REACH

IDEAS TO CHANGE THE WORLD | SPRING 2017

Quantum insecurity

Weaponized microbes

Populism's rise

Our microbes, ourselves

Exploring the life that lives in and on us

CIFAR

Connecting the best minds for a better world.

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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 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 400 fellows, scholars and advisors from more than 125 institutions in 17 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.

President's message
A time of growth and change

THIS ISSUE OF REACH MAGAZINE comes to you as CIFAR is undergoing a period of growth and change.

In Budget 2017, the federal government made two important funding decisions that impact on CIFAR directly: First, they increased CIFAR's core funding to $35 million over five years, our first increase in 15 years. Along with increased support from a number of other partners and donors, this is strong support for our mission of bringing together great minds from around the world into global interdisciplinary networks to tackle problems of importance to the world. That mission is what has made CIFAR unique and "Canada's gift to the world," to quote from a recent speech by Ontario Lieutenant Governor Elizabeth Dowdeswell.

Second, Minister of Finance Bill Morneau announced the launch of a $125 million Pan-Canadian Artificial Intelligence Strategy, to be developed and implemented by CIFAR (see story on p. 4). The strategy will provide core support for three AI institutes in Montreal, Toronto and Edmonton, support the funding of Canada CIFAR Chairs in Artificial Intelligence, augment the pipeline of graduate students being trained in AI research in the country, fund the development of a national AI suite of activities, and help support a global program in AI and Society that will explore the broad societal impacts of AI. The goal of the strategy is to keep Canada at the forefront of AI research and to serve as a strong foundation for a bold innovation agenda based on AI. Canada is globally recognized as a powerhouse in deep learning AI, in large part because of CIFAR's decision to launch a program in 2004, led by Geoff Hinton and now called Learning in Machines & Brains (see "Deep Thinking: Making machines better learners," Reach Spring 2014).

Two of the most important lessons from the AI story: First, if you bring outstanding scientists together and give them the time and opportunity to think big and be bold and creative, you never know what the outcome might be. And second, if you want disruptive innovations that have the potential to create entirely new industries and transform existing ones, you have to invest in great, high risk/high impact research. And that, in a nutshell, is CIFAR's philosophy and culture.

In this issue you'll see other examples of where our philosophy can lead. Our cover feature is about one of CIFAR's new programs, Humans & the Microbiome. The program examines the many ways that the microbes that live in and on us can affect our health, development, evolution, and even culture.

Another feature looks at Michele Mosca and other members of the Quantum Information Science program as they work to understand the security issues that would be created by a working quantum computer – and to put a solution in place before any damage can be done.

There is a report about the CIFAR Forum on the Well-Being of the World's Children which CIFAR organized in London in November. Add in our expanded knowledge mobilization efforts, our new CIFAR Azrieli Global Scholars program, and our beautiful new home in the MaRS Centre, and I hope you will agree that CIFAR has had a busy year of growth and transformation! I'm pleased to be able to share these developments with you, and I hope you enjoy reading about them in this issue of Reach.

Alan Bernstein
President & CEO

Advances
News highlights from our research networks

CIFAR to develop $125 million AI strategy

The federal government announced that it will spend $125 million on a Pan-Canadian Artificial Intelligence Strategy that will be developed and implemented by CIFAR.

The strategy will establish major AI centres, increase the number of outstanding artificial intelligence researchers and skilled graduates in Canada, and develop a national research community on artificial intelligence. It will also develop global thought leadership on the economic, ethical, policy and legal implications of advances in artificial intelligence.

CIFAR has been a leader in artificial intelligence through its Learning in Machines & Brains program, founded in 2004 by **Geoff Hinton**, which pioneered techniques like deep learning and reinforcement learning. Hinton and CIFAR fellows **Yann LeCun** and **Yoshua Bengio** are considered leaders in the field of artificial intelligence.

The strategy will fund AI institutes in Canada's three major centres for deep learning and reinforcement learning research – Edmonton, Montreal and Toronto. The institutes will provide a critical mass of research and innovation excellence, and will work with researchers, industry and other stakeholders across Canada.

A Canada CIFAR Chairs in AI program will help Canada retain and recruit top academic researchers. The program will also support recruitment and training of graduate students and postdoctoral fellows, and include funding for graduate students who will work with the chairs as well as training for students at the three AI institutes.

The strategy will fund a global program in AI and Society that will explore the societal impacts of AI through working groups that will publish their findings and inform the public and policy-makers.

Finally, the National AI Program will support activities that are national and collaborative in scope such as an annual meeting of Canada CIFAR Chairs in AI. It will aim to ensure that Canada is well positioned for sustained global leadership in AI research and innovation.

"Canadian successes in artificial intelligence clearly demonstrate how the support for fundamental research can lead to big dividends in scientific, technological and business innovation," said CIFAR President & CEO **Dr. Alan Bernstein**. "The investments build on much earlier support by CIFAR and others in deep learning and advanced AI research. They will keep home-grown talent in Canada, and attract the scientific talent and capital we need to spur innovative economic growth."

Artificial intelligence will lead to disruptive innovations like the self-driving car.

Photo: iStock

Obese mice regain lost weight faster due to the microbes they carry in their guts.

Gut microbes hold 'memory' of obesity

A study by Senior Fellow **Eran Elinav** (Weizmann Institute of Science) found that the gut retains a "memory" of obesity through lasting changes in the makeup of the microbes living in the intestines.

When obese mice were put on a diet until they reached a lean weight, all of their body systems returned to normal but the altered microbiome remained for up to six months. Furthermore, this microbe memory activated exaggerated weight gain when obese mice returned to a high-fat diet.

To determine the exact trigger for the weight gain, Elinav's team identified bacterial genes that were altered by a high-fat diet. They found the microbiome as a whole appears to control the levels of two molecules that drive weight regain. These molecules, known as flavonoids, control the mice's metabolism and energy expenditure. As the microbiome changes, these flavonoid levels drop and mice put on extra fat and cannot burn it off as quickly.

Elinav's lab has not developed a miracle pill for obesity, but they have found ways to treat it in mice, including a fecal microbiome transplant and a flavonoid-rich drink.

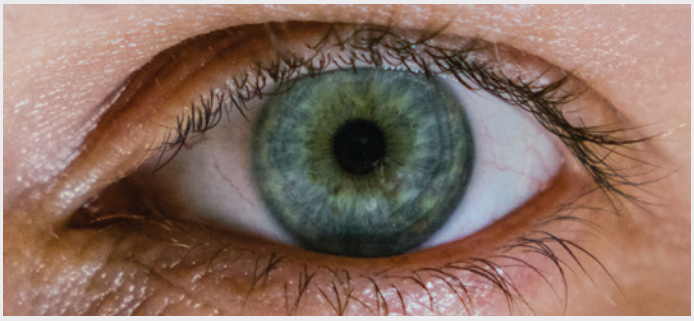
Daniel Trefler wins Killam prize

The Canada Council for the Arts awarded CIFAR Senior Fellow **Daniel Trefler** (University of Toronto) a 2016 Killam Prize.

Trefler was honoured with one of five $100,000 prizes for exceptional career achievements in academia. He studies international trade and its relationship to innovation, institutions, inequality and other areas. Trefler has been appointed to CIFAR for more than 18 years, most recently in the Institutions, Organizations & Growth program.

Daniel Trefler

Photo: Getty Images



New research explains why we're blind to our own blinks.

Understanding consciousness in the blink of an eye

On average human beings blink every five seconds, yet we experience the visual world seamlessly. This is a powerful example of the difference between what information our eyes take in and what our brains perceive.

"We see because the visual system is busy creating an image," says **Rafi Malach** (Weizmann Institute of Science), a senior fellow in the Azrieli Brain, Mind & Consciousness program.

Malach's recent research suggests that perception is linked to the higher-order visual areas of the brain, rather than the early visual cortex, where visual information is first processed.

In an *eLife* paper, his lab examined patients' neural response to spontaneous blinks, voluntary blinks and interruptions such as being shown a blank video screen. In all instances, the signals in the early visual cortex were the same, with increased neuronal activity after the interruption disappeared. However, as the information moves up to the high-order visual cortex, post-interruption activity subsides for blinks but not for other interruptions. Malach says these results contradict existing hypotheses that our brain "fills in" the missing information when we blink. Instead, the data suggest we do not see blinks because a suppression mechanism is blocking the interruption-induced bursts of neuronal activity.

In a follow-up study, researchers examined how perception and sensory input are related to each other in real-life situations, finding that higher order visual areas are likely responsible for producing the stabilized image we perceive despite constant interruptions by blinks and eye movements.

Michèle Lamont awarded Erasmus Prize

Canadian cultural sociologist **Michèle Lamont** (Harvard University) received the 2017 Erasmus Prize, which recognized her as "a champion of diversity in research and society."

The prestigious European prize is presented by His Majesty the King of the Netherlands for exceptional contribution to the humanities, social sciences or arts.

For more than 30 years, Lamont's research has examined the relationship between knowledge, power and diversity. In 2002, Lamont founded CIFAR's Successful Societies program alongside Co-Director Peter A. Hall (Harvard University).

Michèle Lamont

Under their leadership, the program has published two highly-influential books: *Successful Societies: How Institutions and Culture Affect Health* (2009) and *Social Resilience in the Neo-Liberal Era* (2013).

Photo: iStock

Quantum teleportation could lead to more secure data transmission over fibre optic networks.

Photo: iStock

New distance record for quantum teleportation

A team of physicists has succeeded in teleporting the quantum state of a photon over a distance of more than six kilometres – well beyond the previous record of 800 metres.

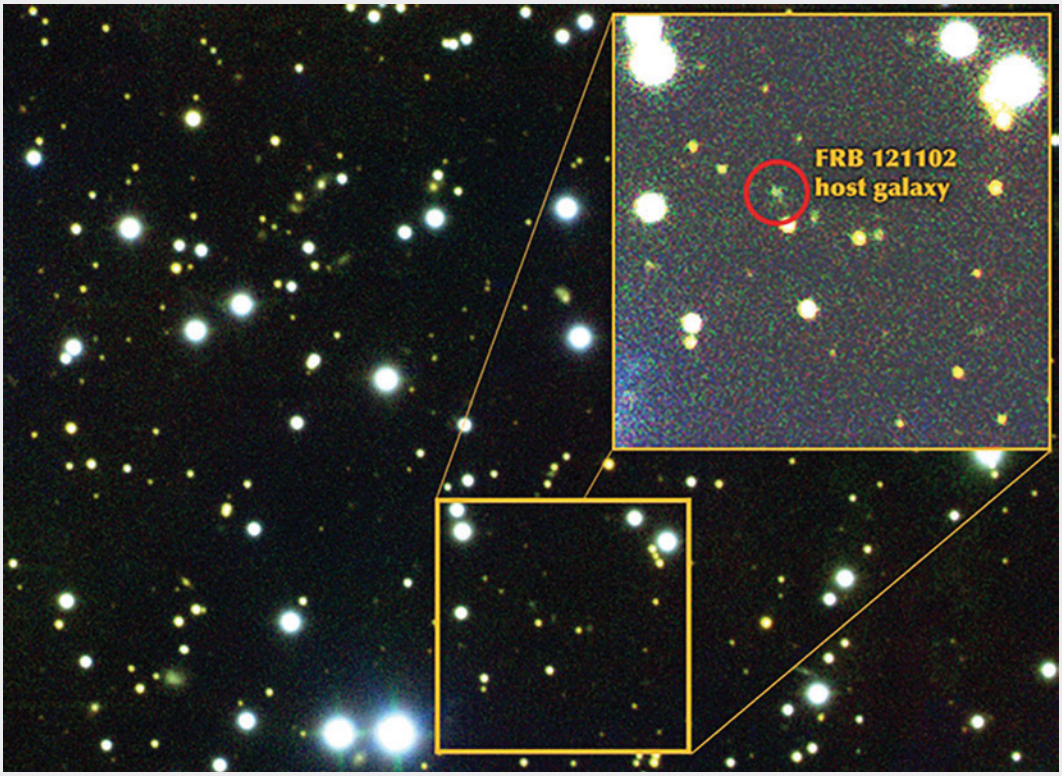
Wolfgang Tittel, a senior fellow in the Quantum Information Science program (University of Calgary), led the team that published the research in *Nature Photonics*. For their experiment, they used Calgary's municipal fibre optic network, which normally carries telephone calls and internet traffic.

The experiment involves three people in communication over the network – dubbed Alice, Bob, and Charlie. In the experiment, Bob creates a pair of entangled photons and sends one to Charlie. Meanwhile, Alice sends a photon to Charlie, who performs an action which "entangles" the two photons. The end result is that the quantum state of the photon created by Alice is "teleported" to Bob. Bob can see what information was encoded in Alice's photon even though her photon never reaches him.

"The measurement at Charlie modifies the quantum state of Bob's remaining photon. This happens without any object travelling between Charlie and Bob," Tittel explains.

Aside from being an impressive feat of pure physics, the work could prove to be an important step toward building a "quantum repeater" – a vital component of a quantum information network. Normally, any measurement of a quantum bit destroys the information it contains, which means that quantum signals can't be easily amplified. A quantum repeater would allow the quantum state of a qubit to be passed along, even if the actual qubit wasn't.

The finding could help pave the way for fundamentally secure encrypted communication, and could even be used to send problems to a quantum computer, without even the computer knowing what it was working on, allowing for more secure problem-solving.



This mysterious fast radio burst has been traced to a galaxy three billion light years away.

Astronomers trace radio burst to its home galaxy

Astronomers have pinpointed the source of a series of mysterious cosmic signals to a distant dwarf galaxy three billion light years away. This is the first time scientists have been able to trace the signals to a specific location and could help uncover what is causing them.

Fast radio bursts (FRBs) last only a few thousandths of a second but are far brighter and more powerful than any known short flashes, such as pulses from a neutron star.

Researchers zeroed in on the location of one of 18 known FRBs using a network of telescopes and special imaging and timing technologies. Associate Fellow **Scott Ransom** (National Radio Astronomy Observatory) and R. Howard Webster Foundation Fellow **Victoria Kaspi** (McGill University) were part of the scientific team that published their findings in *Nature*.

Previously, FRBs could be traced to a region in the sky, but not to any of the hundreds or even thousands of galaxies within that region. In order to narrow this scope, scientists used the Very Large Array (VLA), a multi-antenna radio telescope system, to produce a high-definition image of the sky. They focused on a particular FRB that is the only known repeater.

"This FRB is the one people thought was the oddball but it is now unambiguously at far distances, unambiguously coming from another galaxy," says Ransom.

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) could help answer remaining questions about FRBs. CHIME will measure more than half of the sky each day and could potentially detect as many FRBs in a day as previous telescopes have over the last decade.

Photo: Courtesy of *Nature*

CIFAR fellows lead top AI research labs

In October, Apple hired Learning in Machines & Brains Fellow **Ruslan Salakhutdinov** (Carnegie Mellon Unversity) as the company's first director of AI research.

Salakhutdinov's research focuses on deep learning, an artificial intelligence technique which allows computers to learn to recognize patterns. His recent work has ranged from teaching a computer to navigate Wikipedia to creating an AI model that can read and write.

Apple is the latest tech company to join the AI race. Google's and Facebook's research labs are led by Learning in Machines & Brains Distinguished Fellow **Geoffrey Hinton** (University of Toronto) and Program Co-Director **Yann LeCun** (New York University) respectively. Associate Fellow **Andrew Ng** (Stanford University) was the Chief Scientist of Chinese search engine Baidu until he left in March.

Ruslan Salakhutdinov

Photo: iStock

Even orphans adopted into stable homes showed long-lasting traces of adversity in their epigenomes.

Early childhood adversity may have long-term effects on gene expression

Difficult childhood experiences can often lead to poor physical and mental health later in life. A new study examines a genetic trace on young brains that suggests these experiences make lasting changes to key genes.

Child & Brain Development Associate Fellow **Megan Gunnar** (University of Minnesota) and Senior Fellow **Michael Kobor** (University of British Columbia) explored the effects of early experiences on gene expression in two groups of adolescents: Russian or Eastern European orphans who were adopted and American non-adoptees.

The study compared the adolescents' DNA methylation profiles. DNA methylation is an epigenetic mechanism used by cells to control gene expression, particularly related to neurobehavioural development.

Researchers found 30 regions of DNA that were more methylated on 19 genes in the group of adopted adolescents. They also found the type of immune cells in circulation differed strikingly between the adopted and non-adopted groups, but there were no significant differences in their physical health. Overall, the differences between the two groups were clustered in the neuronal and developmental areas.

Improved technique converts CO_2 to green fuel

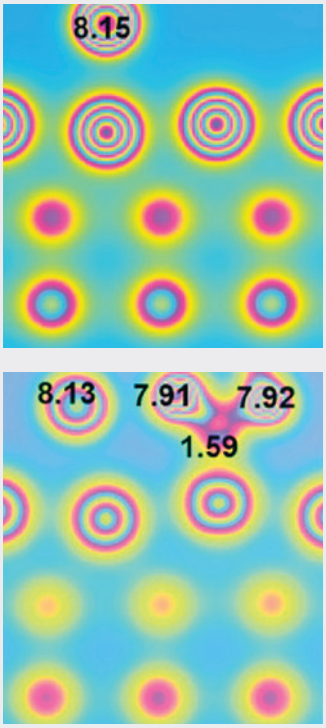
The world needs more fuel and less atmospheric carbon dioxide – and new research on a well-known process could bring us closer toward achieving both.

Reducing carbon dioxide to carbon monoxide is the first step in synthesizing biofuels. The biggest catch is that the electrochemical reaction usually proceeds at a snail's pace.

But Heffernan Director of the Bio-inspired Solar Energy Program **Ted Sargent** (University of Toronto) and a team of U of T colleagues have found a way to speed it up. It turns out that electrodes with certain microscopic structures on their surfaces can help boost the strength of the electric field they generate, which attracts more carbon dioxide to the metal and speeds up the reaction. The needle-shaped gold "nanostructures" act as a catalyst, and behave analogously to a tower that attracts lightning during a thunderstorm.

This was done on a small scale with water in beakers, but researchers say the technique could potentially be scaled up.

The process, known as "field-induced reagent concentration," has another potential payoff: It can help convert energy from renewable sources such as wind and solar into a more readily storable liquid form, such as ethanol and methanol.



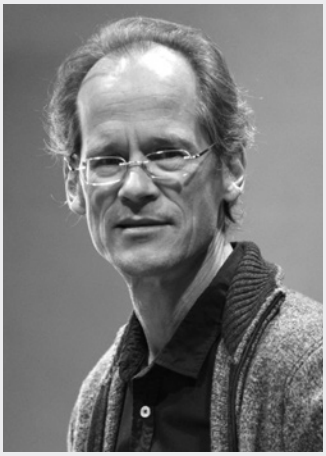
Increased charge density of a catalyst speeds up CO_2 conversion.

Louis Taillefer first Canadian to win Simon Prize

Director of CIFAR's Quantum Materials program **Louis Taillefer** (Université de Sherbrooke) was awarded the 2017 Simon Memorial Prize. He is the first Canadian to win the international physics prize.

Taillefer is renowned for his pioneering research on superconductors – materials that have the ability to conduct electricity without any loss of energy. Known superconductors function at extremely low temperatures; a superconductor that worked at room temperature would have countless applications, from energy efficiency to transportation.

Taillefer is known for several contributions to the field using a number of powerful experimental techniques. In 2007, his team, which included several CIFAR members, made their breakthrough observation of "quantum oscillations" in a copper-oxide superconductor. Quantum oscillations are the clearest signature of electrons in a metal and the discovery caused a paradigm shift in how scientists view electron behaviour in these materials. In 2016, the same team of CIFAR members identified a key signature of the quantum phase transition that underpins why copper oxides are the strongest known superconductors.



Louis Taillefer

Photo: Courtesy of *Nature*

Samples taken from the California coast revealed the microbial predators for the first time.

CIFAR fellows produced the first images ever of this important marine predator.

First photos emerge of elusive marine predators

CIFAR researchers captured the first images of the ocean's most abundant yet previously unseen predators. Marine diplonemids are a diverse group of single-celled microbes that were only recently discovered.

"To put this in perspective, it would be like ecologists studying the Serengeti for decades and never seeing a lion or cheetah," says Integrated Microbial Biodiversity Program Director **Patrick Keeling** (University of British Columbia), who led the team.

During two week-long expeditions off the coast of California, his team scoured water samples for the "invisible" predators. Their findings, published in *Current Biology*, offer the first glimpse of the microbes in photos of 10 colourless, flagellate cells of diverse shape and size.

Researchers learned more about the mysterious microbes back at the lab. Using single-cell genomics, they saw diplonemids feed on algae and bacteria. The analysis also revealed diplonemid genomes are full of "junk" DNA known as introns, which interrupt genes and are removed during expression. All complex cells have introns in their nucleus, but the diplonemid introns were unique and seem to have evolved independently. One intron included clues as to how the introns copy themselves and spread to new genes, similarly to a virus. Keeling says that what's hidden inside diplonemid cells could help answer questions about the introns' origins.

Photo: (left) Alyson Santoro; (right) Noriko Okamoto

In Conversation

The rise of the populist right

A YEAR AGO a majority of citizens in the United Kingdom voted to leave the European Union, reversing decades of increasing integration with Europe. In November, Donald Trump was elected president of the United States on an anti-immigrant, anti-free trade platform. Far-right nationalists have staged strong election campaigns in a number of countries, including France, where presidential candidate Marine Le Pen garnered a third of all votes cast. All of these developments come in the wake of concern about increasing inequality and worries about what globalization and automation will mean for workers.

We asked three CIFAR fellows to discuss the current political and economic situation. **Daron Acemoglu** is a senior fellow in CIFAR's Institutions, Organizations & Growth program and an economist at the Massachusetts Institute of Technology. **Rafael Di Tella** is a senior fellow in CIFAR's Social Interactions, Identity & Well Being program and an economist at Harvard University. **Paul Pierson** is a senior fellow in the Successful Societies program and a political scientist at the University of California, Berkeley.

Photo: REUTERS/Carlo Allegri

In the last year we've seen the U.K. vote to exit from the E.U.; the U.S. elect Donald Trump; and a general increase in right-wing nationalism. Are these events related, and if they are what's the cause?

Rafael Di Tella: I guess a standard starting point is distrust of the elites. There are many dimensions of this, but one that is interesting is disdain for what elites might call "competence." Part of it is a natural reaction to exaggerated claims some educated people make, e.g., some economists regarding the gains of globalization. But part of it is simply voter rejection of something that has not been very useful to them. Sometimes it is translated into something constructive, such as appreciation of "practical" knowledge based on common sense over specialized education. But very often it is not: voters prefer someone incompetent because of the idea that "at least they won't (knowingly) screw us." Like I said, this rejection of competence is just one dimension of populism that seems to matter, and my sense is that it is present more in the cases of Trump and Brexit than in the case of right-wing nationalists.

Daron Acemoglu: They are very closely related. In both cases, these events are a culmination of a series of economic and social changes. The U.S. and the U.K. have witnessed productivity gains from technological change and globalization, but these gains have not trickled down to a significant fraction of the population. On the contrary, both processes have created additional hardships for manufacturing workers and areas with a high concentration of manufacturing. At the same time, long ranging societal changes have continued to undermine the existing social hierarchy that placed white males at the top. Combined with the financial crisis, which further eroded trust in institutions, these changes have created the perfect storm for the rise of right-wing populism. By blaming foreigners and immigrants, asking for protection for the jobs that have disappeared, claiming to reinstate the older social hierarchy, and repudiating the elites that presided over the previous decades' economic changes, this ideology has a natural appeal to the segments that feel alienated, left out and angry.

All of that having been said, we should also not view these political outcomes as inevitable or irreversible. At the end, both Trump's victory and Brexit passed with small margins. Better ways of dealing with the economic changes of the last several decades and a political equilibrium offering policies more responsive to the concerns of those left behind might have easily taken a few points from the support of these right-wing populist agendas.

Paul Pierson: I don't disagree with any of these observations but would suggest a couple of additional points. First, elaborating on Daron's point, I would stress the importance of cultural and demographic change as well as economic dislocation. The decline in perceived status of working class whites has been a very important catalyst – probably as important as purely economic trends – for right-wing populism. In the United States, support for Trump was closely related to measures of racial resentment.

Second, it isn't just a matter of broad and impersonal social trends. It would be a mistake to overlook the role of organized efforts to foment and exploit political anger. Many who we would consider "elites" – both in politics and the media – have perceived advantage, whether in profits or votes, from stoking these resentments. This has been, in many instances, a conscious strategy, pursued for many years. In Britain, this often took the form of cheap shots at the European Union – a readily available scapegoat for a host of social tensions and disappointments. In the U.S., it has involved broadsides at government, established institutions in the media and universities, and the slowly increasing inclusion of various social groups, such as women and minorities, which threatens previous status hierarchies.

How much of the story is an institutional one – a failure of institutions to meet the challenge of changing circumstances? Are people right to distrust the elites? Are there better institutional responses possible than the ones we've seen?

Di Tella: Of course they are right to distrust the elites. There is a tendency by the political system to simplify and oversell what we know. The standard thing is to make rosy predictions about policies that we like and think are on the whole a good thing, but over which we have a large amount of uncertainty. But somehow all the doubts and caveats go out the window when they get into politics. The odd thing is that dissenting voices are given very little room in policy debates. Perhaps it is the nature of how politics works. Perhaps it is something deeper, because I note that such distrust or even shut-down of dissent also takes place in academic circles.

Acemoglu: Yes and no. Yes because the failure of institutions is the failure of elites, and elites have long been silent to the people's plight. On both sides of the Atlantic, both technological change and globalization have been presented to the people as unadulterated gems, processes from which everybody will benefit. And many in society have had the worst decades in memory in terms of economic gains. This breeds distrust of institutions, and it breeds, somewhat justifiably, distrust of elites.

No because the alternative to the current elites is a less trustworthy, more opportunistic and more corrupt new elite in the form of Donald Trump or Marine Le Pen. The distrust of elites fuels the rise of "big man politics," or big woman politics in France, where a charismatic leader tramples on institutions and stokes populist, anti-foreigner fervor, but crucially without articulating viable alternatives.

If the distrust of elites led to a more bottom-up solution process, it would be desirable, but we haven't really seen much of it. Perhaps it's inevitable that the first round of the distrust of current institutions and elites will lead to facile solutions like the ones articulated by Syriza in Greece, Podemos in Spain or Donald Trump in the U.S. Civil society participation in politics does take work and effort.

Pierson: One of the core difficulties of this moment is that our main institutions command less and less respect, in part because of growing evidence of self-dealing amongst the powerful. Yet the evidence remains overwhelming that, however tarnished, core institutions of liberal democracy – including government, universities,

and traditional media – have been critical to an extraordinary long-term expansion of opportunities and living standards. These institutions have been essential in promoting the – yes, imperfect – compromises and reliance on – yes, imperfect – scientific knowledge that made those gains possible. Political movements promising payback against elites, but demonstrating contempt for knowledge and core institutions and disavowing the necessity of political and social compromise, are most unlikely to deliver to citizens understandably frustrated by the status quo. As I write this the Republican-controlled House of Representatives in the U.S. just voted to support the top legislative priority of a supposedly anti-elitist Republican president: eliminating health insurance for more than 20 million Americans in order to pay for huge tax reductions for the richest two per cent of the country.

Right-wing nationalist Marine Le Pen failed to win the French election, and previously Austria and the Netherlands both rejected similar candidates. Has the tide begun to turn? Whether yes or no, what has to happen next for people to regain trust in governments and other institutions?

Acemoglu: The defeat of Marine Le Pen in the French presidential elections is good news for France, good news for Europe and good news for the world. But it would be absolutely incorrect to think that this signifies a turn of the tide.

The support for anti-immigration in the U.K. and for aggressive, ugly white supremacist policies in the United States is, if anything, considerably weaker than anti-Islam, anti-immigrant fervor in France. In all three of these cases, the commonality is that right-wing populism has been on the rise, and in many ways it has become uglier. But in none of these three societies was there a majority in favour of the most extreme version of right-wing populism. It was a series of mistakes and institutional peculiarities that brought Brexit to the U.K. and the disastrous presidency of Donald J. Trump to the United States.

The situation, read this way, suggests not that right-wing populism has triumphed, but that we do live in a deeply polarized world in which the two poles will continue to battle for supremacy in the next decade and perhaps beyond. We need to be ready for the long fight, and that means understanding the grievances that have fueled support for these non-establishment candidates, while still espousing the core values that make democratic, tolerant and open societies the only game in town for our future.

Di Tella: I think I agree with Daron's take. Le Pen's "failure" does not represent a turn of the tide. The fact is that populist candidates have been far more successful relative to what many thought was possible in developed countries. If anything, the French election confirms the view that there are large numbers of people angry with the elites and that we don't have a clear understanding of this phenomenon.

My sense is that to regain trust in institutions, voters will want to see a different balance of power – between the elites and democratically elected officials – and that will probably require a somewhat different functional distribution of income. More long term, it may also require a change in material aspirations. Most of our democratic and taxation architecture was developed during times of high growth. I thought it would be possible to preserve them in an era of low growth, but I think that was a bit of wishful thinking.

Pierson: A relatively high level of confidence in institutions emerged from a set of unusual historical circumstances. Trust in institutions grew out of very successful efforts to build prosperity in the aftermath of a terrible combination of war and Depression. It seems far easier to generate discontent and disruption than trust. One thing that might help would be a strengthened commitment among political elites to support our core institutions, rather than, as is happening in the U.S., a willingness to damage those institutions in pursuit of short-term advantage. These elites also would need to recognize that sustaining these institutions requires more responsiveness to the needs and concerns of those who have been left behind. I wish I felt more optimistic about the prospects for such developments. •

Our Microbes,

Ourselves

CIFAR's Humans & the Microbiome program is untangling how the life that lives in and on us affects our health, development and even evolution. It turns out that the microbiome can tell us a lot about where we've been – and where we're going.

By Hannah Hoag
Illustrations by Jeannie Phan

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MICROBES ARE PRETTY MUCH EVERYWHERE, occupying the same space we do, colonizing our skin, mouths and guts. Coming into contact with a pathogenic microbe, such as the bacterium *Vibrio cholerae* in contaminated food or water, can lead to disease. But most of the time, we're quite agreeably bestrewn with microbes and suffer no ill effects.

Until recently, the human microbiome – the assemblage of bacteria, viruses and fungi that live on and in us – has been neglected by science, seen as interesting only when it leads to infection. But a growing body of research suggests that the human microbiome has tremendous influence on many aspects of an individual's health, from allergies to neurological disorders to healthy childhood development.

CIFAR fellows in the new Humans & the Microbiome program are looking at all of this and more. They're examining everything from how the microbiome has changed across generations, geographies and ethnicities; to how it has co-evolved with humans to help us adjust to changing food supplies and new diseases; to how it may even have guided human behaviour and cultural practices. It turns out that the microbiome can tell us a lot about where we've been – and where we're going. In fact, the collaborative, symbiotic relationship between human host and microbiome is so close, it has been suggested that humans are not individuals but "holobionts" – creatures inseparable from our microorganisms and environment.

Birth of a Program

Brett Finlay, a microbiologist at the University of British Columbia, had long believed there were many big questions about the microbiome that no one was asking. He was convinced the gut microbiome affected fetal development. He also wondered how practices such as the routine use of antibiotics and Caesarean section, which alter the microbiome, might influence a population or society. Did microbiota, which respond rapidly to environmental change, contribute to human evolution?

"When you talk about human evolution, no one uses the word 'microbe,'" says Finlay. "And yet we know that as soon as we started cooking our food we changed our microbes, and that could have affected our evolution."

Finlay raised his questions about human development with Janet Rossant, a developmental biologist at Toronto's Hospital for Sick Children. But the pair never seemed to have time to move the project forward.

Then in 2013, CIFAR issued a global call for proposals, and Finlay and Rossant jumped at the chance to present one. After a series of meetings and discussions, they assembled a wide-ranging cross-disciplinary team of microbiologists, geneticists, developmental and evolutionary biologists and anthropologists from across the globe. The goal: to connect pieces of information that typically aren't connected in conventional collaborations.

"There are lots of microbiome centres around the world that are looking at the effect of diet on obesity or autism, but no one else is trying to embrace anthropology, development and evolution," says Finlay.

Rossant, who co-directs the Humans & the Microbiome program with Finlay, says it gives team members a chance to look at communities around the world in terms of people's relationship with the microbiome. "How does that affect their health and their societal evolution? Can we understand how things have changed over time and how that is influencing human health today?"

"When you talk about human evolution, no one uses the word 'microbe,' and yet we know that as soon as we started cooking our food, we changed our microbes, and that could have affected our evolution."

Stinky Work

Each adult human co-exists with trillions of microbes, a process now thought to begin even before birth. When a baby is pushed through the birth canal it picks up additional bacterial cultures from its mother, which will later colonize its gut. Babies born by Caesarean section encounter skin microbes instead of vaginal ones, giving them a different microbial makeup at birth. In the weeks and years that follow, the infant's microbiome grows and becomes more diverse, picking up new microbes from breastfeeding, a grandparent's cuddles and the family dog's sloppy licks.

Most of these microbes live in our guts, particularly in the large intestine, and for many years scientists cared little about them. "For over a century, we regarded the gut microbiota as a dump," says CIFAR Senior Fellow Eran Elinav, an immunologist at the Weizmann Institute of Science in Israel. "Many of us believed they were not doing anything important."

Studying gut bacteria was also an especially taxing pursuit. Not only was it stinky work, scientists also considered most of the species to be "unculturable." That is, it wasn't feasible to isolate them in the lab because it was hard to identify – and then recreate – the conditions they thrived in.

Significant advances in molecular biology and technology have changed that. DNA sequencing now allows scientists to sift through massive amounts of genetic material to identify microbes and read their genomes. Now that we're starting to understand what molecules microbes produce, we're beginning to dig more deeply into their roles in human health and disease. In addition to manufacturing a number of essential vitamins we need to stay alive, microbes are considered necessary for normal development. These microbes help the infant, child and adult process nutrients, manage metabolism and keep pathogens in check.

Since early in the 20th century, people have engaged in a war on microbes, trying to clear our bodies of harmful bacteria that could cause infection. Vaccines have eradicated smallpox; sanitation and water treatment have decimated cholera in many parts of the world; and antibiotics now treat previously lethal childhood diseases such as scarlet fever.

"It's worked terrifically well," says Finlay. A hundred years ago, 30 per cent of children died of infections; now it's less than 0.1 per cent. The lifespan of the average American has doubled in the past 150 years, from 40 to 80 years. "But the thinking has been that if clean is good, then cleaner is better," he adds. "We're only just starting to realize that by removing microbes, our bodies don't function normally."

"We're only just starting to realize that by removing microbes, our bodies don't function normally."

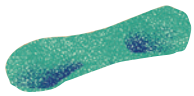
In the same time frame there has been a steady rise in conditions such as asthma, diabetes, inflammatory bowel disease, autism, ADHD, depression, stress and anxiety – the list goes on. "When you look at diseases of the developed or Western world, you can find, in just about all of them, a microbial link," says Finlay.

Asthma is a prime example. In Canada, the number of children with asthma has quadrupled in the past 20 years. Urban living, early-life antibiotics, Caesarean delivery and formula feeding have all been associated with asthma, and all suggest a strong link between asthma and changes in the microbes that live in the gut.

Finlay and his colleagues went looking for bacteria that might have influenced the rising asthma rates. They analyzed stool samples from more than 300 Canadian infants, and found that three-month-old infants who had low or undetectable levels of four bacteria – *Faecalibacterium*, *Lachnospira*, *Veillonella* and *Rothia* – were far more likely to have wheezing or skin allergies by their first birthdays. Wheezing and skin allergies are the early signs of asthma.

And the team went further. They cultured microbiomes of the babies who would go on to develop asthma and infected a group of germ-free mice with the mixture. Some of the mice were then given the four protective bacteria. Those who received the bacteria did not develop lung inflammation; the other mice did.

"We're not yet smart enough to say, 'Your three-month-old is lacking these four microbes. Give him this probiotic,'; or to replenish these microbes after a course of antibiotics. But it will slowly come to that," Finlay says.



Yo-Yo Dieting

Obesity is another disease of the developed world with microbial links. Elinav, an MD/Ph.D studying host-microbiome interactions is interested in recurrent obesity. Many overweight people find short-term success in dieting, only to regain the weight within a year and repeat the cycle. "Almost 80 per cent of the world's overweight population suffers from this phenomenon," he says.

Elinav has found that gut microbiota can drive this yo-yo cycle. In a recent study, published in *Nature*, obese mice had their high-fat diets swapped with more balanced diets until their weight returned to normal, along with metabolic factors such as their blood sugar levels. But their gut bacteria did not change back to normal. And

> “We now have some evidence showing that we need the mother’s microbiome in order for the brain to develop properly in the fetus.”

just like human yo-yo dieters, when previously obese mice were given access to high-fat food again, they gained weight more rapidly than mice induced with obesity for the first time. When post-dieting mice were given bacteria from the naive mice, their exaggerated yo-yo obesity was prevented.

“Our findings suggest that when you successfully diet, that doesn’t normalize your gut microbiome,” says Elinav. “It holds a ‘memory’ of your past obese episodes and drives you to gain more weight the next time around.”

A growing body of research, mostly from animal studies, suggests that gut microbiota also influence brain development and behaviour. Researchers are beginning to discover that gut microbes can influence the brain through the hormones, metabolites and other molecules they produce. Some mouse studies have found that gut microbiota can drive an animal’s behaviour, for example making it more anxious, less social or more adventurous.

What about the interaction between the maternal gut microbiome and the fetus? Scientists know that genetic and environmental factors contribute to the development of neurological conditions such as anxiety, depression, autism and schizophrenia. Could signals from maternal microbiota cross the placenta and influence brain development?

In unpublished studies, Rossant’s lab found brain changes in mice whose mothers lacked a gut microbiome. Reinstating the gut microbiome in the pups could reverse some of the changes, but not all. “We now have some evidence showing that we need the mother’s microbiome in order for the brain to develop properly in the fetus,” says Rossant.

“It’s very preliminary and we have a lot more work to do. But it’s important,” she says, “because it suggests that when we are thinking about making sure that babies develop well, we have to think not only about making sure they pick up the right bugs [at birth], but also that the mother’s microbiome is in really good shape too.”

With just more than two years behind them, these ambitious collaborative projects are coming to fruition. Without the intensive multi-day meetings that come with CIFAR’s Humans & the Microbiome program, these research collaborations might have emerged more slowly, if at all.

Colonial Microbiomes

It was an important day for Senior Fellow Hendrik Poinar when the first set of human remains from Senegal arrived at his lab. Poinar, an evolutionary biologist at McMaster University, is well known for his ability to extract ancient DNA from difficult samples. Working with a team including Ibrahima Thiaw of the University Cheikh Anta Diop of Dakar, he will be examining the dental calculus of people who lived in West Africa in the late 1800s and late 1950s to see if their oral microbiomes changed under colonial rule.

Knowing which microbes are there prior to colonization is one step. Another step is to understand how this fits into the historical context. Other team members are two social anthropologists, CIFAR Fellow Frédéric Keck, at the Musée du quai Branly, and Senior Fellow Tamara Giles-Vernick, at the Institut Pasteur, both in Paris. They will interpret the biological analyses by looking at changes that occur when a society undergoes colonialization.

"Each of us has very different perspectives in how we look at bacteria in general, and microbiomes," says Poinar. "And when you come together, that is where the very best and most interesting science can take place, at the interdisciplinary crossroads."

The work is exacting. Oral microbes become trapped in microscopically thin mineral layers of dental plaque over time, accumulating year after year in adult life. Poinar and his colleagues are using a wide range of techniques including lasers to ablate the mineral layers and microscopy to identify "ghost cells" that contain the microbial DNA. "Getting the bacteria isn't that hard, and sequencing isn't that hard, but these layers are nanometres, microns thick. That kind of dissection is really challenging, and isolating DNA from them even more so," he says.

The major epidemiological transitions, such as changes to agricultural production, food consumption, migration patterns, urbanization and medical care that came with colonialization, likely had dramatic effects on the microbiomes of people living in West Africa at the time. These changes may have left them more susceptible to malnutrition and disease as they were forced to move away from their normal diets.

"We can look at all of these things in a laboratory, but unless we have insight into what people are doing and why they are doing it, it makes no sense," says Giles-Vernick. "Social scientists do not separate environment from human beings, but see them as enmeshed in one another, enmeshed in all of the living and non-living things around them."

Being part of the Humans & the Microbiome program has changed the way many of these researchers look at their own work. The ongoing discussions and collaboration have let them uncover hidden assumptions and biases. Giles-Vernick, who studies human contact with great apes in equatorial Africa and emerging zoonotic diseases, says the interactions have "really made me think, what is shared and what isn't shared between humans and great apes? What is the overlap of their intestinal microbiomes?"

All of these threads, when gathered together, raise larger questions about human biology, behaviour and societies. If we have evolved with our microbes – and if they have helped direct that evolution – what is happening to us as we prune and trim our microbiomes? How are we affecting the susceptibility of future generations to emerging infectious diseases or metabolic disorders? Can we learn from our past, to find a path to a healthier future?

"In the last several years, the data is really stacking up to say that we are removing microbes that are part of our normal evolution," says Finlay. "If we really think the microbiome is important, then we need to know how it is affecting humans on a larger scale." •

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Quantum

title_header_02.jpg

Insecurity

By Dan Falk

Photography by
Markian Lozowchuk

THE ABILITY TO SEND GIGABYTES OF DATA AROUND THE PLANET in the blink of an eye has transformed our world. But it comes with great risk. How do we keep files safe and secure as they zip from computer to computer and country to country? For years, we have relied on encryption systems using math problems so difficult that even a supercomputer can't solve them without the key. But this tried-and-true method may soon be obsolete, thanks to quantum computers.

"We need a stronger cyber immune system," says Michele Mosca, because our current systems have reached "an unprecedented level of vulnerability." Mosca, a senior fellow in CIFAR's Quantum Information Science program and co-founder of the Institute for Quantum Computing (IQC) at the University of Waterloo, is on a mission – to raise awareness of this cyber vulnerability before it's too late.

Michele Mosca stands in front of a clean room at the University of Waterloo.

Attack at Dawn

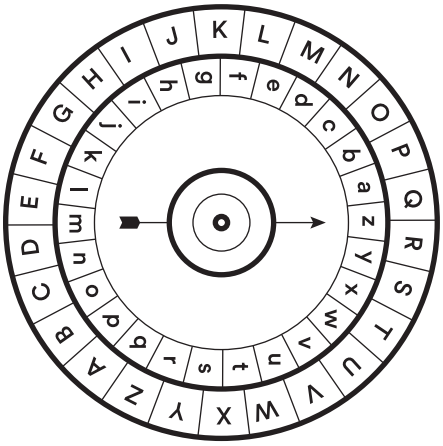
Cryptography – the coding and decoding of secret information – certainly predates computers. Substitution ciphers, where one letter is replaced by another according to a fixed rule, have been used since ancient times. An example: ATTACK AT DAWN becomes CVVCEM CV FCYP if each letter moves two places to the right in the alphabet. (It is said that Julius Caesar used such a code in his personal correspondence.) In the example above, it only takes a minute or two to encode a short message by hand; but decoding it requires a good deal of patience, as one tries various possible substitutions. Decoding, by its very nature, is the hard part. That's the whole idea.

Today's most widely used encryption techniques are mathematical at heart. One common technique exploits the basic fact that it's much easier to multiply two large numbers than to take the result and work backwards. You can use a pocket calculator – or pencil – to find out that 1,307 x 2,153 = 2,813,971. But, given the number 2,813,971, you'd be hard-pressed to work out its divisors (which, in this case, are both prime, so they're the only ones possible). You can program a computer to figure it out, of course. But if the number you want to factor is large enough, even this becomes nearly impossible.

"It takes, effectively, forever to take a 1,000-digit number and find its prime components," Mosca says.

For decades now, we've been trusting all manner of sensitive information to this sort of coding, even when we're not aware of it. Your web browser does it for you whenever you make a secure connection with your bank, buy something on Amazon, or even do a Google search. We trust everything to it – from credit card transactions to intellectual property to government secrets. And it all has the potential to fall into the wrong hands if the codes are hacked.

cipher_disk.jpg



Early cryptologists used "cipher disks" for simple substitution codes. Quantum computers could make modern encryption just as insecure.

Enter the quantum computer. Researchers worldwide are trying to apply the principles of quantum mechanics to build computers that will do things existing computers simply can't. Unfortunately for electronic security, one of the things quantum computers may be able to do is factor large numbers almost instantly.

Bits and Qubits

In a conventional computer, the basic unit of information (the bit) can be either on or off, zero or one. But a quantum bit, known as a qubit, can be in a "superposition" of two states at once – a zero *and* a one at the same time. (See Figure next page). As a result, the power of a quantum computer could expand

exponentially in proportion to the number of qubits: two qubits performing four calculations at once; three performing eight; four performing 16 – and so on. This gives quantum computers the potential to vastly outperform classical computers on certain kinds of tasks.

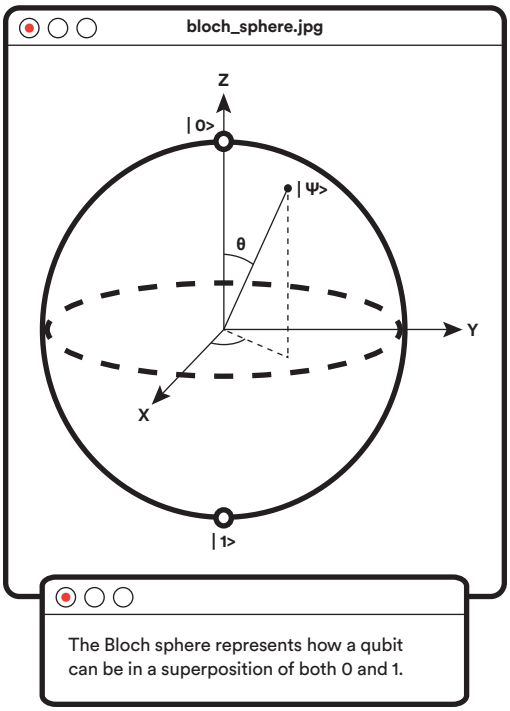
"There are certain problems they could solve very quickly that a classical computer would have to do a lot of work, using the best-known algorithms, to solve," Mosca says. But he adds that a working quantum computer would not be a magic bullet, able to solve any mathematical problem ever devised. "For most tasks, there's really no speed-up. But for some very important tasks" – such as factoring large numbers – "there's an astronomical speed-up."

Algorithms already exist for tackling such problems with a quantum computer. "Shor's algorithm," one of the first, was developed in 1994 by American mathematician Peter Shor. A number that might take a billion years for a classical computer to factor could be factored by a quantum computer in about one second, using Shor's algorithm. (The time required would be roughly proportional to N^3, where N is the number of bits in the number being factored; while a classical computer would require a time proportional to 2^N. As N increases, 2^N becomes astronomically larger than N^3, and the "quantum advantage" becomes enormous.)

How far are we from a fully functional quantum computer? Major challenges are still being faced. First, qubits need to be "stable" – that is, they need to be isolated from their immediate environment so they can maintain their superpositions for longer than a fraction of a second. Also, they need to interact with other qubits in a controlled way. And then there's error correction. Every time a bit is processed, there's a chance of making a mistake.

In classical computing, error correction can be dealt with through redundancy – encoding a 0 as 000, for instance, so that if one bit accidentally flips to a 1, the other two bits still show the correct value. Error correction isn't as easy with quantum computers. To duplicate a qubit you would have to measure it first, but that would collapse it to a single value and you would lose the advantage that qubits give you in the first place. So scientists have had to figure out other ways. For instance, one method "spreads out" the information for one logical qubit over nine physical qubits, allowing subtle measurements that can detect an error without actually disrupting the value being stored. Using these techniques and others, engineers and computer scientists at the IQC and other labs are making progress, gradually taming the problem of qubit errors.

Mosca believes we're getting close to a working quantum computer. As we spoke in his office at the IQC this winter, he outlined the seven stages on the path. The first stage is simply the encoding of qubits; the second stage is getting multiple qubits to interact; the third stage is successfully managing error correction. Fourth: getting that error rate down to the point where your system can function as a "logical bit," the equivalent of a vacuum tube in our first computers. Next: having two of these bits. Next: having many. Finally, at stage seven, you have a full-fledged, fault-tolerant quantum computer.



The Bloch sphere represents how a qubit can be in a superposition of both 0 and 1.

"I think we're really close to stage four," Mosca says. "But people are already starting to anticipate stages five, six and seven – which will have a lot of engineering challenges."

There are many reasons to be excited about the arrival of quantum computers. The problems they're best suited to – juggling huge numbers of combinations, in search of certain patterns – will make them ideal for designing materials, buildings and even the molecular structure of drugs. But, as noted earlier, this also means the power to break codes – including the public-key encryption that we currently use to protect everything from credit card transactions to government secrets.

Mosca estimates a one-in-seven chance that some of the fundamental public-key cryptography tools we rely on today will be broken by 2026. And he sees it as a 50 per cent chance by 2031.

He says the solution is to move beyond the techniques that underlie today's encryption tools, such as the factoring of large numbers. He doesn't believe quantum computation will actually kill off public-key cryptography, but he says it will force us to find more sophisticated encoding techniques. "We think it's possible. We just need to find the right kind of mathematical problems.

"There's a small group of mathematical problems that seem to have the necessary properties where they resist quantum attack. They're hard one way, easy the other way, if you have the private key."

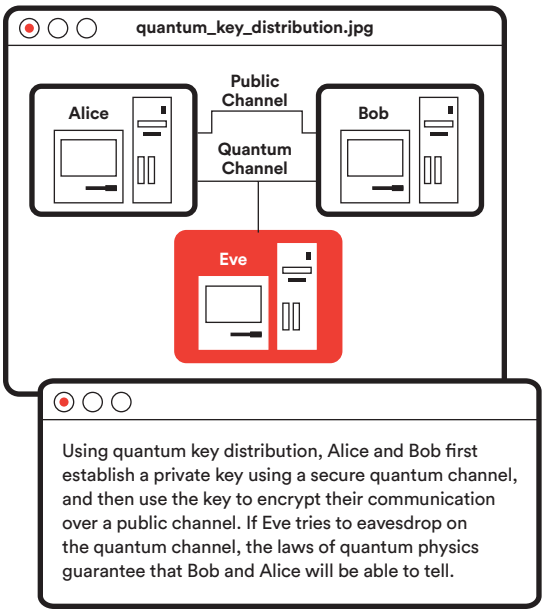
Lattice problems, for example, are a class of optimization problem that involve paths between points on a regular array. Like factoring, these kinds of problems can be easy to do one way, and very hard to do the other. (See illustration next page.)

These investigations are just beginning. Very little study has been aimed at determining which techniques are the most resistant to quantum cracking. Whatever system is developed will need to be "battle tested," Mosca says. To that end, he and Douglas Stebila, an assistant professor of cryptography at McMaster University, have launched an open-source software project. Called Open Quantum Safe, its focus is on the development of prototypes of quantum-resistant cryptography.

Fighting Quantum with Quantum

Quantum mechanics led to the problem in the first place – and may also point the way to a solution. A method called quantum key distribution, for example, would use quantum mechanics to let two people generate a secret key, but over public networks. This would rely on a quantum property called entanglement, in which two particles are entangled so that if you measure one of them, you also learn the measurement of the other.

In simplified terms, it would work like this: You exchange entangled particles with the person you want to communicate with, and measure the particles you receive until you've both taken enough measurements to create a strong key. If a third party tries to eavesdrop during this process, you'll detect a disturbance in your measurements. You'll keep trying until you have generated a key that you know is safe, i.e., until you're sure no one else has a copy.



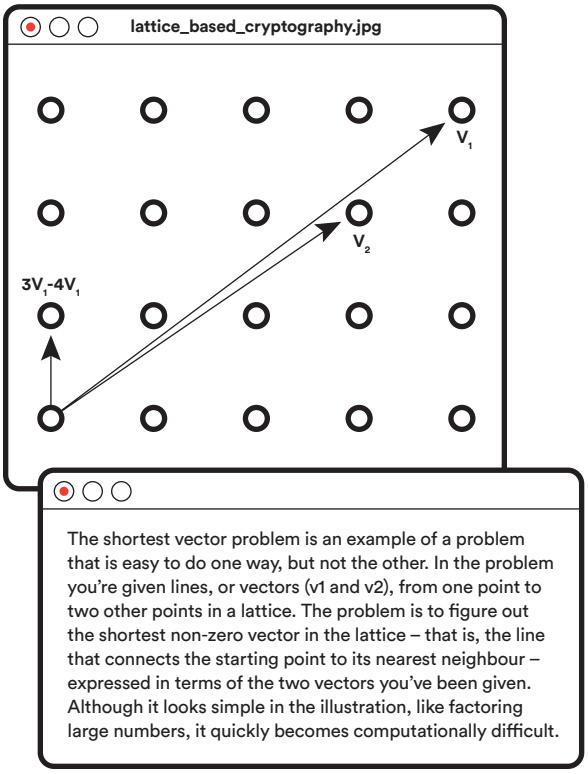
Using quantum key distribution, Alice and Bob first establish a private key using a secure quantum channel, and then use the key to encrypt their communication over a public channel. If Eve tries to eavesdrop on the quantum channel, the laws of quantum physics guarantee that Bob and Alice will be able to tell.

CIFAR fellows have made important contributions in this area. Senior Fellow Gilles Brassard and Advisor Charles Bennett developed the very first quantum key distribution protocol in 1984. More recently, CIFAR Fellow Thomas Jennewein has experimented with sending entangled pairs long distances through the air and over fibre optic cables. He hopes to soon generate them from a satellite in Earth's orbit. And a team led by Senior Fellow Wolfgang Tittel of the University of Calgary succeeded in "teleporting" the quantum state of a photon six kilometres over Calgary's municipal fibre optic network, an accomplishment that could lead to eavesdrop-proof communications networks.

Although our encryption systems are quickly becoming vulnerable, Mosca says we are being presented with an opportunity – as long as we understand the danger. For years he has been speaking to business and government leaders, alerting them to the threat. One sign that the message might be getting through: Last year in the U.S., the National Security Agency (NSA) announced a plan to overhaul its encryption systems to defend against high-level cyber attack. This public announcement by the usually secretive NSA shows that they've recognized a serious threat, says Mosca.

"They made it clear they're going to require quantum-resistant algorithms in the near future. That was a huge wake-up call for many people. Of course, we've been saying this for years. And I think it has stimulated organizations, particularly within the U.S., to come up with a plan."

Cyber security isn't cheap, of course. Defending against the attacks that a quantum computer could enable will require significant investment.



The shortest vector problem is an example of a problem that is easy to do one way, but not the other. In the problem you're given lines, or vectors (v1 and v2), from one point to two other points in a lattice. The problem is to figure out the shortest non-zero vector in the lattice – that is, the line that connects the starting point to its nearest neighbour – expressed in terms of the two vectors you've been given. Although it looks simple in the illustration, like factoring large numbers, it quickly becomes computationally difficult.

But as Mosca points out, not acting can have its own costs, and they can be enormous. A cyber attack could be truly devastating, he says. "It has the potential to undermine everything, from your democratic institutions to bleeding billions of dollars out of your country's economy."

When Mosca meets with government and business leaders, he explains that spending money now to prevent attacks in the future is a large but necessary investment. He just hopes that the message gets through soon. •

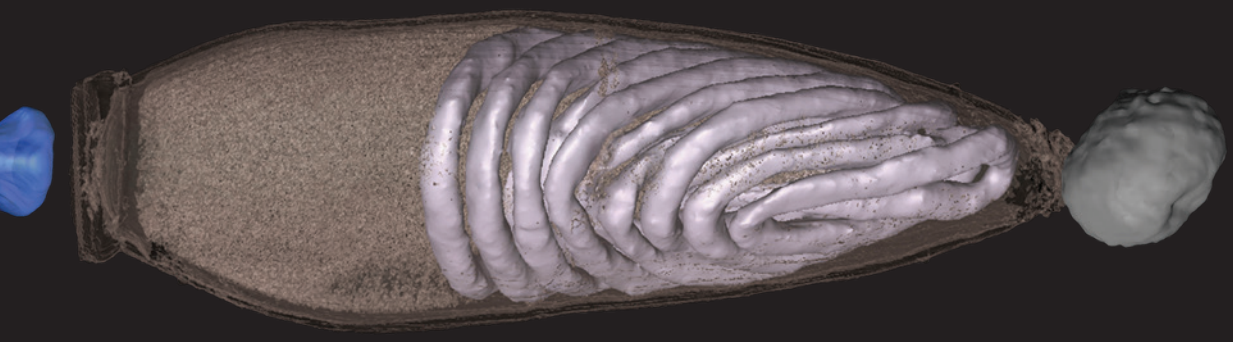
"They made it clear they're going to require quantum-resistant algorithms in the near future. That was a huge wake-up call for many people."

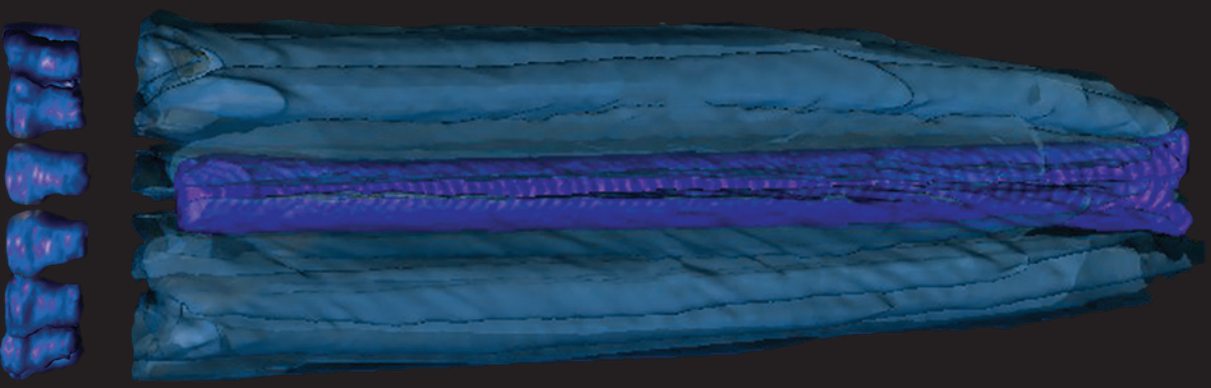
Weaponized Microbes

IN THE MICROSCOPIC ARMS RACE BETWEEN PREDATOR AND PREY, billions of years of evolution have given some organisms fearsome weaponry such as the poisonous armour-piercing harpoons and the Gatling gun-like projectile-launcher shown here.

The dinoflagellate protists *Polykrikos kofoidii* and *Nematodinium* have long been known for carrying these weapons and using them to disable the other single-celled organisms they prey on. Recently, CIFAR fellows and colleagues were able to use Focused Ion Beam Scanning Electron Microscopy to create the first three-dimensional views of the harpoon-like structures called nematocysts, and gain insight into exactly how they work.

Photo: Courtesy of *Science Advances*

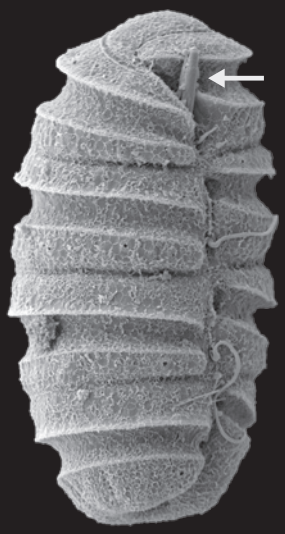




Polykrikos is shown to the right with an arrow pointing at the nematocyst. The detail of the nematocyst, top, shows the capsule that contains a sharp stylet. Connected to it and coiled below is a tubule that serves as a rope to keep the prey attached until it can be eaten.

Although the nematocysts in *Nematodinium* have the same evolutionary origin, they work in a slightly different way. Between 11 and 15 of them are arranged in a circle resembling a Gatling gun and fire off simultaneously, above.

The research was published in *Science Advances*. The lead author was Greg Gavelis, a post-doctoral researcher at Arizona State University. Senior authors were IMB Program Director Patrick Keeling and Senior Fellow Brian Leander. •



CIFAR Forum

IN NOVEMBER CIFAR BROUGHT TOGETHER MORE THAN 100 PEOPLE at Canada House in London to discuss research questions that could help improve the lives of children around the world.

The CIFAR Forum on the Well-Being of the World's Children invited people from across academia and the public and private sectors to share insights about where the gaps in research on child well-being exist, and how the different sectors can cooperate to find solutions and put them into practice.

"Having a collaborative forum to share global research and implementation experiences is a perfect way for all of us to learn, adapt and grow," said Aisha Yousafzai, associate professor of global health at Harvard, who was one of nine plenary speakers at the forum.

A major goal was to begin to build a coalition of partners that could continue to address the questions beyond the forum. CIFAR has already issued a call for workshop proposals around the topic of child well-being which should be funded by the end of the year. In addition, the Global Call for Ideas scheduled for late 2017 will target proposals for programs around child well-being.

In London, participants discussed questions organized around three broad themes: the dynamic experiences of childhood adversity, complex determinants of child development, and protecting and promoting child well-being through policies and systems.

Speakers at each panel session gave remarks that set the scene around the issue and then led an interactive group discussion. Comments were wide ranging, but a number of broad insights emerged from the meeting.

First, priority research challenges require a holistic conception of child well-being. There is a need for interdisciplinary work on the connections among biological, environmental, psychological, sociological and economic variables of development and how they interact over time.

There's a need for a clear global consensus on what is a reasonable level of child well-being. This would help researchers decide what questions to look at, and could also help decision makers decide where interventions were needed and if they were working.

"Having a collaborative forum to share global research and implementation experiences is a perfect way for all of us to learn, adapt and grow"

New research approaches and methodologies are needed to respond to global challenges. Not enough is known about long-term effects of interventions, and more longitudinal studies that track children over a long time are needed. There's also a need to understand how different factors and interventions interact with one another.

Finally, collaboration, coordination and information sharing are needed. Researchers need to work with one another across disciplines, and they also need to learn how to engage with policy makers and other stakeholders from the outset as they develop their research agendas.

The forum was supported by Global Affairs Canada, the Bill & Melinda Gates Foundation and the Canadian Institutes of Health Research-Institute of Human Development, Child and Youth Health. •

Participants in the CIFAR Forum met at Canada House in London to discuss research opportunities that could improve children's well-being.

Photo: Martina Lang

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, 2015 and May 1, 2017, and current multi-year commitments of $10,000 or more.

CIFAR is also pleased to recognize an additional $125 million investment in CIFAR by the Government of Canada dedicated to the Pan-Canadian Artificial Intelligence Strategy.

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History note
Moving on up

IT WAS 1981, and CIFAR was struggling to be born. Created on the recommendation of a committee set up by University of Toronto President **James Ham**, CIFAR had a federal charter and a board of directors, but no money, no researchers and no home – its two office staff were working in borrowed space at Massey College.

Luckily, CIFAR's founding president, **Fraser Mustard**, had discussed the problem with Ontario's Minister of Education Bette Stephenson. She arranged for the fledgling institute to take unused space at an Ontario government office building at 434 University Avenue. In 1982 CIFAR moved in, Mustard officially took office, and within short order CIFAR had secured funding and approved its first program, Artificial Intelligence & Robotics.

Thirty-five years later, CIFAR has 14 programs and almost 400 fellows and advisors from around the world. And the institute has just completed another important move – this one to the MaRS Centre, the largest urban innovation hub in the world. It's an appropriate home for a renewed CIFAR which increasingly emphasizes programs that encourage collaborative and innovative ways of thinking, and it's a great way to kick off the next 35 years. •

The building at 434 University Avenue, above, was CIFAR's first home.
Top: the atrium of the MaRS Centre.

Main photo: MaRS Discovery District

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