific study. Back in the 17th century, Descartes wondered how physical bodies with physical brains could give rise to seemingly non-physical minds. He concluded that body and mind must be two completely separate things. But even for scientists who rejected Cartesian dualism in favour of physical explanations of the mind, the study of consciousness remained problematic. Science couldn't find a way to come to grips with a phenomenon that was so subjective.

The tide began to turn in the early 1990s when Francis Crick (of DNA fame) and his colleague, American neuroscientist Christof Koch, started publishing on the subject. Soon afterward came the first scientific conferences dedicated to the study of consciousness, along with the field's first peer-reviewed journals. Another crucial breakthrough was the development of powerful brain imaging techniques, especially fMRI (functional magnetic resonance imaging), which lets researchers look at brain activity in real time. This gave scientists a tool to examine consciousness that went beyond introspection and verbal reports.

CIFAR's new Azrieli Program in Brain, Mind & Consciousness is tackling the enigma of conscious experience. The program includes researchers from several branches of science, as well as philosophers – not surprisingly, given the complexity of the problem and the interest it holds across a wide array of disciplines, from psychology and neuroscience to physics and computer science.

"Not only is there a debate about the precise shape of a theory of consciousness, people even disagree about who's going to provide it," says Tim Bayne, a senior fellow in the new program and a philosopher who divides his time between Monash University in Australia and Ontario's Western University.

Spot the gorilla

Cognitive science and neuroscience have already provided some insights into the surprising ways consciousness works. Even the seemingly simple act of seeing is a complex act, with much of the processing going on below the level of conscious awareness.

"A lot of cognitive processing is unconscious," says Bayne. "A lot of cognitive states are unconscious; a certain amount of perception is unconscious. And so people are now looking for an account of consciousness which does justice to that fact."

Fifteen years ago, a famous case study by researchers at Harvard and the University of Illinois showed how easily we can 'miss' what's right in front of us. People were asked to watch a video of two teams passing basketballs back and forth, and to count how many times the team wearing white shirts passed the ball. But the researchers had a trick up their sleeves – partway through the video, a woman in a gorilla suit walks through the group, pauses, beats her chest, then walks on. Surprisingly, about half of the study subjects failed to see the gorilla. Or rather, they *saw* it – it registered on their retinas – but their brains failed to raise the signal to the level of conscious experience.

In the gorilla-video study, the subjects were healthy. But people with certain types of brain damage are also unable to 'see' what's in plain view. Ivey Fellow Mel Goodale, co-director of the program and a neuroscientist at Western University, has spent much of his career examining the interplay between different kinds of visual processing and consciousness. A crucial moment came when Goodale was put in contact with a woman known as 'DF.' Exposure to carbon monoxide had left DF with brain damage and impaired vision; she could no longer make out shapes. If Goodale held out a pencil, DF couldn't identify it as such, or tell if it was pointing up and down or side to side. But when she reached out to grab it, her hand oriented itself correctly – every time.

"Her hand 'knew' the orientation of the pencil, even though she didn't," Goodale says.

After more tests with other subjects, Goodale began to understand that the brain has at least two distinct ways of handling visual information. One pathway, known as the ventral stream, is responsible for our visual experience of the world. The other, known as the dorsal stream, is responsible for visual control of limbs and fingers. (The two streams are named for the physical routes they take through the brain.) In DF's case, the ventral stream was impaired – a scan would confirm a lesion – while the dorsal stream was still able to function. Later, Goodale tested patients who had the opposite kind of impairment; they could describe an object, but struggled to pick it up under visual guidance.

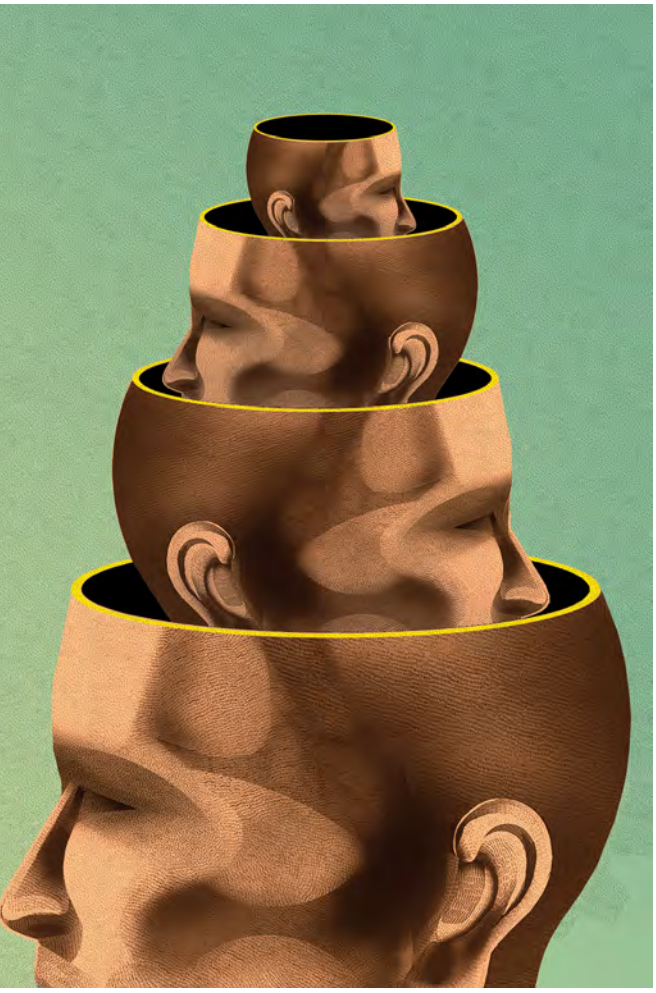
What does this tell us about consciousness? To start with, it shows that different brain systems make very different contributions to conscious awareness. The ventral stream is essential for visual perception, but not for the visual control of fine hand movements. The dorsal stream is vital for visuomotor control, but not for the conscious perception of objects. It could be said that the former stream tracks how we represent

the world in our minds – our mental picture of things – while the latter co-ordinates our movements, based on visual data, whether or not that data is rendered conscious.

No little man

There is still much to be learned about the not-so-simple act of seeing, and matters are complicated by a number of common misconceptions. For example, it's tempting to compare the human eye to a camera, with the retina standing in for the film or digital chip. But the two systems are actually quite different.

"It's not a picture; it's not even a video," says Goodale. "It can't be something that's 'displayed' in our head, because who's looking at the picture?" (The old idea of a homunculus – a figurative 'little man' – in the brain is obviously problematic; after all, who would be viewing the picture in his brain? An infinite regress is inevitable – and not very helpful.)



Neuroscience has made progress, Goodale says, but "how the brain delivers up this experience that we call vision is still a great mystery. We'd like to know how the brain actually ends up delivering the experience of that colour, or that shape. We don't have a handle on that yet. You might say that's the *raison d'être* for the Brain, Mind & Consciousness program at CIFAR. These are hard questions to grapple with, but they're questions we shouldn't shy away from."

Theatre of the mind

Clearly, the human brain is a busy place. Signals flow in many directions at once; different brain regions are called on to perform different functions, sharing information in some situations and keeping it 'local' in others. The crucial point is that not all of the information produces conscious experience. Most of it seems to pass under the radar, with only a small portion rising to the level of conscious awareness. Science wants to know which bits of information rise to this level – and why.

In the late 1980s, American neuroscientist Bernard Baars put forward an idea called global workspace theory, which aims to answer this question, and also to explain how conscious and unconscious brain processes relate to one another.

The theory's central metaphor is a theatre: the mind a darkened stage with only a small area in the spotlight at any one time. (The "spotlight of selective attention," Baars called it.) Countless brain processes – equivalent to the playwright, director and so on – play a crucial role in determining what gets illuminated, though they themselves remain in darkness. According to the theory, any information that is successfully shared across multiple brain regions has to be stored in memory long enough for the sharing to take place, and has to be made 'globally available.' Certain bits of information – those that are the most salient and useful – make their way into the spotlight.

To its proponents, the theory seems to illuminate the 'self' – the singular 'I' that emerges from the underlying chaos of information flow. What the spotlight picks out, according to Baars, is the mental space "in which we carry on the narrative of our lives."

"Any information that is successfully shared across multiple brain regions has to be stored in memory long enough for this sharing to take place."

Senior Fellow Stanislas Dehaene, a neuroscientist at the Collège de France, read about Baars's work and was deeply influenced. Dehaene has devoted much of his career to determining how the brain shares and stabilizes information across multiple regions – and why only some of this requires consciousness.

"Consciousness is a selective system," he says. "Out of the thousands of processing streams that are occurring at a given moment, it selects one of them and it amplifies this information so that it becomes the focus of our conscious thoughts."

Mental tennis

For most of us, consciousness is like an invisible friend – a companion who follows us around from the time we wake up in the morning to the moment we go to sleep. But for people with certain kinds of brain damage, that companion seems absent, or nearly so. In the neurology literature, such people are said to be in a 'vegetative state.' This is not quite the same as being in a coma, explains neuroscientist Adrian Owen, the other co-director of the program and

the CIFAR Koerner Fellow. Coma patients are completely unresponsive and appear as though asleep. Vegetative patients have sleep-wake cycles, can make occasional movements and can yawn and sneeze. But they don't respond to verbal commands. As Owen puts it, they appear to be "awake but unaware." ('Minimally conscious' patients have a slightly higher level of awareness and may occasionally be able to respond to commands.)

Owen, who came from the University of Cambridge in 2010 to take up a Canada Excellence Research Chair at Western, spent his early career using brain imaging to study Parkinson's patients. Then, in 1997, he heard about a 26-year-old woman who was left in a vegetative state after a viral infection. Owen put her in a brain scanner, and showed her pictures of faces, both familiar and not. When she saw a familiar face, the part of her brain known as the 'fusiform face area' lit up – just as it does in healthy subjects. The woman improved over time, and can now get around in a wheelchair.

A few years later, Owen had another breakthrough. Once again the subject was in a vegetative state – a woman who had been unresponsive since a traffic accident five months earlier. Again, Owen used a brain scanner. He asked the woman to imagine playing tennis, and then to imagine walking through her house. When healthy subjects imagine playing tennis, they show activation of a brain area called the supplementary motor area. And when they think about tasks that involve spatial navigation, like walking from room to room, they use a region called the parahippocampal gyrus, near the centre of the brain.

Remarkably, Owen's subject showed the same response as healthy subjects do. Soon Owen was using the technique to allow patients like her to communicate – tennis for *yes*, house-navigation for *no*. It was painfully slow, but it worked (and made headlines around the world). Owen estimates that as many as one in five vegetative patients has some level of awareness, and would be able to communicate through the 'playing tennis' technique.

> "I don't think we understand everything about every level of consciousness, but we do know that there are some vegetative patients who are entirely conscious."

"I don't think we understand everything about every level of consciousness," he says. "But we do know that there are some patients diagnosed as vegetative who are entirely conscious. They're very aware of who they are, where they are, how long they've been there, what has happened to them in their lives."

Aside from having real-life implications for brain-injured patients, Owen's work serves as an interesting contrast to that of Dehaene, whom Owen describes as taking a "top-down" approach to consciousness, in contrast to his own "bottom-up" approach. Rather than trying to construct a top-down theory of how consciousness works, Owen is trying to zoom in on its most essential features – what actually has to be happening in the brain for consciousness to arise.

In the end, the top-down and bottom-up approaches may prove complementary.

Consider the workings of an orchestra. You need the conductor to oversee the whole affair, to make sure everything is in synch. But you also need the individual musicians to produce the notes. Neither job is more important than the other.

The hard problem

One major puzzle remains unsolved: How do neural processes, however complex they may be, yield the subjective feeling of being conscious? Why should neural activity feel like anything at all? This puzzle received renewed attention in the mid-1990s, when philosopher David Chalmers dubbed it the 'hard problem' of consciousness. He distinguished it from the easy (or at least easier) problems of linking certain neural processes to certain kinds of perception – the type of bottom-up work to which scientists like Owen and Goodale are contributing.

Bayne, the Monash/Western philosopher, says he sometimes sympathizes with this skeptical 'hard problem' view – that there really is a deep explanatory gap, one that won't go away no matter how much understanding we gain of neural processes. Both Dehaene and Owen, on the other hand, say they're more inclined to the opposite view – that once we understand the neural processes which underlie consciousness, there won't be any mystery left.

"I'm not a great believer in the hard problem." Dehaene says. The current approach of cognitive neuroscience – attempting to build a theory of consciousness based on computational models of brain activity, and on the numerous 'easy problems' that researchers have begun to illuminate – might be enough to explain the mind.

This view has been championed by others, including Tufts University philosopher Daniel Dennett, an advisor to the program.

Adrian Owen is in full agreement: "I think if we can truly understand how the brain works, any 'hard problem' will just disappear." Consciousness, he suspects, "will just be something that the brain produces – just a product of the extremely complex organ that we have in our heads."

Much work remains, though, even if the hard problem *isn't* an insurmountable obstacle. For one thing, the so-called easy problems are extraordinarily daunting, as scientists struggle to discern the detailed workings of sensory perception, memory, language, emotion and more. Then there are the puzzles associated with the brain's ability to integrate all of this neural processing, producing a unified 'self' from the multitude of neuronal traffic.

"As a neuroscientist, the only place I can begin is studying solvable problems," says Mel Goodale. "But that's how scientific progress works. And that's how we'll make progress on solving consciousness." •

CIFAR fellows conducted research dives at coral reefs off the coast of Curaçao to gain a better understanding of microbial communities. Photo: Patrick Keeling

ARTICLE **Anne Casselman**

Healthy Oceans

—

New understanding of microbial life could help us heal coral reefs and even give insight into how the oceans help regulate the world's temperature.

Right: Integrated Microbial Biodiversity Co-Director Patrick Keeling examines the surface of a coral reef. Photo: Claudio Slamovits

Last April, Patrick Keeling and Forest Rohwer were driving back to their hotel after a long day of diving off the Caribbean island of Curaçao, as part of a CIFAR Integrated Microbial Biodiversity field trip. As they chatted with the director of the local research station, Mark Vermeij, they had a brainstorm: they were in a position to quickly collect samples of every single species of Caribbean coral, along with the associated microbial communities that help to sustain them. By dinner the next day, they had 50 samples.

"That's the kind of thing you can do on the fly with a group like that, that you could never do by yourself," says Keeling, director of the IMB program and a microbiologist at the University of British Columbia.

The fellows had organized the trip specifically to study protists, a group of microorganisms that are profoundly important for the health of coral reefs and of oceans in general. Protists even play a major role in the Earth's carbon cycle, which has serious implications for climate change.

"The last 10 years has been the age of discovery in microbiology, and in my opinion the protists are the last frontier of that," says Rohwer, a senior fellow in the IMB program and a marine microbial ecologist at San Diego State University. "We're right at that edge where we don't really know what's going on, and so we're finding things out."

Protists are major contributors to ocean productivity and marine food webs. But much about their ecological role in the ocean remains unknown, and their contribution to carbon and nutrient cycles remains unquantified. Understanding protists better will allow us to create more accurate models of global climate change, which has serious implications for the future health of our planet.

Well aware of the knowledge gaps – and of the urgency to narrow them as global change stresses marine systems – many of CIFAR's IMB fellows are studying marine protists. They are using a combination of field research and dogged lab work, aided by innovative biomolecular tools and techniques which, often, they're developing and beta-testing as they go.

Eyeballs and harpoons

Protists are defined more by what they aren't than by what they are. They are eukaryotes (that is, organisms whose cells contain a nucleus) which are not animals, fungi or plants. Some familiar protists are amoebae, algae, slime moulds and dinoflagellates. Others verge on the outlandish. Some species have evolved a poisonous harpoon to capture prey. Another contains a unicellular eyeball, complete with a lens and retina. Some are photosynthetic, others are predatory; many even switch back and forth.

In other words, despite being single-celled (mostly) and tiny, protists often inhabit ecological niches that we're used to seeing in terrestrial ecosystems. There are hunters, photosynthesizers and grazers. And there are protists that defy categorization: hunters who can also be grazers and hunters who are also like plants.

Researchers know that protists play critical roles in marine ecosystems. For instance, phytoplankton form the base of marine food webs and are responsible for transporting atmospheric CO_2 into the deep ocean. Other protists play huge roles in the ecology of microbial sea life through predation and parasitism.

But protists have remained relatively understudied and largely uncatalogued, largely because they're the hardest micro-organisms to isolate and investigate. Despite their outsized role in marine microecology, they are not numerically abundant. Also, they are hard to culture in the lab, and extremely complex at the levels of structure and behaviour; bulk DNA sequencing of seawater doesn't tell biologists much about their life strategies.

Also, unlike zoologists studying lions, microbiologists cannot yet tag a single cell in the ocean, track its whereabouts and study its behaviour – although this is something IMB

Left: CIFAR fellows handle an invertebrate they collected during a research dive. Photo: Gordon Lax

investigators are working on. More sensitive and innovative methods are required to understand how protists interact with and influence the marine environment.

Biologists focus their efforts on certain model ecosystems to infer and extrapolate how protists function in the oceans. And they have been testing new field techniques perfected for the microscopic, invisible wild.

Hot spots

The field trip to Curaçao was in partnership with CARMABI, the Caribbean Research and Management of Biodiversity Foundation, which runs a research station on the island.

"We were doing some of the first general surveys of what was there to start with," Keeling says. Coral reefs are known hot spots of microbial and fish biodiversity, hosting over one quarter of the world's fish species. But no one had really looked at their protist diversity before.

"We know that coral reefs are changing, and we know that they're threatened. But how can you say what that effect is going to be if you don't know what they're like to start with?" Keeling asks. "You have to figure out what they're *supposed* to be like before you can actually start to monitor how they're changing."

Over half of the world's corals are predicted to be affected by climate change as rising sea temperatures bleach corals and ocean acidification compromises their ability to build skeletons. During the 1998–1999 El Niño event, 20 per cent of the world's reefs were lost to high water temperatures. And another global coral-bleaching event is currently underway, projected to impact 38 per cent of the world's corals and kill over 12,000 square kilometres of reefs.

"We see major changes going on in the Arctic, and again in corals. If we don't understand the system as it exists today, we won't have a baseline against which we can measure change," says Senior Fellow Alexandra Worden, a senior scientist at the Monterey Bay Aquarium Research Institute and adjunct professor at UC Santa

CIFAR

GORDON AND BETTY MOORE FOUNDATION

CIFAR AND THE GORDON AND BETTY MOORE FOUNDATION

—

CIFAR and the Gordon and Betty Moore Foundation are combining efforts on research that will lead to better understanding of marine microbiology and the health of the oceans.

As part of a larger collaboration between CIFAR and Moore, researchers in CIFAR programs, including Integrated Microbial Biodiversity, are working with the Moore Foundation's Marine Microbiology Initiative. The two organizations are creating joint workshops to explore the complexity of microbial life in the oceans and its importance in marine microbial ecology and evolution. Workshops will cover areas such as the mechanisms of chemical signalling, persistent viral infections and the microbial communities associated with marine fauna, among others.

The joint venture builds on strong existing relationships between the two programs. Many members of the IMB program are also heavily involved in Moore Foundation-funded research.

"We work really well together," says IMB Program Director Patrick Keeling. "IMB is working with them more and more, both in helping guide research program directions, informally and as members of panels, and also leading teams funded by Moore. This has been a great success."

Right: A student collects samples during a dive. Photo: Emma George

Cruz. "So it's key that we get right on it, in a way that brings together the right people and approaches, and lets go of disciplinary or political boundaries in how we look at ecosystems."

The CIFAR fellows are especially interested in the interaction among protists and the bacteria, as well as the phages and viruses that infect bacteria and protists, all of which live in the coral communities.

"We're really trying to figure out this interface – not just between the coral, the phage and the bacteria, but also the coral and the phage, the bacteria and the protist," says Rohwer. His research has already revealed how bacteria and their phages can cause disease in corals, but can also provide corals with a kind of proto-immune system, protecting them against harmful pathogens.

Corals rely on a symbiotic relationship with a protist that lives inside their tissues – a photosynthetic alga called zooxanthellae. Like a plant, this alga can convert sunlight into energy, but also drives the chemical production of coral skeletons from CO_2 and provides the coral with nutrients. If the water gets too warm, corals lose their algae and they bleach. If they're lucky, the corals might acquire new zooxanthellae that are more tolerant of higher temperatures, and thus adapt. In other words, microbes may be one of the keys to the adaptability and survival of corals in the face of environmental change.

Rohwer points out that corals are one of the oldest types of animal on the planet. They've survived the past 200 million years, and their interactions with microbes may be why. At the same time, disrupting the balance of coral-reef microbes can kill corals.

"Corals are a tight community of microbes and the coral, and when you start disrupting any part of that community, you could kill the whole thing," says Keeling. Tiny interactions at the microbial level can have far-reaching consequences across a coral reef. By the same token, larger-scale human activities can affect the tiniest of microbe interactions, upsetting the balance.

For example, human overfishing reduces the number of fish that are eating algae in a coral-reef ecosystem. This increases the amount of algae on the reef, which increases the amount of bacteria, which can cut off the corals' oxygen supply and kill them. Examples like this highlight the importance of figuring out the role that protists play in coral health and disease at the microbial level, in addition to the other microbial players.

"I think the field is recognizing that you can't just take one or two elements [like bacteria or viruses] and try to understand an ecosystem with it," says Worden. "If you're going to understand the demise of the frogs in the rainforest, it actually isn't just about the frogs. You have to get all the different players and study what changed in their interactions. So I think that's where the approach of the IMB project has the possibility for very different findings."

Carbon cycling

Protists play a major role in the important ocean carbon cycle, in which carbon moves between the atmosphere and the ocean. Marine algae – which are photosynthetic protists – remove about 50 gigatons of carbon from the atmosphere each year, which is more than all terrestrial plants do.

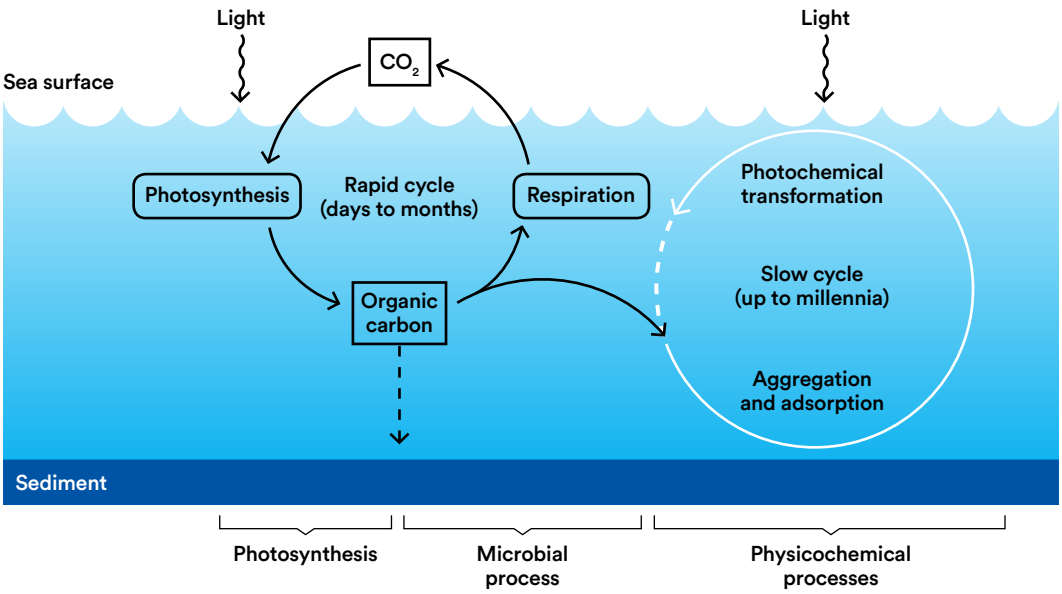
"Protists are massively important for regulating our climate," Worden says. "But they have this complexity in their behaviours and a lot of other facets that you don't expect." The sheer diversity of protistan behaviours makes it difficult to predict how the warming of the oceans will affect them.

"I think we have been treating them in this really simplistic way, like something akin to bacteria where you're going to have a relatively defined role, and it turns out they're a lot more complex than that," Worden says. Protists not only create energy through photosynthesis – they're also part of the process that moves energy up the food chain.

To increase the predictive power of global climate models, Worden says it is key that we understand the behavioural and biochemical intricacies of protist life and of their interactions with other microbes. "That will be incredibly valuable for getting toward more predictive climate models."

Parasitologist Jan Votypka.
Photo: Gordon Lax

The ocean carbon cycle is massive and complex. Light drives a carbon cycle that utilizes respiration and photosynthesis, to which microbes are a major contributor. This short-term cycle also feeds into a longer-term cycle. Studying microbial interactions is helping us understand both cycles better.



Not just bags of genes

Protists' complex behaviours make them especially hard to study using standard techniques. As Worden says, they aren't merely a "bag of genes." You can't simply sequence the genes of a protist and understand how it fits into the microbial ecosystem, just as you can't sequence an eagle's DNA and know that it flies and hunts salmon.

"It's going to take a lot of really hard biology, because protists are really interesting at many different levels," Keeling says.

It's not surprising that a group of organisms so complex requires interdisciplinary teams and some seriously creative lab and fieldwork. The tools the IMB group took to Curaçao included a pocket-sized DNA sequencer, capable of sequencing the full genome of small organisms. It was especially useful in studying protists, which are incredibly tricky to culture. Often, the only window to understanding their behaviour or physiology is to observe them live in the field. Hence, the importance of developing new, sensitive field approaches to study them in situ, or very near in situ.

Keeling's lab has spearheaded methods such as single-cell transcriptomics, which allow scientists to pick up a single protist cell and sequence all of the genes it is expressing at any one time. They were able to beta-test the techniques in the field at Curaçao, and plan to do more in another field trip to the island this spring.

"If you do it under a microscope, you can watch the protist, take movies of it, take pictures of it, so you know what it is, and then you can pick it up and get all its genes," Keeling says. "So we're going to be doing a lot of that in Curaçao." His lab will also be taking a mini-PCR machine, used to amplify DNA segments.

"It is complicated, but we have the tools nowadays," says Rohwer, who will be packing his pocket-sized DNA sequencer again this year. "Ten years ago we wouldn't have been able to figure out the interface between coral, phage, bacteria and protists. But now we can." •

The secret of our success

ARTICLE Bob Holmes

In 1845, Sir John Franklin set off with two fully equipped ships in search of the Northwest Passage. Three years later, icebound in the Canadian high Arctic and unable to figure out how to keep warm or feed themselves, the remnants of Franklin's expedition starved to death. They died in an environment the Inuit had occupied comfortably for generations – so comfortably, in fact, that a nearby bay was known locally as *Uqsuqtuuq* ("lots of fat").

Franklin's men were mostly young and healthy, well-equipped with the latest European technology, and had no children or old people to support. Yet over their three-year ordeal they failed to learn how to survive. Why?

The answer, according to Joseph Henrich, is that they lacked something the Inuit possessed: a package of adaptations for Arctic living that evolved culturally over thousands of years. The Inuit knew how to hunt seals, find fresh water, make snow houses, heat them with seal-oil lamps and perform a thousand other skilled tasks far too complex to work out in a single lifetime.

The story of the Franklin expedition illuminates a key fact about humans and our success as a species. We survive and thrive not because of our individual adaptability and intelligence, which are rather over-rated. Instead, cumulative cultural evolution is what makes us so successful as a species, and is the key to understanding how evolution has shaped our anatomy, physiology and psychology over the last few million years.

"Our species' immense ability to adapt to diverse environments and develop large bodies of know-how is due to our unique ability to learn from others, not to our raw brainpower," says Henrich, who is a senior fellow in CIFAR's Institutions, Organizations & Growth program and holds appointments in Harvard University's Department of Human Evolutionary Biology and at the University of British Columbia.

"Our intelligence alone isn't the whole story, or the most important part of the story," he says. "We need the cultural knowledge." Henrich develops these ideas further in a new book, *The Secret of Our Success*, published in 2015.

Captain Sir John Franklin, left, perished with 128 officers and crew after they became trapped in the ice off of King William Island.

Previous: an artist's conception of the expedition abandoning one of their ice-bound ships.

Not as smart as we think

Henrich likes to point out that of all the mental skills, social learning is the one where humans excel most compared with other species. Researchers have recently shown that chimpanzees and orangutans do almost as well as human toddlers in tests of spatial reasoning, tool use, understanding causality and estimating quantities. In other studies, chimps compare well – even with adult humans – in tests of working memory, information-processing speed and simple strategic-game reasoning. But when it comes to watching and imitating others – social learning, in other words – we humans leave our simian cousins in the dust.

We're not the only species to practice social learning, of course. Chimps do learn from one another, too, as do a few other species, such as orcas. But at some point in our evolutionary past, ancestral humans got so good at social learning that cultural knowledge began to accumulate from one generation to the next, so that the whole process began to snowball.

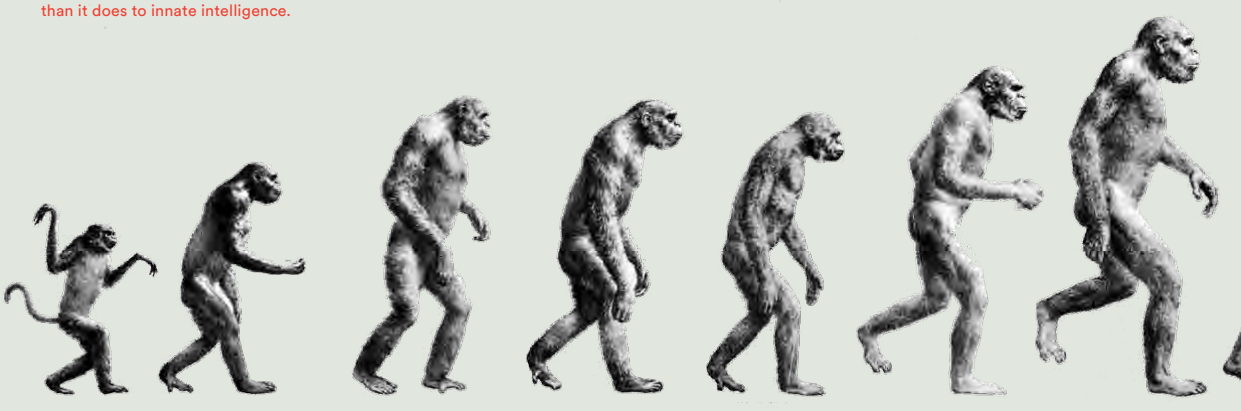
This changed the evolutionary game. Suddenly, the ability to acquire this expanding body of cultural knowledge became the most important skill of all. Any adaptations that improved cultural learning – such as an innate tendency to imitate others – were therefore favoured by evolution. This, in turn, helped cultural knowledge accumulate more quickly, making this kind of learning even more valuable – a self-reinforcing cycle.

One way to learn more effectively is to imitate the right people. If you want to learn to hunt, tag along with a successful hunter. If you want to learn to cook, help a skilled cook. Skilled and successful models have what is called 'prestige' – a new form of status, almost unique to humans, that is based on knowledge and ability rather than raw physical power. Humans have evolved to instinctively imitate prestigious individuals. (This explains why car companies and insurance companies pay famous athletes millions of dollars to endorse their products – we tend to copy what they do, even outside their field of expertise.)

As cultural evolution progressed, our ancestors' environment became more and more defined by cultural adaptations such as fire and tools. This, in turn, began to shape the physical adaptations of our species. "That's been a kind of duet, a kind of dance, with our genetic evolution for hundreds of thousands of years," says Henrich. "What we are can only be understood by understanding the pressures that culture put on our genes."

Consider our anatomy. Our jaws and teeth, for example, are much smaller and weaker than those of chimps and gorillas. Almost certainly, that's because we have developed the package of

The ascent of humans owes more to our ability for social learning than it does to innate intelligence.



cultural adaptations known as cooking, which makes food quicker and easier to chew. Look also at our efficient bipedal gait, hairless bodies and copious sweat glands. These are best understood as adaptations for pursuing prey animals to exhaustion in warm climates, a technique that some hunter-gatherers still use today. But this hunting strategy works only if the hunters have the cultural knowledge to track individual animals for long distances, and to find or carry water during the long pursuit – a clear case of cultural adaptations feeding back to affect physical traits.

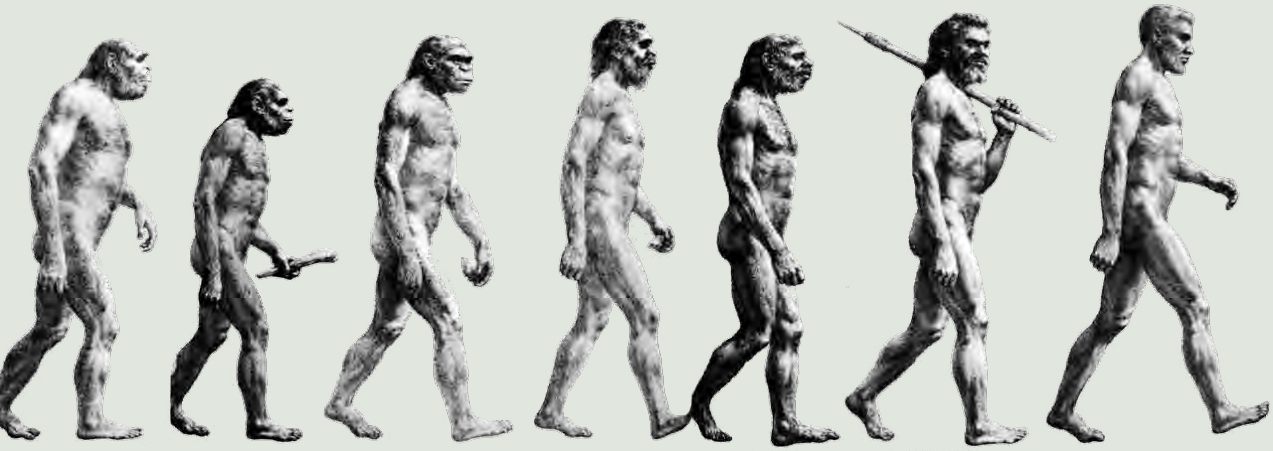
The process for detoxifying manioc root isn't obvious, but has been determined by trial and error and then passed down through many different cultures.

Useful taboos

Over time, cultural practices that help people survive gain widespread adoption, even when the reasons for them might not be obvious. In Fiji, for example, where Henrich has done fieldwork, taboos prevent pregnant and breastfeeding women from eating certain types of reef fish. None of the women know why – it's just taboo. But Henrich and his wife Natalie later found that the taboo covered precisely the fish species most likely to carry ciguatera toxin, which is apt to harm fetuses and infants.

Similarly, cultures in the Amazon process manioc root, a staple food, through an intricate, multi-step process that involves scraping, grating, soaking and boiling the roots, then letting them stand for two days before eating. All of this is crucial because it prevents poisoning from high levels of cyanide in the unprocessed roots. To the people themselves, though, it's merely what they've always done. Few have ever seen cyanide poisoning, because no one deviates from the cultural practice. In effect, says Henrich, the culture itself is smarter than the people in it.

The same is true, of course, of our own culture and its practices. Take our strong preference for monogamous marriage, for example. Most of us accept the norm, but few can explain



why, other than to say, "That's the way it is." Actually, there's more to it. "When you analyze normative monogamy, you find out it's doing some functional work," says Henrich. Monogamy fosters social harmony by providing most adults of both sexes with a mate, and this may have helped our set of social norms survive over many generations.

From engineering to the Amazon

Cultural differences like these, evolved over time by particular cultures, are what attracted Henrich to this area of research in the first place. He originally trained as an aerospace engineer, but his interest in anthropology led him back to graduate school and to fieldwork among the Matsigenka tribe in the Peruvian Amazon. There, he was struck by how unwilling the Matsigenka were to work together for the common good in tasks such as cutting grass. He began to wonder if this reflected a different set of learned social norms. To test this idea, he asked them to play the ultimatum game, a favourite tool of economists.

In the game, one player is given a sum of money and told to divide it with a second player. If the second player accepts the division, each gets to keep their share; if the second player refuses, neither gets anything. Rationally, the second player should accept any offer, since even a small amount is better than nothing. But people from Western societies almost uniformly reject anything much less than a 50:50 split. This reflects our societal idea of fairness. In contrast, none of the Matsigenka ever rejected an offer, no matter how small. They had learned a different set of norms, and thus weren't culturally primed to expect a fair split.

This got Henrich thinking. Back in North America, he took a year away from his graduate research to read not just about anthropology, but also economics, sociology, psychology and evolutionary biology.

"I was interdisciplinary from the beginning, because I wanted to explain the economic decision-making of these people in Peru," he recalls. He even drew on his aerospace engineering training, which helped him understand the sophisticated mathematics of evolution with both genetic and cultural inheritance. He found a rich lode in the intersection of all these fields, and has now been developing his ideas for nearly two decades, often using economic games to compare social norms across societies.

Henrich's work is a perfect fit for CIFAR's program on Institutions, Organizations & Growth, which seeks to understand why some societies are more successful than others.

"People like Joe are really key to our work," says Program Director Torsten Persson, an economist at Stockholm University. "A multi-faceted approach to understanding societies brings richness to the discussion." In particular, Persson points to Henrich's cross-social survey of economic games. "That's a good example of how different contexts produce different behaviours. It makes all of us think about the importance of cultural context."

The collective brain

In essence, Henrich's position is that it's better to be social than to be smart: the vast majority of our knowledge comes from other people, not from figuring things out on our own.

"We rely on a collective brain," he says. "The larger and more connected a population, the more technologies it can produce." Isolation leads to cultural and technological poverty, as illustrated dramatically by the Aboriginal Tasmanians. After rising sea levels isolated them from the mainland, they gradually lost the knowledge of bone tools, stone spear points, fishing, fitted clothing and almost everything else, ending up with the simplest tool kit known among modern humans.

Going much further back, it may have been isolation that did the Neanderthals in. Based on brain size, Neanderthals were probably slightly smarter than us, at least in raw processing power. But they lived in small, widely scattered groups in ice-age Europe. Henrich hypothesizes that they probably lacked the large collective

An 1879 depiction of a Tasmanian islanders. Tasmanians were cut off from the mainland they gradually lost learned skills, including the ability to make fire and fitted clothes.

brain that allowed our more social African ancestors to evolve better cultural packages.

Modern humans stayed connected, and their technologies and genes continued to co-evolve. That brings us to today, when we routinely connect more quickly to more people and ideas than our prehistoric ancestors could have imagined. And that's a good thing, since it allows our collective brain to be exposed to more ideas, more ways of doing things. "If you buy the collective brain," says Henrich, "then infusion of new ideas brings large benefits."

And he says we're probably not done changing yet. Our technology will continue to interact with our genes in ways we can't necessarily predict. Cooking gave us easier access to the energy content in food, and reduced the size of our guts and teeth. It's hard to tell what the advances in communications technologies will do to our brains and bodies, but it seems likely that the changes haven't stopped.

"Genes and culture evolve together," Henrich says. "Culture has always driven evolution. We should expect that to continue to happen."

Circles in the sky

This mid–20th-century woodcut based on 19th-century mathematics provides a surprisingly accurate illustration of how our universe may have begun.

Illustration showing that the apparent crowding and shrinking of the figures at the edge of the disk disappear when the figures are projected onto a hyperboloid.

Right: A detail from M.C. Escher's *Circle Limit IV*.

The inflationary theory of the universe, developed by cosmologists including Senior Fellow Andrei Linde (Stanford University), says the universe expanded exponentially for a fraction of a second after the Big Bang, then slowed and grew into the relatively flat, uniform universe we see today.

The inflationary theory explains aspects of the universe, such as why matter clumps together into galaxies, but questions remain about exactly how to model the way the expansion took place.

Linde and CIFAR Associate Fellow Renata Kallosh (Stanford University) have found that one class of models aligns closely with observational data. These models, called cosmological attractors, also have a deep mathematical relationship with a geometric model of a hyperbolic plane known as the Poincaré disk. One of the best representations of the Poincaré disk is almost as beautiful and simple as the inflationary theory itself – the artist M.C. Escher's *Circle Limit IV*.

Escher, known for his infinite staircases and other mind-bending illustrations, created a series of *Circle Limit* woodcuts that represent infinity. In this one, rings of angels and devils become smaller and smaller as they move from the middle of the circular frame toward the outer edge, where they become crowded and infinitesimally small. In fact, the image shows perspective: they are all the same size, appearing to shrink with the distortion of space.

In a recent research paper, Linde and Kallosh described how a calculation based on the geometry of the Poincaré disk represents the amplitude of gravitational waves in cosmological attractor models.

"That is how inflationary theory, mathematics and art joined forces to explain cosmological data in a rather unexpected way," Linde says. •


MCE
VII-'60

Knowledge you can act on

CIFAR's new IdeasExchange platform connects researchers, change makers and innovators to drive change in society.

PHOTOGRAPHY BY KAREN WHYLIE

Upper right: Maureen Fair, executive director of the West Neighbourhood House. **Bottom:** Axelle Janczur, executive director of the Access Alliance Multicultural Health and Community Services.

Ending poverty was at the top of Lucenia Ortiz's mind when she attended a CIFAR event about the power of groups and social connections to improve well-being in communities. Ortiz is a planner in community services with the city of Edmonton. She left the event that day with new ideas, which she has since incorporated into a strategy called EndPoverty Edmonton.

Ortiz's new understanding of social identity – how people define themselves based on the groups they belong to – helped her team develop a recommendation to shift attitudes about poverty in Edmonton, starting in neighbourhoods.

"Changing the conversation was really about building a movement, which is really in itself a collective undertaking. Building a movement is about being able to build group identity on a wider scale," Ortiz says.

The event that changed her thinking was called "Social Identity: the creative power of groups to improve community well-being." It was part of CIFAR's Change Makers dialogue series. The event was just one example of how CIFAR connects experts in our research networks with social innovators, business leaders, policy-makers and practitioners who care about healthier, stronger communities in Canada and around the world.

This innovative platform for knowledge sharing is called IdeasExchange. The idea behind it is that the world's supreme challenges will only be solved when leaders across sectors are given the chance to talk to each other, exchange ideas and move forward together.

CIFAR launched IdeasExchange in 2014 with leadership support from its Major Platform Partner the RBC Foundation, which works with CIFAR to advance research in economic growth, human development, strong societies and child development.

IdeasExchange develops tailored meetings, forums, talks and other events that help decision-makers understand and solve problems. It aims to build bridges between people who are doing cutting-edge research and practitioners who are dealing with issues on the ground.

And the insights flow both ways: researchers gain valuable perspective from professionals on the ground who are working to end poverty, improve health and solve other challenges.

For instance, a recent Change Makers event called "Researching with Communities" was designed to help communities become partners in the research process, enabling them to help conduct the research and also benefit from its results. CIFAR Senior Fellow Philip Oreopoulos (University of Toronto) attended the event. While there, he discussed with community leaders the idea of developing a collaborative website – a site where organizations can post ideas for research projects and academics can search for research opportunities that match their interests.

"There is a missing market here, and I have been pursuing the idea," he says. "I think it could be very fruitful."

Future Change Makers events will focus on exploring issues relevant to broader society, such as how to create more inclusive societies in light of rising inequalities; and how our understanding of early life experiences and individual vulnerability can help us to develop better interventions for at-risk children in school environments.

Since CIFAR launched the IdeasExchange platform, it has connected 1,340 people with its research. Surveys show that a large majority of those who attend the events find them useful and start using the ideas immediately.

The IdeasExchange platform includes an online component as well, with a website that has been redesigned to serve as a knowledge hub. Visitors can follow CIFAR's progress and access CIFAR knowledge through a number of avenues, including papers and articles, timelines of key developments and links to videos by CIFAR researchers. Searches can be made by keyword, subject of interest, program or individual researcher, and the site continually makes new recommendations according to areas of interest. •

See CIFAR's IdeasExchange platform in action.

—

Visit us at
cifar.ca/ideasexchange

CIFAR Knowledge Circle

CIFAR is grateful to its partners and donors for helping to connect the best minds for a better world. This list recognizes annual contributions to CIFAR between July 1, 2014, and January 28, 2016, and current multi-year commitments of $10,000 or more.

CIFAR Visionary ($50,000 and above)

$25 million
Government of Canada*

$10 million +
Azrieli Foundation • Brain Canada Foundation through the Canada Brain Research Fund • Government of Ontario*

$2 million+
Government of British Columbia* • Richard W. and Donna Ivey* • *(1 Anonymous Donor)*

$1,000,000 to $1,999,999
BMO Financial Group* • Genome Canada • Government of Alberta* • Jerry and Geraldine Heffernan* • Margaret and Wallace McCain* • Power Corporation of Canada

$500,000 to $999,999
Fonds de recherche du Québec • Gordon and Betty Moore Foundation • Maxine Granovsky and Ira Gluskin* • The Estate of Beryl M. Ivey • Richard M. Ivey* • Michael and Sonja Koerner* • R. Howard Webster Foundation* • RBC Foundation* • Trottier Family Foundation • Western University • *(1 Anonymous Donor)*

$200,000 to $499,999
David and Chris Dodge* • George A. Fierheller* • Genome British Columbia • Google Inc. • Anthony R.M. Graham* • The Henry White Kinnear Foundation* • Inria • Ivey Foundation* • The Lawson Foundation* • Magna International Inc. • Max Bell Foundation* • Metcalf Foundation*

$100,000 to $199,999
The Alva Foundation • Crabtree Foundation • Bruno Ducharme* • Facebook • George Weston Limited* • Great-West Life, London Life and Canada Life* • Chaviva M. Hošek* • Céline and Jacques Lamarre • Scotiabank* • Barbara Stymiest* • The W. Garfield Weston Foundation*

$50,000 to $99,999
The Arthur J.E. Child Foundation • John and Mary Barnett* • Peter Bentley* • Flair Foundation • Geoffrey Hinton • The Lawrence and Judith Tanenbaum Family Foundation* • The McLean Foundation* • Bruce H. Mitchell* • Richard and Donna Ivey Fund at Toronto Foundation

CIFAR Leader ($25,000 to $49,999)

$25,000 to $49,999
Alan Bernstein and JoAnn Breitman* • Val and Dick Bradshaw • Fiera Capital Corporation • N. Murray and Heather Edwards* • Stephen Lister and Molly Rundle* • Jon and Nancy Love Foundation at Toronto Foundation • Patricia Meredith and Stephen Karam* • Kara M. Spence* • The Young Fund at Hamilton Community Foundation*

CIFAR Insider ($10,000 to $24,999)

$10,000 to $24,999
Alvin and Mona Libin Foundation • The Chawkers Foundation • Jim Dinning and Evelyn Main • Brenda Eaton • Morten N. Friis • Lindsay Gordon • Nancy and Richard Hamm* • Charles Hantho and Eileen Mercier* • Joe and Marie Heffernan* • Sydney Jackson* • The Joan and Clifford Hatch Foundation • Sheryl and David Kerr* • Rémi Marcoux • Julia and Gilles Ouellette* • Kara Palleschi* • Barrie D. Rose and Family* • Alfred Wirth* • Janet and Bill Young* • *(1 Anonymous Donor)*

CIFAR Partner ($5,000 to $9,999)

$5,000 to $9,999
Frank And Julie Barker* • Bill Blundell* • Claridge • Tony Comper* • Barnie Cowan • Devon Canada • Pierre Ducros* • Derek and Adrienne Fisher* • Douglas and Ruth Grant* • Richard F. Haskayne* • John F. and Judith I. Helliwell* • Suzanne Ivey Cook* • Rosamond Ivey* • Jacqueline Koerner • Vahan and Susie Kololian* • Robin Korthals* • Martha Piper* • C. Douglas Reekie* • Penny Rubinoff through the Jewish Foundation of Greater Toronto • S.M. Blair Family Foundation* • Allan and Shirley Taylor* • Michael and Renae Tims • Waugh Family Foundation • William Young and Ruth Dowling • *(1 Anonymous Donor)*

CIFAR Member ($2,000 to $4,999)

$2,000 to $4,999
Alberta Children's Hospital in recognition of Dr. Alan Bernstein* • James C. Baillie* • Timothy Casgrain • Dominic D'Alessandro • Rob Dowsett and Anne Folger* • John T. Ferguson* • Rebecca Finlay and Gordon Koch* • Leslie Gales and Keith Ray • Ralph and Roz Halbert • Janet E. Halliwell • Trisha Jackson* • The Jon and Laura Hantho Family Foundation • Spencer Lanthier and Diana Bennett* • Sabi Marwah* • Michael McKenzie* • Paul and Martha McLean* • Brenda Milner • The Rotman Family Foundation* • Pekka and Pat Sinervo* • Suncor Energy Foundation in honour of Jacques Lamarre • Stephen J. Toope • Daniel Trefler* • Carol Mitchell and Richard Venn* • John Vivash • Jane M. Wilson* • *(2 Anonymous Donors)*

CIFAR's Broader Community of Supporters

Patrons ($1,000 to $1,999)

$1,000 to $1,999

Beverley Brennan* • J. Trevor Eyton • Pierre Fortin* • Heather Gordon* • Peter A. Hall* • Digvir and Manju Jayas • Jessica Kamphorst and Alex Whitehead* • Michèle Lamont* • John & Maggie Mitchell* • Roger Parkinson • Pirie Foundation* • Heather Rae Johnson • Gail Regan* • Seattle Children's Hospital Research Foundation in recognition of Dr. Alan Bernstein* • Dr. Stephen W. Scherer • William Sewell • Louis Taillefer and Louise Brisson* • Doug and Gail Todgham* • *(3 Anonymous Donors)*

Supporters ($500 to $999)

$500 to $999

AMSSA in recognition of John Helliwell • Éric Archambault and Johanna Kratz • Gérard Bouchard • Aqueduct Foundation • Brooks Family Charitable Fund* • David Cory • Elizabeth Gerrits and Gordon Evans* • David Hartwick* • Joseph Heitman, MD, PhD • Val James • Catherine Kallin • David H. Laidley* • Scott and Sara Lamb* • John C. Madden* • Robert McGavin • Aimee C. Park* • Dr. Ronald Pearlman* • RBC Employee Volunteer Grant Program • Research Money in recognition of John Helliwell • Science-Metrix • Huntington Sheldon* • Elizabeth and Hugo Sonnenschein* • Hugh Wright* • *(3 Anonymous Donors)*

Friends ($100 to $499)

$100 to $499

Lara Aknin • Jonathon Alsop • David J.R. Angell* • Dr. Patricia Baird, OC, OBC* • Karen Baker-MacGrotty • Ronald G. Barr • Brent Barron • Roland Benabou • John Berry • Alexandre Blais • Irene Bloemraad in recognition of Chaviva Hošek • Jorg Bornschein • Leon Bottou • Nyla Branscombe • Wendy M. Cecil* • David Clayton • Amy Cook* • Marie Day • Mauricio Drelichman • Paula Driedger • Lesley Evans* • James Fearon • Marc Frigault • Morten Friis • Guillaume Gervais • Dr. Joseph Glaister* • David Goldbloom, OC, MD, FRCPC* • Steve Goudge • David and Annette Grier* • Alex Hayat • Peter A. Herrndorf • Russell Hiscock • Nancy Howe* • Hulbert Family • Joan Johnston • Stephen Julian • Victoria Kaspi • Helen Kearns • Hae-Young Kee • Bryan Kolb in honor of Esther and Jack Kranton • Eva Kushner, OC, FRSC* • Ann and Jack Laidlaw* • Graeme Luke • Mariko and Suneel Manhas • Rosalyn Manthorpe • Gail Martin • Jennifer Mauro* • Thom McDade • D. McQ Shaver* • Michael Meaney • Simon Miles* • Jonathon J. Millard • Fiona Nelson* • Melisa Ngan • Lara and Paul O'Donnell • Michel Pioro-Ladrière • Donald S. Rickerd* • David Sankoff* • Eldar Shafir • T. Ann Smiley* • Anke Snell • Michèle Thibodeau-DeGuire* • Joseph Thywissen • André-Marie Tremblay • Ludovic Van Waerbeke • Allan A. Warrack* • Kathy (Chunlin) Zhang • Fei Zhou • *(6 Anonymous Donors)*

Government

CIFAR wishes to thank the following federal and provincial government representatives for investing in CIFAR's global excellence and innovation.

Government of Canada

The Right Honourable Justin Trudeau, Prime Minister • The Honourable Kirsty Duncan, Minister of Science • The Honourable Navdeep Bains, Minister of Innovation, Science and Economic Development

Government of Alberta

The Honourable Rachel Notley, Premier • The Honourable Deron Bilous, Minister of Economic Development and Trade

Government of British Columbia

The Honourable Christy Clark, Premier • The Honourable Terry Lake, Minister of Health • The Honourable Andrew Wilkinson, Minister of Advanced Education

Government of Ontario

The Honourable Kathleen Wynne, Premier • The Honourable Reza Moridi, Minister of Training, Colleges and Universities and Minister of Research and Innovation

*
Indicates donors who have given consecutively for five or more fiscal years

—
If you have any questions about this listing, or if your recognition wishes have changed, please contact (416) 971-4453 or donations@cifar.ca

THANK YOU TO CIFAR'S DONORS

History note
The psychology of tyranny.

Photo: Courtesy of Alexander Haslam

In December 2001, 15 men volunteered to participate in social science experiment. When they turned up, they discovered that they were to play the roles of guards and prisoners in a study designed to explore the psychology of tyranny. Over the course of the experiment, guards attempted to assert their power, prisoners revolted and a communal government was instituted and overthrown – all within eight days.

The study made for good television and was broadcast in a four-part documentary by the BBC in early 2002. But the experiment was also a serious piece of social science research, conducted by Senior Fellow Alexander Haslam (University of Queensland) and his colleague Stephen Reicher (University of St. Andrews).

The BBC study re-examined the lessons of the famous Stanford Prison Experiment of 1971, in which students designated as guards quickly became abusive. The experiment seemed to show that normal people can easily adopt a role that leads to sadistic behaviour.

But the BBC experiment suggested there was more to it than just individual roles. Instead, identifying with a group – social identity – made all the difference. Prisoners built group solidarity, while guards were uncomfortable with their roles, and within a few days the prisoners rebelled and instituted an egalitarian order.

However, the new system lasted only two days in the face of opposition from some of the original rebels. By the time the experiment ended, the discouraged communal government was ready to accept self-proclaimed 'new guards' who were far more authoritarian than their predecessors.

The researchers concluded that tyranny is most likely to thrive when a history of group failure makes people receptive to extreme solutions, and where there is a leadership team that offers them. The researchers noted that this analysis is consistent with accounts of the rise of Fascism in post-Weimar Germany.

They argue that evil does not flourish because perpetrators do not know what they are doing. Instead it thrives because they know full well what they are doing, and believe it to be right. •

Announcing a new program for young investigators in the natural, biomedical and social sciences and the humanities: the CIFAR Azrieli Global Scholars.

The CIFAR Azrieli Global Scholars program helps exceptional early career researchers to become tomorrow's research leaders. Each scholar will join a CIFAR program addressing the most complex challenges facing the world today, and will receive funding and support to build research networks and develop essential skills.

SCHOLARS RECEIVE:

- A two-year appointment to a CIFAR research program
- $100,000 CDN in undesignated research support
- Specialized leadership and communications training

CIFAR
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Fondation Azrieli Foundation

Watch for appointments later this year. To learn more about the CIFAR Azrieli Global Scholars program, please visit:

www.cifar.ca/global-scholars

CONNECTING THE BEST MINDS FOR A BETTER WORLD.

CIFAR

CANADIAN INSTITUTE FOR ADVANCED RESEARCH
180 Dundas Street West, Suite 1400
Toronto, ON M5G 1Z8

cifar.ca