Annual Report 2017 - 2018

Convening Great Minds





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Message From Our Chair



CIFAR has done remarkable work throughout its history, bringing together some of the world's best researchers to examine some of the most important questions to humanity. I'm extremely proud to be able to work with this organization and I'm excited to see the progress it has made in the last five years.

This year marked what I believe is a turning point for CIFAR. After long and careful consultation, the CIFAR Board of Directors approved a new five-year strategic plan that sets out the roadmap to CIFAR's future.

The new plan is called "Advancing Excellence, Increasing Impact." It includes a clear description of CIFAR's values, goals and activities for the next five years. It is an ambitious and yet realistic plan for CIFAR to achieve the next level of global impact.

In the plan, we detail five core activities that are at the heart of what CIFAR does. They include: strengthening our global research programs; conducting a new Global Call for Ideas; continuing our work as leaders in artificial intelligence, including our leadership of the Pan-Canadian Artificial Intelligence Strategy; operating a Global Academy program to educate the science leaders of tomorrow; and expanding the knowledge exchange efforts that connect our fellows and programs with potential users of the new insights, knowledge and technologies that are generated by our programs.

Perhaps just as important, the plan articulates the six core values that underpin everything CIFAR does. These values are excellence, creativity, collaboration, diversity, risk-taking and respect. It is these values, together and in combination, that will lead to our continued success.

The past five years have been a time of building on CIFAR's long history of excellence and driving towards making maximum impact on the world. I believe we have made tremendous progress under the leadership of Dr. Alan Bernstein. Armed with this new strategic plan, I believe CIFAR will complete its transition into the first rank of global research institutions, a position that will allow it to successfully address the challenges that face the world.

Barbara Stymiest Chair, CIFAR Board of Directors

Message From Our President & CEO

CIFAR has a long and distinguished history as a research institution that creates positive impact on the world. For close to 40 years, CIFAR has convened interdisciplinary teams of the world's best minds and facilitated their efforts to address complex challenges too large and open-ended for traditional funding mechanisms. Our approach to addressing questions of importance to the world has been to convene global communities of top scientists and scholars – regardless of country or discipline. Today, our 373 fellows, advisors and scholars come from 22 countries and over 120 institutions.

This disarmingly simple formula sparked and spurred world-leading discoveries across a broad range of fields since our founding in 1982. Together, CIFAR fellows have tackled and solved some of humanity's most important questions – from understanding the lifelong consequences of early childhood experiences to catalyzing the development of today's Al revolution.

I believe that this year was truly an inflection point for CIFAR, one that saw the institution advance to the next level as a recognized global player, one that is known and trusted by researchers and institutions around the world.

Consider just a few of our successes this past year. In November, *The Economist* wrote an article that lauded CIFAR's unique research model, and credited it with kick-starting the artificial intelligence revolution.

This year CIFAR co-sponsored a workshop together with the US Department of Energy and the Mexican Ministry of Energy (SENER), co-led by CIFAR Senior Fellow Alán Aspuru-Guzik, that laid out a revolutionary new approach to materials discovery for harvesting and storing solar energy. The report that resulted from that workshop was part of Mission Innovation, the group of 20 countries plus the EU countries that came together during the Paris Climate Change Accord meeting. That report is now serving as the scientific roadmap for a number of countries, including Canada, as they ramp up their research into clean energy.

More recently, we are partnering with two major international science funders – France's National Centre for Scientific Research (CNRS) and UK Research and Innovation (UKRI) – to run a series of workshops to explore the ethical, social, legal and economic impacts of AI research.

This year we also continued to build the \$125 million Pan-Canadian Artificial Intelligence Strategy, established by the federal government and led by CIFAR. Dr. Elissa Strome was appointed as the executive director, and we also appointed an internationally renowned scientific advisory board. The program is just one part of CIFAR's global leadership in Al, which we can trace back all the way to our very first research program, called Artificial Intelligence, Robotics & Society.

If it's true that you can judge someone by the company they keep, then CIFAR can clearly be judged as having joined the top ranks of international science institutions. Of course, at the core of everything we do is research excellence, and we continued to demonstrate that. With hundreds of top re-



searchers from across the world in our 12 research programs, CIFAR is helping to drive forward research that answers questions of importance to the world, as detailed at length in the research section and program pages in this report.

This year we also began the enormous and important task of refreshing our programs of research, beginning with the launch of the second Global Call for Ideas, which resulted in 103 applications from researchers from 50 countries. We are now in the process of considering proposals from 12 finalists, as well as the renewal applications from six of our existing programs. The process will result in a refreshed slate of programs by 2019, aimed at building a portfolio of cutting-edge research programs that address the most exciting scientific questions and the most important problems facing humanity today.

I am very pleased at the progress CIFAR continues to make, and about the exciting future ahead for the organization. Thank you to everyone who has made this success possible – our Board of Directors, donors and partners, our fellows, advisors, advisory council members and staff.

> Alan Bernstein, OC, PhD, FRSC President & CEO



Year in Review

Introduction

This year saw CIFAR attain major achievements, recognition and impact in its mission to bring together outstanding researchers to address important global challenges. Externally, we were recognized by major research organizations, governments, media and our partners for the excellence of what we do. And internally, we finished the first five-year phase of CIFAR's renewal, and launched into a second five-year phase with a bold new Strategic Plan that outlines a refreshed mission and vision, along with a roadmap to completing them.

As you will read in this Annual Report, this year CIFAR began its second Global Call for Ideas, which attracted 103 letters of intent from researchers from 50 different countries. CIFAR is now conducting a thorough selection process, with the intention of announcing next year which applicants will be selected to form new programs. Fellows in our 12 programs continued to create new knowledge with the potential to impact the world. We named the second cohort of 15 CIFAR Azrieli Global Scholars, who will work with fellows across our research programs. We expanded and refined our Ideas Exchange efforts to connect knowledge created by CIFAR programs with knowledge users.

This year, CIFAR's Board of Directors approved the CIFAR Strategic Plan 2018-2022: Advancing Excellence, Increasing Impact. The plan recognizes that CIFAR has made major advances in its core efforts to create new knowledge for a better world. It also recognizes that the world and the research landscape are changing. The way science is done has become faster, more global, and more interdisciplinary than it was in 1982, when CIFAR was founded. At the same time, the problems facing the world have become more complex. From climate change to terrorism to inequality, the world's problems require long-term and interdisciplinary efforts.

The new strategic plan recognizes that CIFAR's unique approach and our strengths put it at the nexus of these changes, and position it to have major impact. The CIFAR approach features four mutually reinforcing characteristics – a focus on complex global challenges; global, interdisciplinary networks; an environment that fosters deep collaboration; and sustained, long-term commitments.

CIFAR will continue over the next five years to maintain the highest standards of research excellence and deliver on three interconnected areas of accountability: Knowledge Creation; Development of Future Research Leaders; and Knowledge Mobilization. Specifically, we will focus on five areas of activity. They are:

- > Core Research Programs
- > The Global Call for Ideas
- > Artificial Intelligence Leadership Activities
- > The Global Academy
- > Ideas Exchange





Top: Element AI SVP Research Philippe Beaudoin and CIFAR Senior Fellow Joelle Pineau spoke about Montreal's strength in artificial intelligence at a CIFAR event hosted by Power Corporation. Above: CIFAR Board Member Olivier Desmarais, Senior Vice-President, Power Corp.; CIFAR Senior Fellow Yoshua Bengio; Beaudoin; Pineau; Chief Scientist of Quebec Rémi Quirion; Pierre Boivin, Chairman of the Board, Mila.

Improving the world through interdisciplinary research

CIFAR creates knowledge that addresses the complex global challenges facing the world. We do that by convening international and interdisciplinary groups of researchers who interact closely for long periods of time, and focus on asking and answering questions of importance to the world.

The essence of our model is to select from among the best researchers in the world, regardless of country or discipline, and foster long-term, sustained interactions, building global communities of some of the world's very best investigators. We enable a dialogue that drives innovation and collaboration, leading to the creation of transformative knowledge.

This year a total of 373 researchers – including 280 Fellows, 60 advisors, and 33 CIFAR Azrieli Global Scholars – were engaged across CIFAR's 12 core research programs. The fiscal year saw five new fellows appointed to CIFAR's programs.

CIFAR brings together researchers from dozens of disciplines and all parts of the world. A full 58 per cent of our fellows hail from outside of Canada. They are among the most prestigious researchers in the world - this year CIFAR program members contributed to the creation of new knowledge through written works that included 2,967 major publications, including peer-reviewed articles, books, and conference proceedings. And our fellows were honoured with 90 major national and international awards and honours, such as the Guggenheim Fellowship, the Killiam Prize, and appointments to the Royal Society of Canada.

At the core of our research are the 12 programs, which range across the research landscape, from artificial intelligence to clean energy to cosmology and gravity. This year, CIFAR held 29 program meetings which brought together 275 guests from 15 countries to interact with CIFAR fellows and advisors and share their knowledge of frontier research areas. Activities of these individual programs are detailed beginning on page 25.

CIFAR also continued to create opportunities for collaboration and discussion among members of our programs in interaction meetings.



Clockwise from top left: A cap used to collected EEG data from people engaged in real-world tasks; Alona Fyshe, Joel Zylberberg and Craig Chapman are carrying out the research.





Catalyst Programs

CIFAR's new Catalyst Program has been designed to foster and stimulate collaborative projects between fellows within or across our programs. Projects can include institutional visits between fellows, research workshops, and shared trainees working on short-term collaborative research projects both within and across programs. To date, CIFAR has supported over 55 collaborative projects between CIFAR fellows. The examples below demonstrate the breadth, scope and creativity of these projects, as well as some of the ground-breaking results that CIFAR has helped to catalyze.

EEG in the Wild

Brain imaging experiments are often carried out in highly controlled laboratory situations where virtual stimuli can easily be manipulated and responses measured. But how does the brain respond when it is engaged in real world tasks? CIFAR Azrieli Global Scholars **Craig Chapman** and **Alona Fyshe** (both University of Alberta) – members of the Azrieli Program in Brain, Mind & Consciousness – and **Joel Zylberberg** (University of Colorado, Denver) – member of the Learning in Machines & Brains program – are exploring brain imaging outside of the lab, in more naturalistic settings. The research team has begun collecting electroencephalography (EEG) data combined with eye and motion capture in controlled settings, with the long-term goal of extending this to measuring data from participants performing daily activities around their homes. Initial results have been presented at a number of national and international symposia and workshops, including at the 2018 Game Developers Conference, where the results are seen to have potential applications in virtual reality and gaming. (See page 22)

Understanding the brain

Thirty-nine CIFAR fellows from seven programs and many disciplines gathered March 12-13 in the inaugural CIFAR Brain Symposium in Toronto. The symposium was intended to foster new opportunities for interdisciplinary research and collaboration.

Researchers in brain-related fields share many common goals, such as discovering the best ways to use new data capture and brain imaging tools. Other issues discussed at the symposium included: the microbiome's role in human brain health; the latest findings around neuro-developmental and neuro-degenerative conditions, such as autism and Alzheimer's disease; advances in vision and language research; and the effects of individual differences in brain development.

"The thought-provoking talks spurred intense discussions and friendly disagreements. I think we all learned an enormous amount from each other," said **Sheena Josselyn** (Hospital for Sick Children), a neuroscientist and Senior Fellow in the Azrieli Program in Brain, Mind & Consciousness. She co-planned the symposium's program with **Blake Richards** (Learning in Machines & Brains; University of Toronto), **Takao Hensch** (Child & Brain Development; Harvard University), and **Brett Finlay** (Humans & the Microbiome; University of British Columbia).

At the event, scientists studying how adversity affects development, as well as the nature of consciousness, traded insights with those working in the field of artificial intelligence and deep learning. The symposium revealed the many ways in which biological and machine study inform and complement each other.

CIFAR is grateful to its research partners, including Brain Canada, Fonds de recherche du Québec, Genome British Columbia, Genome Canada, Inria and Western University for their support of CIFAR's brain-related research programs.



CIFAR fellows from seven different programs met over two days to trade interdisciplinary insights about our understanding of the brain.

Christianity in late Antiquity: Effects of divinelysanctioned social norms on the social structure of Medieval Europe

During the late Antiquity (ca. 200-700 A.D.), the spread of a particular brand of Christianity in Europe was driven by new divinely-sanctioned social norms. These social norms, which were completely different from the complex kinship systems of all previous human societies, completely altered the social structure of Medieval Europe, including concepts around inheritance, ownership, and marriage. The change eventually led to new social structures and concepts including voluntary organizations, urbanization, commercial law, and new forms of political institutions.

CIFAR Senior Fellows **Joseph Henrich** (Harvard University) and **Avner Greif** (Stanford University), both members of the Institutions, Organizations & Growth program, have been exploring how similar shifts in social norms and cultural evolution are shaping society today. The researchers are testing the possible underlying causes of cultural change and trying to document historical patterns. Two publications are currently in preparation.

'Active Environments' in Light Harvesting

Understanding how light is absorbed by plants and photosynthetic organisms and subsequently funneled towards 'reaction centres' is the key to better understanding efficient light harvesting and energy conversion, in both natural and artificial systems. Senior Fellows in the Bio-inspired Solar Energy program, Alán Aspuru-Guzik (Harvard University), **Rienk** van Grondelle (Vrije Universiteit Amsterdam) and Gregory Scholes (Princeton University), collaborated to understand how this energy transfer and funneling occurs in a particular type of light absorbing pigment protein complex known as PC645, which is found in cyanobacteria. The results point to an entirely new mechanism for energy transfer known as 'incoherent vibronic transport,' which stands in opposition to the previously-accepted mechanism. This work was recently published.

> Scholes, Aspuru-Guzik et al. (2018) "Local protein solvation drives direct down-conversion in phycobiliprotein PC645 via incoherent vibronic transport." Proceedings of the National Academy of Sciences. DOI: 10.1073/pnas.1800370115. van Grondelle, Aspuru-Guzik et al. (2018) "Mechanistic Regimes of Vibronic Transport in a Heterodimer and the Design Principle of Incoherent Vibronic Transport in Phycobiliproteins." *Journal of Physical Chemistry Letters*, 9: 2665.

Research Workshops

CIFAR's research workshops are designed to bring together researchers and partner organizations from around the world to explore key questions of global importance that are timely, high-risk, or have strong potential for advancement through interdisciplinary collaboration.

This year CIFAR held 10 research workshops in six countries. Five of the workshops focused on child and well-being to connect with stakeholders from the CIFAR Forum held in 2016. CIFAR partnered with organizations including **UNICEF**, Sciences Po, The Nuffield Foundation, Jacobs Foundation and See Things My Way: Centre for Innovation in Autism and Intellectual Disabilities. The workshops were:

- **1. Famines and Vulnerability of Adolescents** (Florence, Italy from October 16-27, 2017), with support from the UNICEF Office of Research-Innocenti
- 2. Revisiting Core Concepts in Autism with New Tools (Boston, MA from December 1-2, 2017), in partnership with the See Things My Way: Centre for Innovation in Autism and Intellectual Disabilities and the Miriam Foundation

- 3. Earth 3D Subsurface Science and Exploration (Toronto/ Sudbury, ON, from December 4-8, 2017), with support from The Nuclear Waste Management Organization
- New Measures in Adolescent Development (Oxford, UK, from December 11-14, 2017), with support from Young Lives
- 5. Multisystemic Resilience (Pretoria, South Africa, from December 11-15, 2017), with support from *The Resilience* Research Centre at Dalhousie and *The University of Pretoria*
- 6. Governance, Crisis and Disorder in the Metropolis (Paris, France from December 14-15, 2017), with support from *Sci*ences Po
- 7. Inequalities in Child Development (London, UK, December 18, 2017), with support from *The Nuffield Foundation*
- 8. Supporting International Dialogue on Children and Work (Florence, Italy from February 19-21, 2018), in partnership with the Jacobs Foundation, and with additional support from Children & Work and UNICEF Office of Research-Innocenti
- 9. Smart Inclusive Cities (Banff, AB, from May 26-27, 2018)
- What's at Stake in the Fourth Industrial Revolution? (Computer History Museum, Mountain View, CA, from June 16-17, 2018)

Gravitational waves detected from colliding neutron stars

This year, scientists including CIFAR fellows directly detected the first sign of gravitational waves from the spectacular collision of two neutron stars. They were simultaneously able to detect visible light from the merger.

Neutron stars are the smallest, densest stars known to exist and are formed when massive stars explode in supernovas. As these neutron stars spiraled together, they emitted gravitational waves that were detectable for about 100 seconds. They also released electromagnetic radiation in the form of X-rays, ultraviolet light, optical, infrared, and radio waves.

The observation made on August 17, 2017, was reported by a collaboration of scientists from around the world, and marked the first time that a cosmic event was detected through both light and gravitational waves – the ripples in spacetime predicted a century ago by Albert Einstein's general theory of relativity.

The discovery heralds a new era of multi-messenger astronomy, in which different kinds of electromagnetic radiation and gravitational waves combine to teach us more about the universe than either could by itself.

Five CIFAR researchers in the Gravity & the Extreme Universe program were involved in the discovery: Harald Pfeiffer, Gabriela Gonzalez, Vicky Kalogera, Daryl Haggard and Parameswaran Ajith.







An illustration of the neutron star collision. Clockwise from top left: Harald Pfeiffer, Vicky Kalogera, Daryl Haggard and Parameswaran Ajith



Distribution of CIFAR Researchers by Region

29 program meetings held in 8 countries 20 workshops held or supported in 9 countries with 28 organizations



> Fellows: **63%** > Advisors: **60%**

*Percentage of CIFAR researchers contributing to the top 1% of most-cited papers at world level from 2010-2015 based on data compiled by Science Metrix.

Innovative new radio telescope will scan the universe

A Canadian telescope with unprecedented abilities to image the sky and capture signals from space was unveiled on September 7 in Kaleden, BC. The newly completed radio telescope will open the universe to a new dimension of scientific study thanks to key contributions from CIFAR researchers.

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a radio telescope made up of "half-pipe" reflectors with an array of radio receivers along the focus. Unlike other radio telescopes, it has no round dish and no moving parts. CHIME will survey more than half the sky each day as the Earth turns.

CHIME captures radio frequencies that can map hydrogen gas in the universe, which will allow scientists to create a three-dimensional map of the largest volume of space ever surveyed. This will help us better understand the history of the universe, the nature of distant stars and will help with the study of gravitational waves.

CHIME brings together scientists from the University of British Columbia, the University of Toronto, McGill University, and the Dominion Radio Astrophysical Observatory, where the telescope was built.

In addition to mapping the universe, CHIME captures a frequency range that is ideal for studying fast radio bursts – transient flashes in the sky that last milliseconds. First noted in 2007, their origin is still a mystery.

The \$16-million investment for CHIME was provided by the Canada Foundation for Innovation and the governments of British Columbia, Ontario, and Quebec, with additional funding from the Natural Sciences and Engineering Research Council and CIFAR.



CHIME's innovative design will help researchers map the structure of the Universe, and might help determine the origins of mysterious fast radio bursts.



Thirty early-career researchers from Canada and Japan came together at the Japanese-Canadian Frontiers of Science Symposium in Okinawa, co-organized by CIFAR.

Developing Global and Canadian Partnerships

CIFAR is continuously working to expand its portfolio of research partners and develop new relationships with strategically aligned research organizations, corporations, foundations and governments nationally and internationally. Our partnership efforts help to connect CIFAR fellows with like-minded organizations in Canada and around the world.

CIFAR has a broad portfolio of research partnerships with key international and Canadian organizations, including Brain Canada, the Gordon & Betty Moore Foundation, Inria, Fonds de recherche du Québec, Genome Canada, Genome British Columbia, Ontario Genomics and Western University. These partnerships build on shared research interests and goals and provide a platform for exchanging ideas and building collaborative networks.

CIFAR also partnered with 25 organizations in nine countries to host or support 18 program meetings, workshops or special events in Canada and abroad, with eight CIFAR programs holding at least one of their program meetings outside of Canada. Partners included: African Academy of Sciences, African Institute for Mathematical Sciences, Berggruen Institute, Centre national de la recherche scientifique (CNRS), Collège de France, the Future of Life Institute, Global Young Academy, Gordon and Betty Moore Foundation, Jacobs Foundation, Japan Society for the Promotion of Science (JSPS), London School of Economics and Political Science (LSE), Max Planck Institute for the Structure and Dynamics of Matter, Nanyang Technological University in Singapore, Secretaria de Energia (SENER) in Mexico, Sciences Po, and the U.S. Department of Energy (DOE).

By teaming up with other research organizations to hold joint research meetings, symposia and workshops on challenging questions of shared interest, CIFAR expands its global networks, enabling the organization to tap into new sources of talent, leverage our resources and strengthen the global profile of CIFAR and our research programs.

Global Call for Ideas

In Fall 2017, CIFAR launched its second Global Call for Ideas, inviting the global research community to submit proposals for new programs that address complex, fundamental questions of importance to the world. CIFAR challenged the research community to submit ideas that were sufficiently novel, bold, and potentially transformative to warrant the creation of a sustained, interdisciplinary, and collaborative research program.

The first Global Call for Ideas in 2014 resulted in four new CIFAR programs: The Azrieli Program In Brain, Mind & Consciousness; Bio-inspired Solar Energy; Humans & the Microbiome; and Molecular Architecture of Life.

The second Global Call was officially launched on November 15, 2017 and closed on January 21, 2018.

Review Process

A total of 103 letters of intent (LOI) were submitted by teams of researchers from 50 different countries. LOI topics included migration and citizenship, the origins of life, child well-being, and many others.

LOI submissions were reviewed by internationally recognized research leaders in relevant topic areas from around the world. These reviews addressed the significance and impact of the proposed research, the team's expertise, and proposed leadership.

The President's Research Council deliberated on the shortlisted proposals and made recommendations to CIFAR's President. Twelve teams were selected to advance to the Full Proposal development stage of the competition.

The 12 final teams represent 14 countries and a wide range of disciplines, and each convened a two-day workshop between June and September 2018. The workshop allowed teams to refine and deepen their research program proposal, expand their team, and prepare for the full proposal submission on October 1, 2018. Full proposals will be sent to a panel of expert reviewers to assess the proposal. Ideas for new programs will be assessed alongside ideas proposed from the six renewing research programs: Child & Brain Development; Genetic Networks; Institutions, Organizations & Growth; Learning in Machines & Brains; Quantum Information Science; and Quantum Materials.

CIFAR is assembling an International Assessment Panel (IAP) to assess all 18 ideas for new CIFAR programs. The IAP will provide its recommendations to the President's Research Council. Decisions on new programs will be made by the board in Spring 2019.

12 Global Call finalists

- > CIFAR Program for Accelerated Discovery of Matter Alán Aspuru-Guzik (University of Toronto) and Jason Hein (University of British Columbia)
- Boundaries, Solidarities and Collective Action Citizenship
 Irene Bloemraad (UC Berkeley) and Will Kymlicka (Queen's University)
- Understanding the Determinants and Impact of Distribution-Sensitive Innovation Policies
 Dan Breznitz (University of Toronto) and Amos Zehavi (Tel Aviv University)

> Microbial Pathogens in the Fungal Kingdom: Threats to Biodiversity,

Agriculture, and Global Health Leah Cowen (University of Toronto) and Joseph Heitman (Duke University)

- How Can Society Most Effectively Leverage Machine Intelligence to Enhance Social Welfare and Economic Efficiency?
 Avi Goldfarb (University of Toronto), Catherine Tucker (Massachusetts Institute of Technology) and Ajay Agrawal (University of Toronto)
- Light to Life (Study of photosynthesis)
 Kurt Konhauser (University of Alberta) and Paul Falkowski (Rutgers University)
- > Urban Governance and City-ness: The Production of Alternative Forms of Order in the 21st Century Metropolis
 Patrick Le Galès (CNRS) and Michael Storper (UCLA and LSE)
- Microbial Metabolites in the Ocean Carbon Cycle
 Mary Ann Moran (University of Georgia) and Elizabeth Kujawinski (Woods Hole Oceanographic Institution)
- Fundamental Interactions (Quantum Information Science and Quantum Physics)

Christine Muschik (University of Waterloo) and Karl Jansen (NIC/DESY Zeuthen)

- Earth 4D Subsurface Science and Exploration
 Barbara Sherwood Lollar (University of Toronto) and Jack Mustard (Brown University)
- Multisystemic Resilience: Adaptation and Transformation in Contexts of Change and Adversity
 Michael Ungar (Dalhousie University) and Katrina Brown (University of Exeter)
- Emergence in Living and Non-living Systems
 Peter Zandstra (UBC) and Hiroaki Kitano (Systems Biology Institute)

Artificial Intelligence Leadership Activities

CIFAR has a long and influential history of supporting artificial intelligence research. In 2017, the Government of Canada chose us to lead the \$125 million, five-year Pan-Canadian Artificial Intelligence Program, which includes research into the societal implications of AI.

CIFAR has a long and influential history of catalysing today's revolution in Al. The very first CIFAR program in 1983 was AI, Robotics & Society. In 2004 we launched what is now the Learning in Machines & Brains (LMB) program, with the goal of learning how human neural networks might form the basis of artificial intelligence. CIFAR's LMB program has brought together pioneering researchers in the field of AI from across Canada and around the world, including program founder Geoffrey Hinton, and current co-directors Yoshua Bengio and Yann LeCun, and has played a major role in launching the current Al revolution.

In part because of this leadership, in 2017 the Government of Canada approached CIFAR and asked it to lead an innovative new \$125 million, five-year **Pan-Canadian Artificial Intelligence Strategy**. The Strategy has four pillars:

- > Centres of Excellence for Al Research and Innovation: Establish interconnected nodes of scientific excellence in Canada's three major centres for Al in Edmonton (Amii), Montreal (Mila) and Toronto (Vector Institute).
- > Canada CIFAR Chairs in Al: Increase the number of outstanding Al researchers and skilled graduates in Canada.
- > **Pan-Canadian Activities:** Support a national research community on AI.
- > AI & Society: Develop global thought leadership on the economic, ethical, policy and legal implications of advances in AI

In January 2018, **Dr. Elissa Strome** was appointed CIFAR's Executive Director of the Pan-Canadian AI Strategy. Dr. Strome holds a PhD in Neuroscience from the University of British Columbia and was previously a senior research administrator at the University for Toronto for nine years prior to joining CIFAR. Dr. Strome works closely with our three national AI Institutes (see below) and AI researchers across the country to implement the Pan-Canadian AI Strategy.

The Al Institutes

This year saw the incorporation of three independent research institutes each designed to build on the academic excellence at their affiliated universities and to interact with and strengthen their associated innovation ecosystems. The three are: the Alberta Machine Intelligence Institute (Amii) in Edmonton; Mila in Montreal; and the Vector Institute in Toronto. All are in the process of building impressive leadership and research teams and establishing dedicated research and administrative facilities within the hearts of their respective innovation ecosystems. CIFAR has executed funding agreements with all three of the Al Institutes. The Institutes all operate in close partnership with their local universities and receive significant additional funding from their provincial governments. While each of the Al Institutes has their own research priorities and strengths, they are all dedicated to advancing Canada's research excellence in Al,



Students came from around the world to attend CIFAR's Annual Deep Learning & Reinforcement Learning Summer School in Toronto. The school was offered by the CIFAR's Learning in Machines & Brains program and Pan-Canadian AI Strategy, in partnership with the Vector Institute.

training the next generation of students and working closely with industry and other partners to implement AI applications for positive social impact.

CCAI Chairs

The **Canada CIFAR AI (CCAI) Chairs Program** is the cornerstone program of the Pan-Canadian AI Strategy. A total of \$86.5M over five years has been earmarked for this program. The goal is to recruit and retain in Canada some of the world's leading researchers in AI and support their research programs and trainees. At least 50 CCAI Chairs will be named across the three AI Institutes over the next few years.

CIFAR has established a prestigious International Scientific Advisory Committee (ISAC), who have responsibility for making recommendations on Canada CIFAR AI Chair appointments and providing overall advice and guidance on the Pan-Canadian AI Strategy.

The members of ISAC are international scientific leaders from major institutions and companies around the world, including Google, DeepMind, Facebook and the French national science agency. They are:

> Prof. Shirley Tilghman, OC, FRS (Chair),

President Emerita, Princeton University; United States

> Dr. Jennifer Chayes

Technical Fellow & Managing Director; Microsoft Research New England, New York City and Montreal

> Dr. Victoria Krakovna

Research Scientist, DeepMind; Co-Founder, Future of Life Institute, United Kingdom

> Prof. Yann LeCun

Co-Director, CIFAR Program in Learning in Machines & Brains; Chief Al Scientist, Facebook; Professor, New York University, United States

> Prof. Fei-Fei Li

Director, Stanford Artificial Intelligence Lab; Associate Professor, Stanford University; Advisor, Google, United States

> Prof. Antoine Petit

Member, CIFAR Research Council; President, National Center for Scientific Research (CNRS), France

> Prof. Sebastian Seung

Advisor, CIFAR Program in Learning in Machines & Brains; Evnin Professor in Neuroscience, Professor of Computer Science, Princeton Neuroscience Institute, United States

> Prof. Max Welling

Fellow, CIFAR Program in Learning in Machines & Brains; Research Chair in Machine Learning, University of Amsterdam, Netherlands

National Program of Activities

A key component of the Pan-Canadian AI Strategy is the National Program of Activities. These are a series of workshops, training programs, conferences and other events to bring AI researchers from across Canada together to foster collaboration and partnerships, increase the number of highly-skilled graduates in AI and advance AI research and innovation.

This year CIFAR named a National Program Committee with membership across the AI Institutes, CIFAR, and the Waterloo and Vancouver AI ecosystems:

The Founding of Maple Valley

In its Nov. 4 edition The Economist published an article praising CIFAR for its innovative model and crediting it with helping to make Canada a leader in artificial intelligence research.

Entitled "The Founding of Maple Valley: How Canada's Unique Research Culture Has Aided Artificial Intelligence," the story examined CIFAR's beginnings in 1982, as a "university without walls" in which researchers could work across countries and disciplines. Five years later one of these researchers, Geoffrey Hinton, joined the organization to begin work on the burgeoning field of artificial intelligence. This led to the establishment in 2003 of CIFAR's Neural Computation and Adaptive Perception program (NCAP) – known today as Learning in Machines & Brains.

"Learning in Machines & Brains funds researchers from all over the world, not just Canada," the story noted. "It does not require them to work in the same place. But by providing them with modest financing and a framework for collaboration, it has created a breeding ground for out-of-the-box ideas."

"How did this breakthrough emerge from the land of moose and maple syrup?" the story asked. "Canada cannot compete with America in research funding. Instead, it has made a virtue of limited resources, developing an alternative model of innovation based on openness to unorthodox ideas."

> Prof. Doina Precup (Chair),

Senior Fellow, CIFAR Program in Learning in Machines & Brains; Mila faculty member; Associate Professor of Computer Science, McGill University

- Prof. Michael Bowling Amii faculty member; Professor of Computing Science, University of Alberta
- > **Dr. Garth Gibson** President and CEO, Vector Institute
- Prof. Randy Goebel
 Amii faculty member; Professor of Computing Science, University of Alberta
- Dr. Roger Grosse
 Vector Institute faculty member; Asstistant Professor of Computer Science, University of Toronto
- > Prof. Greg Mori Research Director, Borealis Al Vancouver; Professor of Computing Science, Simon Fraser University
- > Valerie Pisano,
- President and CEO, Mila
 Dr. Elissa Strome
 Executive Director, Pan-Canadian Al Strategy, CIFAR
- > Prof. Peter van Beek
 Co-Director, Waterloo Al Institute; Professor of Computer
 Science, University of Waterloo



Pineau discusses Al revolution at CIFAR Massey Talk

CIFAR Senior Fellow Joelle Pineau analyzed Canada's Al revolution at the annual CIFAR Massey Talk Oct. 23, and said it would lead to advances in sectors across society, including those as divergent as healthcare and transportation.

"We're calling it a revolution because the impact of the new artificial cognitive technology is really showing up in many different sectors of our economies and our societies," said Pineau, who co-directs McGill University's Reasoning and Learning Lab and heads the new Facebook AI Research Lab in Montreal.

Though AI research goes back to the 1950s, major breakthroughs didn't come until recently. Now, scientists don't need to program pages of instructions, but instead can show a machine how to make its own decisions. Canadian researchers have been in the forefront of the research, she said.

"Here in Canada we've been really lucky to be at the forefront of this revolution. We've been sitting in the front seat watching it happen because we had some of the leading researchers... [CIFAR fellows] Geoff Hinton, Yann LeCun, Yoshua Bengio and of course the great population of grad students who they've trained over the years," Pineau said.

Pineau said that she is particularly interested in Al applications for healthcare. Currently, her lab is working with top neuroscientists to explore better ways to treat epilepsy. She said one of the biggest challenges in Al is training enough researchers to keep up with demand across all fields.

She also called for more diverse representation of thought in the field. "As a woman in tech, this has been a familiar theme throughout my career. There's really a sense that as researchers a lot of our job is picking the right questions to ask. And when we pick the question, we're directing the research agenda." CIFAR hosted, sponsored and organized a series of workshops and training programs in 2017-18 as part of our Pan-Canadian AI Strategy National Program of Activities. These included:

- > Al for Public Health: A joint workshop with CIHR's Institute of Population and Public Health, January 2018, Toronto. The workshop brought together public health and machine learning experts to understand the opportunities for Al applications to advance public health research and policy.
- > Al for Social Good Summer Lab: A program organized by McGill University, Mila and the Osmo Foundation and sponsored by CIFAR. This annual six-week program for female undergraduates provides foundational training in machine learning and helps them develop new Al solutions to social problems.
- > Invent the Future Summer Camp: A program organized by Simon Fraser University as part of the Al4All Initiative and sponsored by CIFAR. This two-week program for Grade 11 girls introduces them to the field of Al, exposes them to career opportunities and gives them a chance to work in teams to develop Al solutions in an area of interest.

The principal training program of the Pan-Canadian Al Strategy is CIFAR's Annual **Deep Learning & Reinforcement Learning Summer School**. Organized and supported by CIFAR's LMB program since 2005, this summer school has an international reputation as one of the best training programs in Al. In summer 2018, it was incorporated as part of the Pan-Canadian Al Strategy for the first time and delivered by the Vector Institute in Toronto, with tremendous success. The 10-day intensive training program for 250 attendees from 20 countries included lectures from the world's leading Al researchers and an industry-sponsored jobs and data fair.

AI Partners

Al is a field of research and innovation that is of broad interest to both the public and private sectors. While the potential for positive impact of Al applications in healthcare, transportation, clean energy and many other areas is significant, there are important societal implications that also must be considered. CIFAR is working with partners across sectors to advance Al research and innovation in a socially responsible manner.

In September 2017, Facebook and CIFAR announced a new partnership as part of Facebook's establishment of its first Canadian AI Research lab in Montreal. The partnership also includes funding for a Montreal-based **Facebook CIFAR Chair in AI**, as part of the CCAI Chairs Program.

AI & Society

This year, CIFAR launched the AI & Society Program, dedicated to exploring the societal implications of artificial intelligence. To catalyze interdisciplinary and intersectoral collaboration on this important emerging area, CIFAR issued an **International Call for Workshops on AI & Society** with three themes: policy considerations; global dynamics of AI; and, discovery and creation. CIFAR received 39 applications from a variety of disciplines, and members of the application teams originated from 81 organizations located in 21 countries. CIFAR is evaluating the submissions and will announce the funded workshop proposals shortly. As part of this effort, each workshop will be supported to deliver a relevant,

A road map for the clean energy revolution

New methods in AI and robotics could create "self-driving labs" that automate the discovery of new clean energy materials. That's one possibility laid out in a report by an international panel of experts, enabled in part by CIFAR. The report makes recommendations that could cut the time to discovery of useful new materials from 20 years down to one or two.

The report is the result of a September 2017 workshop sponsored by CIFAR, the Mexican Ministry of Energy (SEN-ER) and the U.S. Department of Energy. It brought together 55 international researchers as part of Mission Innovation, an international partnership designed to improve global clean energy development.

Materials are the foundation of clean-energy technologies such as advanced batteries and improved solar cells. But discovering and testing new materials is time-consuming and expensive.

The report laid out a research road map that will encourage cooperation among multidisciplinary, international teams of scientists and engineers with expertise in chemistry, materials sciences, advanced computing, robotics and AI, and other disciplines.

"I'm pleased that CIFAR was able to contribute to Mission Innovation's important work," said CIFAR President & CEO Alan Bernstein. "CIFAR and Mission Innovation share similar goals, and our emphasis on excellence, global participation and tackling tough questions is the best strategy for creating the disruptive technologies needed to address the world's growing demand for energy."





International experts, above left, met in Mexico City and created a report that lays out a road map for how to develop new clean energy technology, above right.

non-technical publication, synthesizing the insights from the workshop for government, civil society and the private sector. CIFAR will be launching another International Call for Workshops on AI & Society next year, in partnership with CNRS in France and UKRI in the UK.

CIFAR also launched a series of facilitated policy foresight workshops, designed to help early-career policy innovators understand the long-term policy implications of potentially disruptive new technologies. CIFAR established a partnership with the Brookfield Institute for Innovation and Entrepreneurship to undertake four AI Futures Policy Labs across Canada in 2018, with a fifth planned for Quebec in 2019. In June, CIFAR and Brookfield hosted the first Policy Lab in Toronto. This workshop provided an opportunity to engage provincial and municipal governments, non-profit and public agencies, academia, and the private sector. Upcoming workshops will be held in Edmonton, Vancouver, Ottawa and Montreal. A report will be issued following each Policy Lab and a final, summative bilingual publication will be released to support a national conversation about the future of policy in a world where AI-driven technologies are widespread.

To provide guidance to its AI & Society program, CIFAR established a Council of Advisors. The Council membership is as follows:

> Prof. Ian Kerr (Chair)

Canada Research Chair in Ethics, Law & Technology and Full Professor, University of Ottawa

> Prof. Joanna Bryson

Reader, Department of Computer Science, University of Bath

> Prof. Mario Mariniello

Digital Adviser to the European Political Strategy Centre, European Commission

> Prof. Doina Precup

Senior Fellow, CIFAR Program in Learning in Machines & Brains; Mila faculty member; Associate Professor of Computer Science, McGill University

> Meredith Whittaker

Co-Director, Al Now Institute, New York University

Global Academy

CIFAR values the exceptional contributions that the next generation of research leaders brings to the research enterprise. The Global Academy provides a unique opportunities for outstanding early career researchers from across Canada and around the world to further develop their research and leadership skills by connecting them with leading research networks, where they can learn from and collaborate with the world's top minds.

Key activities related to the Global Academy over the past year include the following:

CIFAR Azrieli Global Scholars Program

The CIFAR Azrieli Global Scholars program was launched in April 2016 with the generous support of the Azrieli Foundation. This year the program welcomed its second cohort of 15 scholars, announced in October 2017. This exceptional group of scholars comes from five countries and four continents.

The CIFAR Azrieli Global Scholars Program seeks outstanding early career researchers from around the world who are within the first five years of their first faculty position – a pivotal time in their careers. The scholars become an integral part of a CIFAR program for two years, where they are given the opportunity to network with CIFAR's outstanding fellows, to, form new research collaborations, and be mentored by a senior fellow. Each Global Scholar also receives \$100,000 in unrestricted research support.

CIFAR held its second Annual Meeting for the CIFAR Azrieli Global Scholars in Victoria, BC, from May 2-6, 2018. This year's meeting saw the participation of two Global Scholars cohorts (2016-2018; 2017-2019) and strengthened connections between them. The meeting provided a platform for peer-to-peer learning, expanding their global networks, and identifying opportunities for interdisciplinary collaboration across programs. Scholars benefited from leadership workshop sessions, developed by facilitators Barefoot Thinking Company and The Professor is In. Sessions focused on creative and strategic thinking, grant writing, and productivity and time management.

The keynote speaker for this meeting was **Andrew Weaver**, Leader of British Columbia's Green Party. He is a Professor at the School of Earth and Ocean Sciences at the University of Victoria, where he was



The next generation of research leaders: members of the Global Scholars Class of 2016 met at their Annual Meeting in Banff, top; while the Class of 2017 met in Victoria, above.

the Canada Research Chair in climate modelling. Weaver discussed his journey from science to politics and public policy. This was an inspirational opening keynote, which emphasized the potential for scientists to have a direct impact on society and how they might affect change as researchers. The scholars also received a master class by **Candice Odgers**, a CIFAR Fellow in the Child & Brain Development program, who discussed the many challenges faced by researchers as they ascend in academia. She identified practical ways to tackle challenges based on her personal experience, which was particularly well received by the Global Scholars.

In response to the third call launched in December 2017, CIFAR received 402 eligible applications for five CIFAR programs (GEU, BMC, HMB, MAL, BSE), making this a very competitive year, and one where the number of participating countries increased from 49 to 55. A group of 20 candidates (four per program) were shortlisted by program selection committees comprised of CIFAR fellows and advisors. At the in-person selection meeting held in June 2018, a group of 12 new CIFAR Azrieli Global Scholars were selected. They will start participating in CIFAR research programs in the Fall.

The program is generously supported by the **Azrieli** Foundation and the Love Family.

CIFAR Azrieli Global Scholars Facts

> 15 new Global Scholars chosen from 445 applicants in 49 countries

Additional Trainee Opportunities and Benefits

- > CIFAR fellows supervised **2,213** trainees:
 - > **707** postdoctoral fellows
 - > 1,506 graduate students
- > 174 graduate students and postdoctoral fellows attended CIFAR program meetings (represents 20% of total meeting attendees)

"Every year, the Global Scholars Meeting restores my optimism about the positive role of science in society, and reinvigorates my commitment to be a force for good in our uncertain and struggling world. I cannot imagine a more inspiring and more motivating event."

- Giulio Chiribella



Above: Facilitator Karen Kelsky, with CIFAR Azrieli Global Scholar Huy Bui, at the CIFAR Azrieli Global Scholars Annual Meeting in Victoria; above, right: CIFAR Azrieli Global Scholars Jeffrey Warren, Katherine Amato and Gerhard Kirchmair; right: CIFAR Azrieli Global Scholar Giulio Chiribella and other scholars from the 2016 and 2017 cohorts.



Women in Science Leadership Workshop

The CIFAR Global Academy held its second Women in Science Leadership Workshop in Kigali, Rwanda, March 22-24, 2018. It was organized in partnership with the African Academy of Sciences (AAS), the African Institute for Mathematical Sciences (AIMS) and the Global Young Academy (GYA), and is part of CIFAR's growing efforts to address equity, diversity and inclusion challenges in research. The aim of the workshop was to foster diverse and inclusive leadership in academia by targeting early career researchers from across the world. The workshop was held as part of the official preevents of the Next Einstein Forum 2018, a prominent event that brings together researchers with policy-makers.

The workshop gathered together exceptional early- to mid-career researchers and provided practical tools, opportunities for peer-to-peer learning, and mentorship by senior women in research and other sectors. The workshop opened with a keynote talk by **Agnes Binagwaho**, former Minister of Health in Rwanda and Vice Chancellor of the University of Global Health Equity. She discussed the challenges for women in research, and made a call to action for overcoming the unconscious bias women face in advanced research. Discussion sessions focused on: the myths and realities of leadership, creating change from the inside, contextualizing "feminine leadership," reflective listening and questioning, networking skills, negotiation skills, mentoring, advocacy, and coaching.

The workshop provided me with aspiring models to look up to, a large network of people with similar interests in diversity in science advocacy and implementation, and a better understanding of myself, leadership, collaboration, and mentoring.

- Sophie Rochette

Global Women in Science Leadership Workshop Facts

- > **39** participants from **12** countries
- > 100% believed the workshop will strengthen their personal leadership capacity and ability to mentor others
- > 100% said the workshop met or exceeded their expectations



Above: Associate Professor and the Head of Chemistry Ghada Bassioni of Ain Shams University addresses other members of the Women in Science Leadership Workshop in Kigali, Rwanda.



Thirty-nine people attended the CIFAR Global Academy's Women in Science Leadership Workshop, held this year in partnership with the African Academy of Sciences, the African Institute for Mathematical Sciences, and the Global Young Academy.

Japanese-Canadian Frontiers of Science Symposium

In partnership with the Japan Society for the Promotion of Science (JSPS) and the Royal Society of Canada (RSC), CIFAR co-organized the Japanese-Canadian Frontiers of Science (JCFoS) Symposium at the Okinawa Institute of Science and Technology in Okinawa, Japan on November 2-5, 2017. Additional support was generously provided by the Canadian Institutes of Health Research (CIHR), Fonds de recherche du Québec (FRQ), and the National Research Council (NRC) of Canada.

The symposium brought together 30 early career researchers each from Canada and Japan, and aimed to foster interdisciplinary discussion, exchange ideas, and identify synergies and collaboration between the two countries and various disciplines. The symposium explored the frontiers of research in six disciplines and provided a forum for cross-disciplinary discussion and engagement. Each two-hour session focused on a specific theme defined from a broad disciplinary area, as listed below.

- > Aging: Quest for the Elixir of Life
- > Deciphering the Origin of Life on Earth
- > Global Governance
- > High Efficiency Materials
- > Learning Like Humans
- > Mapping the Cosmos

Two CIFAR Azrieli Global Scholars, **Kieran O'Donnell** (Child & Brain Development; McGill University) and **Graham Taylor** (Learning in Machines & Brains; University of Guelph) contributed to the symposium as session co-leads. Invited speakers included CIFAR Senior Fellows **Curtis Berlinguette** (Bio-inspired Solar Energy; University of British Columbia) and **Matt Dobbs** (Gravity & the Extreme Universe; McGill University). Other general participants included CIFAR Azrieli Global Scholars **Alona Fyshe** (Azrieli Program in Brain, Mind & Consciousness; University of Victoria) and **Jeffrey Warren** (Bio-inspired Solar Energy; Simon Fraser University), and CIFAR Fellows **Sara Mostafavi** (Child & Brain Development; University of British Columbia) and **Blake Richards** (Learning in Machines & Brains; University of Toronto).

ENGAGEMENT OF TRAINEES

CIFAR's 12 research programs involve trainees (PhD students and postdoctoral researchers) in key activities. For instance, they are invited to participate in program meetings, where they can present talks and posters, and engage in discussions with research leaders in their field. Trainees are also central to summer and winter schools, where they connect with peers while learning from distinguished lecturers. These schools offer training on cutting-edge topics not covered in regular university curricula, and trainees often contribute to the planning and organization, thus acquiring valuable leadership development skills.

CIFAR held the following **summer and winter schools** this past year:

The Deep Learning and Reinforcement Learning Summer School: Key themes included learning on little data, modular models, AI ethics, and reinforcement learning

Japanese-Canadian Frontiers of Science Symposium Facts

- > 60 early career researchers from Japan and Canada participated in the symposium (30 from each country)
- > 15 prominent women researchers from across Canada and 8 CIFAR Fellows and Global Scholars from 5 CIFAR programs
- > 100% of participants said the workshop met or exceeded their expectations
- > 96% indicated the symposium helped broaden their scientific perspective through exposure to other fields
- > **96%** indicated they would participate in a similar symposium in the future

models. From June 28 - July 5, 2017 the program held its largest-ever Deep Learning and Reinforcement Learning Summer School in Montreal, QC. More than 1,100 applications were received and successful participants included 271 trainees and researchers from 23 countries.

Neuroscience of Consciousness Winter School: Thirty-two trainees (graduate students and postdocs) attended the winter school and engaged in collaborative work with mentors and peers. Trainees were involved in lectures from leading experts on consciousness research, ranging from identifying biomarkers of consciousness to the philosophy of consciousness. They also participated in valuable training in science communication through two intensive workshops including presentation skills bootcamp and effective science writing. CIFAR Azrieli Global Scholars **Alona Fyshe** and **Craig Chapman** took the lead in successfully co-organizing this winter school.

CIFAR Quantum Materials Summer School: Seventy-four students and postdoctoral fellows as well as 11 speakers from around the world explored a wide range of topics relevant to both the theoretical and experimental communities working in quantum materials research. Topics covered included: the interplay between interactions and topology, unconventional superconductors, advanced experimental techniques, and new methods for modeling quantum many-body systems (including Al and tensor networks).

Quantum Computation: CIFAR Azrieli Global Scholar Thomas Vidick co-organized a summer school on quantum computation at the University of California, Santa Barbara in March 19-22, 2018 for 60 participants. The school was targeted to trainees and faculty seeking core knowledge and understanding of questions at the forefront of quantum complexity. Topics included: restricted models of quantum computation, theory of quantum error correcting codes, and quantum interactive proofs and their connection to cryptography and complexity.

Ideas Exchange

CIFAR connects its research programs with global thought leaders to enrich the ongoing research process and catalyze new social, economic and technical innovations. We create ongoing dialogues with sectors that align with CIFAR research programs including health and well-being, industry and innovation, international development and public policy.

CIFAR programs are tackling some of the most fundamental questions of our time. Our model of bringing together fellows who would not normally interact, due to disciplinary or geographic boundaries, provides a unique approach that opens up new ways of thinking about important research challenges. Such novel insights and perspectives not only have the power to transform research but also to catalyze change in society. Through knowledge mobilization, CIFAR brings together fellows from its programs and thought leaders from relevant communities to engage in mutually beneficial dialogues that inform the research agenda and advance innovations in policy and practice.

This year, we accomplished a number of important goals.

We continued to create sustained and respectful dialogue between researchers and innovators. For instance, CIFAR's Genetic Networks program held its second precision medicine conversation with thought leaders from genomics companies and the medical community, and a third is planned for next year.

We increased CIFAR's impact in research-intensive business sectors by holding a number of engagements with R&D industry leaders. For example, we hosted an introductory dialogue between the Azrieli Program in Brain, Mind & Consciousness and the virtual reality gaming community.

In our continuing development of sustainable and long-term impact, CIFAR staff worked with the leads of proposed and existing programs to help them develop their goals for societal impact and their knowledge mobilization plans.

We reached out to new communities of thought leaders and enriched our expertise in knowledge mobilization by presenting at panels and participating in conferences throughout the year, including the **G7 Innovation Minister's Stakeholder Conference** in Turin, Italy; the **Canada 150**

Conference on Innovation and Globalization; the Max Bell Foundation's Annual Partner Conference; and AESIS – Advancing and Evaluating the Societal Impact of Science Conference.

We promoted evidence-based knowledge transfer and dissemination by developing 20 online resources that included research briefs and event briefs. A new publication called Horizons aims to inform our communities about how research relevant to their work may impact their practice within a five- to 10-year horizon.

These accomplishments and more are detailed by sector, below.

CIFAR Exchanges in Health and Well-being

Today's challenging and transforming healthcare environment requires leaders in health to stay at the forefront of knowledge and to collaborate across sectors. CIFAR engages Canadian and global leaders in health-based organizations – including healthcare practitioners and public health officials, and decision makers within non-governmental organizations, government, associations, and industry – to advance understanding and drive innovation in health research and practice. Highlights from the year include:

Brave New World Conference: Utilizing Genetic Networks to Decode Complex Disease

Healthcare is changing significantly as revolutionary new technologies bring a focus on precision and personalized medicine. Building on a December 2016 genetic networks and personalized medicine workshop, CIFAR partnered with **GET (Genes, Environment, Traits)** to hold a one-and-a-half day conference in June 2018. The conference brought fellows in CIFAR's **Genetic Networks** program together with nearly 100 scientists, clinicians and industry leaders to explore how genetic interactions and networks of genes contribute to complex traits and diseases in humans. The conference was sponsored by **Autodesk**, **JLABS** and the **University of Toronto McLaughlin Centre**.

Humans & the Microbiome Core Story

An emerging trend in public health is the decline in deaths from communicable diseases and the increase in deaths caused by chronic diseases. Lifestyle and social determinants of health, particularly as experienced in early life, are increasingly recognized as core drivers of chronic disease, providing opportunities to intervene and improve health and well-being and to reduce healthcare costs. CIFAR's **Humans & the Microbiome** program has developed a partnership with the Washington, D.C.-based **FrameWorks Institute** to develop a Core Story of the Microbiome that offers a set of essential ideas and principles related to research on the microbiome and its implications for health. These ideas will provide an evidence-based foundation for future knowledge mobilization engagements. **FrameWorks** is conducting a literature review and interviews with CIFAR fellows that will form the elements of a Core Story to be reviewed at an upcoming meeting.



Left: CIFAR President & CEO Alan Bernstein, the Honourable Elizabeth Dowdeswell, Lieutenant Governor of Ontario, and Harvard professor George Church at the June GETx Conference on Utilizing Genetic Networks to Decode Complex Disease; right, CIFAR Azrieli Global Scholar Hannah Carter, Calico Principle Investigator David Kelley, and UC San Diego Professor Trey Ideker.

Roundtable on Cognition & Consciousness in Brains & Machines

The health sector has also witnessed an influx of new and emerging technologies including machine learning, biosensors, next generation sequencing and virtual reality. These technologies have the potential to transform how diseases are detected and treated, and are also providing new tools for researchers to gather data and better how the human body and brain function. A breakfast roundtable on March 13, 2018, brought fellows from the **Azrieli Program in Brain**, **Mind & Consciousness** and the **Learning in Machines & Brains** program together with a neuro-ethicist and a representative of **Autodesk** working at the brain-computer interface. Participants had a robust discussion about consciousness and how it is defined in brains and machines. There was interest in pursuing some of the ethical questions at another workshop next year.

CIFAR Exchanges in Industry and Innovation

Industry is undergoing significant change with the advent of disruptive technologies, globalization and an increasing pace of change. Digital networking and globalization have made the exchange of ideas faster, more open and often multi-directional. CIFAR works to connect academic researchers with thought leaders in industry to advance understanding and create opportunities for innovation. Here are some of this year' exchanges.

Future of Virtual Reality: Panel on Neuroscience and Biosensor Driven Development

From the launch of mainstream artificial intelligence to the development of quantum computers, new abilities to see previously undefined patterns and connections will alter a multitude of industries. At this year's Game Developers Conference in San Francisco, CIFAR Azrieli Global Scholars **Craig Chapman** and **Alona Fyshe** (Azrieli Program in Brain, Mind & Consciousness) along with Jake Stauch, **CEO NeuroPlus**, held a panel that engaged tech developers in the potential for brain and cognition research and biosensor technology to advance understanding of the brain and VR innovations. The panel was moderated by Kent Bye, host of the popular podcast **Voices of VR**, and attracted approximately 200 people in person and 600 livestream views. An engaged question and answer session was followed by in-depth discussions with some participants. A small follow-up roundtable is planned for the coming year.

Industry Workshop on New Clean Energy Materials

Researchers are developing novel materials for energy storage; developing new understandings to explore the frontier of quantum computing; and generating new superconducting materials. In May, CIFAR partnered with Natural Resources Canada and the Mexican Secretariat of Energy (SENER) to run a meeting for scientists, industry leaders and other stakeholders to discuss research into Clean Energy Materials and to explore collaboration opportunities under the Mission Innovation Materials Challenge #6. This workshop built on CIFAR's support for fellows in our **Bio-inspired Solar Energy** program and the development of the first research and innovation roadmap under Mission Innovation. Participants discussed combining advanced theoretical and applied physical chemistry with next-generation computing, machine learning, and robotics, with the aim of developing an integrated materials innovation approach.

Vision for a New Frontier in Drug Discovery Roundtable

Research that untangles the complex molecular processes which underlie disease will create novel opportunities for the pharmaceutical and medical devices industries to explore aspects of biological and chemical diversity that cannot be understood with current technologies. CIFAR's **Molecular Architecture of Life** program held a one-day workshop on **New Frontiers in Drug Discovery** that brought together fellows from the program with senior leaders from national and global pharmaceutical companies. Participants explored how state-of-the-art imaging technologies are advancing our fundamental understanding of the cell and how this might support development of more effective, targeted technologies and therapies. This was the program's first engagement with the pharmaceutical sector and discussions are underway for how to build upon and continue the dialogue. Feedback from the industry participants was very encouraging with requests for ongoing engagement. At the meeting, some CIFAR fellows also entered into direct, one-on-one commercialization discussions with some of the industry participants.

CIFAR Exchanges in International Development

Countries around the world face an array of development challenges as reflected in the UN's Sustainable Development Goals. CIFAR reaches out to leaders in international development, NGOs and the broader civil society to share the scholarship and insights emerging from our research programs. Through sustained dialogue and interactions, our aim is to catalyze new perspectives to drive innovative and effective development interventions. The following are some highlights from this year.

Panel on a New Approach to State Fragility

One of the ongoing obstacles of development is poverty and inequality. While there has been a reduction of absolute poverty and income inequality between countries, we have recently been witnessing rising inequalities within countries and an increased concentration of poverty in fragile states. This has led to significant challenges in addressing malnutrition, emerging infectious diseases, crime, and poor health in early child development to name a few. In partnership with the British Academy of Sciences and the International Growth **Centre**, CIFAR hosted a panel discussion on fragile states at the Academy. Sir Tim Besley, Senior Fellow from the Institutions, Organizations and Growth program, spoke alongside other contributors to the LSE-Oxford Commission on State Fragility, Growth and Development. The discussion was attended by thought leaders in government, development think tanks, international development non-profit organizations and academic institutions. It was followed by a private dinner

Knowledge mobilization impact

- > **9** major events and activities
- > **580** participants across 9 programs
- > 12 engagement partners
- > 476 new knowledge users engaged
- > Total knowledge user community 2,276
- > Participants rated excellence of experience at 85%
- > 20 publications

hosted in partnership with the British Academy that engaged a small group of influential stakeholders on how to connect research and public policy leaders most effectively.

World Happiness Report 2018: Roundtable on Migration

Poverty, along with conflicts, violence, human rights violations and natural disasters, has been a core driver of recent record levels of international migration. The resulting surge in refugees and migrants is raising new social, economic and environmental challenges and opportunities that will need to be addressed to ensure our economies and how people adapt and live are managed effectively. In partnership with the Centre for Sustainable Development, and with generous support from the Crabtree Foundation, CIFAR co-hosted a panel discussion in support of the launch of the 2018 World Happi**ness Report**. Themed around migration – a major focus of the 2018 report – the panel session brought together nearly 100 leaders from public policy and development organizations to explore how the findings from the 2018 report inform policy and practice. The session was held at the United Nations Building in New York, providing an opportunity for country representatives and UN agency leaders to participate.

CIFAR Exchanges in Public Policy

Policy domains such as health, economic development, justice, and planning require research and evidence-informed policy development. Governments around the world are aware of the importance of co-creating policy with stakeholders from all sectors who. Through dialogue and evidence, CIFAR helps to prepare policy-makers for emerging areas of policy disruption and to understand the possibilities for policy innovation. Our goal is to help to incorporate the science of the future into the policy thinking of today. The following are some of CIFAR's public policy activities.

2018 David Dodge CIFAR Lecture

In an interconnected world, policy takes on a global dimension. Capital, labour, information, and culture move across borders more easily than ever before. As a result, the policy community of 2018 is a global one: whether through joint action and coordination, or through the sharing of best practices and informative failures, collaboration is a precondition to success. This year's David Dodge CIFAR Lecture was held in partnership with the Ontario Council of Agencies Serving Immigrants (OCASI) and Cities of Migration, and funded by the Crabtree Foundation. The lecture featured Irene Bloemraad, Senior Fellow in the Successful Societies program. Titled "The Boundaries of Inclusion: Migration, Human Rights and National Values," the talk explored issues at the nexus between immigration, politics and national identities. The lecture attracted nearly 100 civil society, policy and academic leaders, in person and via webcast.

AI Policy Exchanges

CIFAR held a number of briefings and engagements with policy-makers in Ottawa and across Canada on the state of the science of AI and its potential policy and societal implications. In December, CIFAR led a joint meeting of the **Government** of Canada's Deputy Minister Committees on Economic

David Dodge CIFAR Lecture

With a rise in populism, many countries have turned less welcoming to immigrants. Beyond physical and technological barriers, they are increasingly engaging in "discursive boundary-making," says Irene Bloemraad.

"There's boundary making, both symbolically and socially, casting people as 'us' versus 'them," she said at the David Dodge CIFAR Lecture in Toronto on May 2, 2018. Bloemraad is a senior fellow in CIFAR's Successful Societies program and a professor of Sociology at the University of California, Berkeley.

Politicians like Donald Trump who cast immigrants and refugees as others often use the term "national values" to defend their position. But are "national values" intrinsically hostile, or could this language be used to promote inclusivity? To answer this question, Bloemraad created a survey experiment.

Californians in her study were asked to evaluate the situation of a woman who lacked adequate social support. Each questionnaire contained different wording, with respondents asked variously whether, in this case, the United States had done enough to uphold "American values," "civil rights," or "human rights."

Bloemraad was surprised that people were more likely to see the issue as a problem when it was framed by "American values", even when the subject was described as an undocumented immigrant. Respondents were also more likely to support government intervention, regardless of their ethnic or ideological background.

She says that discourse in Canada is more inclusive, although that doesn't make Canada immune to antiimmigrant backlash. Moderator Elizabeth McIsaac, President of the Maytree Foundation, pointed to the example of a Canadian politician who campaigned on a "Canadian values" test for immigrants.

While advocates for immigrants may be wary of such language, Bloemraad says it can be used to promote inclusivity.

Trends and Policies and Science and Technology Committees. Presentations were given by Doina Precup (McGill University and DeepMind), Yevgeniy Vahlis (Borealis AI), and Carole Piovesan (McCarthy Tétrault) on the state of AI research, ethics in AI innovation, and AI regulation and law.

In April, CIFAR President **Alan Bernstein** presented to **Alberta's Deputy Minister Committee on Economic Development** to discuss the history of Al research and the lessons that can be drawn for economic development and diversification.

In May, CIFAR was invited to provide a lunchtime briefing with staff in the **Prime Minister's Office** on the state of AI, the Pan-Canadian AI Strategy and its implications for society and government. **Yoshua Bengio**, **Elissa Strome**, and **Rebecca Finlay** spoke to and answered questions from over 50 members of staff.

In June, CIFAR brought together a panel of Al researchers and business leaders to discuss the state and future of Alberta's Al ecosystem at the **Inventure\$** conference in Calgary. The panel included **Alan Bernstein**, **Matthew Taylor** (Borealis Al), **Ashlyn Bernier** (Social Asset Management) and **Chandra Rink** (ATB Financial).



CIFAR Senior Fellow Irene Bloemraad discussed how we decide who deserves social inclusion at the David Dodge CIFAR Lecture; above, Maytree Foundation President Elizabeth McIsaac conducted a Q&A with Bloemraad.

"Not embracing the language of values leaves it to people who might be willing to put up more boundaries and borders against others. And it might be a chance to retake the language of values and recast it in a way that is more inclusive."

AI & Society Program

This year, CIFAR focused much of its public policy work on exploring the societal implications of artificial intelligence, in support of our new AI & Society program. The program was established last year as part of the \$125 million Pan-Canadian AI Strategy. See more about AI & Society in the artificial intelligence section on page 15.

Research Programs

Annual Highlights



At a Glance

Founded:

2014

Program Directors:

Melvyn Goodale, Western University, and Adrian Owen, Western University

Fellows, Advisors and CIFAR Azrieli Global Scholars: **30**

30

Institutions represented:

24, in 10 countries

Meetings:

2; in Montreal, Canada and Kraków, Poland

Research Partners:

Brain Canada Foundation through the Canada Brain Research Fund, Western University

Supporters:

Azrieli Foundation, The Henry White Kinnear Foundation, Richard M. Ivey, Michael and Sonja Koerner, The Larry and Judy Tanenbaum Family Foundation

Azrieli Program in Brain, Mind & Consciousness

Seeks to examine the neural underpinnings of consciousness, leading to better treatments for mental health disorders and insights into the most profound questions about human nature.

Fellows in the Azrieli Program in Brain, Mind & Consciousness published a number of papers this year on topics related to consciousness, including human memory formation and retrieval, visual awareness, and consciousness in machines. Program Co-Director **Adrian Owen** also published an award-winning book, *Into the Gray Zone*, around themes that emerged from program meetings.

The program added six new program members and held two program meetings this year. The December 2017 meeting highlighted topics around the development of consciousness and the challenges of measuring consciousness in infancy and childhood. The meeting in June 2018 was held immediately before the Association for the Scientific Study of Consciousness (ASSC) conference, and focused on altered states of consciousness in the healthy brain, spanning discussions on states induced by various psychedelic drugs, a range meditative states, and the transition between wakeful consciousness and sleep.

This year the program also held its first annual winter school on the Neuroscience of Consciousness, bringing together 32 trainees from across the globe. Trainees engaged in interactive lectures from eight leading consciousness researchers and two intense workshops on science communication.

Research Highlights

Senior Fellows **Stanislas Dehaene** (Collège de France) and **Sid Kouider** (École normale supérieure) together provided insights into how human and animal brains process information compared to information processing methods used in today's Al. In a recent paper, these authors highlighted features that allow human brains to experience consciousness to support the ongoing development of computer algorithms.

> Dehaene, S., Lau, H., & Kouider, S. (2017). Science, 358(6362), 486–492.

Discussions between Senior Fellow **Tim Bayne** (Monash University) and Program Co-Director **Adrian Owen** (Western University) at program meetings laid the groundwork for their recent paper discussing how disorders of consciousness may be categorized. They propose a new framework for classification including behavioural and brain imaging data, which is relevant both for future fundamental research and treatment.

> Bayne, T., Hohwy, J. & Owen, A. (2017). Ann Neurol, 82/6, 866-872.

Senior Fellow **Rafael Malach** (Weizmann Institute of Science) and colleagues published evidence for a new neuronal mechanism that controls memories retrieved from different categories. These findings may have significant clinical implications in the future.

> Norman, Y., Yeagle, E. M., Harel, M., Mehta, A. D., & Malach, R. (2017). Nat Commun, 8(1), 1301.



At a Glance

Founded: 2014

Program Director:

Ted Sargent, University of Toronto

Fellows, Advisors and CIFAR Azrieli Global Scholars:

21

Institutions represented:

18, in 6 countries

Meetings:

2; in Mexico City, Mexico and Toronto, Canada

Research Partners:

Fonds de recherche du Québec – Nature et technologies (FRQNT)

Supporters:

Arthur J.E. Child Foundation Endowment Fund at the Calgary Foundation, Chisholm Thomson Family Foundation, Genome Canada, Charles Hantho, Jerry and Geraldine Heffernan, Ivey Foundation, Max Bell Foundation, Metcalf Foundation, Ontario Genomics The Bio-inspired Solar Energy Program brings together experimental and theoretical experts in biochemistry, biophysics, chemistry, materials science, engineering and computer science to understand how photosynthetic organisms (such as plants and algae) effectively use solar energy, and how this in turn can help design improved materials and innovative renewable energy technologies.

This past September, a number of fellows, Global Scholars and Advisors from the program - including Program Director Ted Sargent (University of Toronto), and Senior Fellows Alán Aspuru-Guzik (University of Toronto) and Curtis Berlinguette (University of British Columbia) - met with researchers from around the world in Mexico City as part of Mission Innovation to develop a vision for Mission Innovation Challenge 6 on Clean Energy Materials. Co-chaired by Aspuru-Guzik, the workshop was held in partnership with the Mexican Secretariat of Energy (SENER), the U.S. Department of Energy (DOE) and CIFAR, and brought together 130 researchers from 17 countries. The workshop resulted in a report: Materials Acceleration Platform: Accelerating Advanced Energy Materials Discovery by Integrating High Throughput Methods with Artificial Intelligence that is heralded as a scientific roadmap for addressing this global challenge.

In March, the program explored current challenges in the field, including ongoing materials design considerations for next generation solar devices, bio-inspired strategies for nitrogen reduction, and design principles for materials to enhance the conversion of carbon dioxide into fuels and carbon-based products. CIFAR Azrieli Global Scholars **Nathaniel Gabor** (University of California, Riverside), **Gabriela Schlau-Cohen** (MIT), and **Jeffrey Warren** (Simon Fraser University) presented their latest research. Presentations from guests, global scholars and trainees on the latest research in these areas helped to spark discussion and research collaborations.

Research Highlights

Bio-inspired

Solar Energy

Understanding how to efficiently harvest and store light energy from the sun – inspired by the remarkable effectiveness of photosynthesis in plants and algae.

Gabriela Schlau-Cohen and Alán Aspuru-Guzik utilized rigid scaffolds of synthetic DNA, or "DNA origami" to study energy flow between pigment aggregates positioned along the scaffold. Using computational models to guide and optimize the design of the structure, the research team was able to observe and measure long-range energy transfer along these pigment "circuits." This work demonstrates how artificial systems can be built from the ground up to support efficient energy transfer.

> Schlau-Cohen, Aspuru-Guzik et al. (2018). Nature Materials, 17, 159.

In natural photosynthetic systems, energy from the sun is absorbed and transferred on ultrafast timescales, taking only trillionths of a second to occur. **Ted Sargent** and Senior Fellow **Greg Scholes** (Princeton) recently observed a similar process occurring in nanoparticles called perovskite quantum wells, where energy was found to transfer from one nanoparticle to another on ultrafast timescales. Perovskite is a very-promising next generation material for solar cells and light-emitting diodes (LEDs). CIFAR supported this work through a catalyst seed grant.

> Elkins, Proppe, Sargent, Scholes et al. (2017). J. Phys. Chem. Lett., 8, 3895.



Child & Brain Development

Explores the core question of how social experiences and early adversity affect and help set early trajectories of lifelong development and health.

At a Glance

Founded: 2003

Program Directors:

W. Thomas Boyce, University of California, San Francisco, and Marla Sokolowski, University of Toronto

Fellows, Advisors and CIFAR Azrieli Global Scholars:

25

Institutions represented:

18, in 5 countries

Meetings:

3; in Paris, France; Vancouver, Canada; and Öhningen, Germany

Supporters:

The Alva Foundation, George Weston Limited, Great-West Life, London Life and Canada Life, The Joan and Clifford Hatch Foundation, The W. Garfield Weston Foundation, 1 anonymous donor The Child & Brain Development program examines the fundamental question of how genes and environments interact to affect trajectories of health and behaviour throughout development. This program is uniquely positioned to examine the neurodevelopmental processes within the brain that underlie how genes and environments work together.

The program held three meetings this year. The first meeting in September 2017 focused on brain plasticity in development and was held in partnership with Collège de France in Paris to engage more deeply with European-based researchers. In February 2018, the program members proposed ideas for pieces of a collective work that captures emerging themes from the program, including the concept of developmental timing, and experience-based neuronal plasticity. In April 2018, the program organized a conference 'Reconciling Genes and Contexts' at Marbach Castle in Germany held in partnership with the Jacobs Foundation and CIFAR. This meeting focused on understanding gene-environment interactions on brain development, integrating data sets and the application of machine learning, and developing key metaphors for articulating how social experiences and adversity can affect brain development.

Research Highlights

Children are spending an unprecedented amount of time online and it is important to understand how this is influencing children's developing bodies, brains and social relationships. Fellow **Candice Odgers** (University of California Irvine) reports on the 'new digital divide' which has conventionally referred to differential access to new technologies, but this gap is shrinking and a new divide is occurring through differences in online experiences which are amplifying risks among already-vulnerable adolescents.

- > Odgers, C.L. (2018). Nature, 554m 432-434.
- > Odgers, C.L. & Adler, N.A. (2017). Child Development Perspectives, 12(2)

Senior Fellows Thom McDade (Northwestern University) and Michael Kobor (University of British Columbia) show evidence that nutritional, microbial, and psychosocial exposures in infancy and childhood predict adult levels of DNA methylation (biochemical marks on the genome that affect gene expression) in genes that regulate inflammation, an important risk factor for many diseases. These results suggest that epigenetic mechanisms may partially explain how early environments have enduring effects on inflammation and inflammation-related diseases. This work and that of the program inspired the pursuit of a new line of research in human social epigenetics.

> McDade, T.W., ... , Kobor, M.S., & Kuzawa, C.W. (2017). PNAS 114, 7611-7616.

Program Co-Director **Marla Sokolowski** (University of Toronto) developed the first study of its kind to show a causal link between epigenetics, genetics and behaviour. This study isolated gene products key to shaping the different feeding behaviours of flies. The findings showed that genetic differences in flies interact with epigenetic mechanisms to regulate behavioural differences. This work was inspired by discussions in the program with experts ranging from fruit fly behavioural geneticists, evolutionary biologists to pediatricians.

> Anreiter, I., Kramer, J.M., & Sokolowski. M.B. (2017). PNAS 21;114, 12518-23.





At a Glance

Founded: **2005**

Program Directors:

Charles Boone, University of Toronto, and Frederick Roth, University of Toronto

Fellows, Advisors and CIFAR Azrieli Global Scholars:

18

Institutions represented: 10. in 2 countries

Meetings: **2; in Toronto, Canada** Genetic Networks

Devoted to mapping the biological networks that translate genomes into complex traits and improving our fundamental understanding of biological systems to enable new treatments and preventive measures.

The central goal of the Genetic Networks program is to map complex genetic interactions to traits, the most significant challenge facing geneticists, using experimental and computational approaches in model systems. Working to solve this genotype to phenotype problem uncovers interactions between gene variants leading to observed traits and offers insights into the complex genetics of human disease.

The Genetic Networks program has moved further towards using human cells as models and applying analysis methods in model organisms to human genetic studies. Work by program fellows on mapping gene variants has great potential to alter thinking about genome-guided precision medicine.

This year the program held two meetings in Toronto and added one new member. The November 2017 meeting highlighted recent progress to expand the genetic interaction studies to more complex model systems. Members and guests also highlighted technological advances that use model organism studies to interpret genetic variation in the human genome with greater precision. At the second meeting in June 2018, participants presented new analysis tools and concepts to explore and link diverse phenotypic traits to the vast amount of genotype data being collected.

Research Highlights

Members of the Genetic Networks program built the first genetic interaction map for any organism. Using this framework, Program Co-Director **Charles Boone** (University of Toronto) and Senior Fellows **Brenda Andrews** (University of Toronto) and **Chad Myers** (University of Minnesota) found that trigenic interactions, involving a combination of three distinct mutations, are about 100 times more common than double mutant interactions and have the capacity to impact gene expression. Ultimately the potential role of these complex interactions can be assessed in human disease.

Kuzmin, E., ... Andrews, B.J., Boone C., & Myers C. (2018). *Science*, 360 (6386). pii: eaao1729.

Determining which genetic variants increase disease risk remains a challenge. Program Co-Director **Frederick Roth** (University of Toronto), Senior Fellow **Maitreya Dunham** (University of Washington), and CIFAR Azrieli Global Scholar **Doug Fowler** (University of Washington) are working to generate systematic experimental maps of functional human variation, which may be applied to many different human disease genes.

- > Matreyek, K.A., ... Fowler, D. A. (2018). Nature Genetics, 50, 874-882.
- McDonald, M.G., ... Dunham, M. J., Fowler, D. M., & Rettie, A. E. (2017). Drug Metabolism and Disposition. 45(12), 1364-1371.
- Yang, F., ... Andrews, B. J., Boone, C., & Roth, F. (2017). PLOS Genetics. 13(5): e1006779.

Program members **Chad Myers**, **Charles Boone** and **Brenda Andrews** previously developed a computational platform (BridGE) to assess whether interactions between gene variants are associated with disease risk. This year, support through CIFAR's catalyst funding program allowed these fellows to work with Senior Fellow **Stephen Scherer** (The Hospital for Sick Children) to conduct a preliminary analysis to identify autism-related genetic interactions. Continued development will identify new strategies for precision medicine for a range of human diseases.



At a Glance

Founded:

1986, as the Cosmology & Gravity program

Program Director: Vicky Kaspi, McGill University

Fellows, Advisors and CIFAR Azrieli Global Scholars:

37

Institutions represented:

21, in 5 countries

Meetings:

2; in Montreal and Banff, Canada

Supporters:

R. Howard Webster Foundation

Gravity & the Extreme Universe

Aims to answer profound questions about the Universe including the nature of gravity and extreme phenomena such as colliding black holes and neutron stars.

The inaugural year of the Gravity & the Extreme Universe program coincided with the revolutionary and fortuitously-timed detection of both gravitational waves and light signals (including X-rays, infrared, visible and ultraviolet light) from two colliding neutron stars 130 million light years from Earth. This event marked the beginning of a new era of 'multi-messenger astronomy' that combines different methods of detection and provides researchers with a plethora of new information on some of the most extreme phenomena in the Universe.

The program held its first workshop in November 2017 at the **Space Institute at Mc-Gill University** dedicated to discussing this important 'multi-messenger event.' International researchers including Senior Fellow, **Vicky Kalogera** (Northwestern University), Associate Fellow **Harald Pfeiffer** (University of Toronto), CIFAR Azrieli Global Scholar **Ajith Parameswaran** (Tata Institute of Fundamental Research) and CIFAR Azrieli Global Scholar **Daryl Haggard** (McGill University) discussed the initial detection of the colliding neutron stars.

The annual general meeting was held in February 2018 in Banff, Alberta, with presentations from program members and invited speakers from around the world. The meeting highlighted advances in multi-messenger astronomy with a focus on the landmark detection of the neutron star merger among other areas, such as Fast Radio Bursts (FRBs) — with the Canadian telescope CHIME coming online.

Research Highlights

Program Director Vicky Kaspi (McGill University) and Senior Fellow Scott Ransom

(National Radio Astronomy Observatory) were part of a team that examined the only known repeating FRB – a high-energy astrophysical phenomenon of unknown origin – to better understand the nature of the source and its environment. Kaspi and Ransom, along with fellows **Ingrid Stairs** (University of British Columbia), **Matt Dobbs** (McGill University) and **Ue-Li Pen** (University of Toronto), have developed expertise on FRBs in large part due to the CIFAR-catalyzed CHIME/FRB project.

> Kaspi, Ransom et al. *Nature*, 553, 182.

Senior Fellow **Dick Bond** (University of Toronto) played a leading role in the development of the Websky Suite of simulations, in an effort to interpret measurements of the large-scale structure of the Universe. Important new results have been reported by Bond along with Senior Fellows **Mark Halpern** (University of British Columbia), **Gil Holder** (University of British Columbia), **Gil Holder** (University of Illinois at Urbana-Champaign) and **Matt Dobbs**, and Associate Fellow **David Spergel** (Princeton University), on polarization within the Cosmic Microwave Background.





Humans & the Microbiome

Examines the human microbiome – the microbes that live in and on us – and the role it plays in human development and behaviour, as well as how it is affecting our evolution and society.

At a Glance

Founded: 2014

Program Directors:

Brett Finlay, University of British Columbia, and Janet Rossant, Hospital for Sick Children, Toronto

Fellows, Advisors and CIFAR Azrieli Global Scholars:

23

Institutions represented: 19, in 8 countries

Meetings:

2; in Galiano Island, BC, Canada and Singapore

Research Partners:

Brain Canada Foundation through the Canada Brain Research Fund, Fonds de recherche du Québec – Santé (FRQS), Genome British Columbia,Genome Canada

Supporters:

Manulife, Trottier Family Foundation, 1 anonymous donor The Humans & the Microbiome program strengthened its interdisciplinary profile over the past year, especially thanks to increased collaborations between biologists, anthropologists, ancient DNA experts, philosophers and historians. The goal of the program this year has been to examine how the microbiome affects different stages of life, and how our collective microbiome changes in different geo-cultural settings.

The Fall program meeting was held in October 2017 in Galiano Island, BC, and was devoted to discussion of the future directions of the program. The Spring meeting was held in March 2018 in Singapore, in partnership with the Lee Kong Chian School of Medicine at Nanyang Technological University (NTU) and the Ageing Research Institute for Society and Education (ARISE) at NTU. The location was motivated by the desire to understand how the microbiome is influenced by diverse societal practices around the world and throughout history.

As a result of the meetings the program is focusing on five themes around the effects of the microbiome: 1) early life, 2) aging, 3) brain development, 4) the anthropocene and 5) human evolution. There is now an increased focus on "community" microbiomes and how they change over time, place and cultural context. This focus has fostered new collaboration between biologists and scholars from the social sciences and humanities, including exploring the concept of self when one being is colonized by another.

As part of their knowledge mobilization efforts, program advisors and members have committed to engaging stakeholders beyond academia, including medical and public health professionals, in an ongoing dialogue around the healthy microbiome. For instance, they have given several public talks, most notably at the **Royal Institution** and the **Royal Canadian Institute of Science**.

Research Highlights

The program focus on the effects of the microbiome and the brain has yielded two notable collaborations. First, a CIFAR catalyst research project among Sven Pettersson (Nanyang Technological University), Janet Rossant (University of Toronto) and Brett Finlay (University of British Columbia) led to Finlay's PhD student working in Pettersson's lab as part of an exchange that explored differences in neurogenesis and neuronal proliferation in specific-pathogen-free and germ-free mice. Future work will examine early brain development and the role of the maternal microbiota/vertical microbial transmission. Second, program members took part in CIFAR's inaugural Brain Symposium in Toronto in March 2018 and identified avenues for collaborations with other CIFAR programs.

Liping Zhao (Shanghai Jiao Tong University) examined how much dietary fibre was consumed by ancient humans. It turns out to be 200-400 g fibre per day. He thought that this would drastically change the microbiome to a more beneficial one and experimentally tested the hypothesis.

> Zhao, Liping ..., Zhang, Chenhong (2018). Science, 359, 1151-1156.

Two program members, **Eran Elinav** (Weizmann Institute of Science) and **Sven Pettersson** published a review in the leading journal *Cell*, entitled "Our gut microbiomethe evolving inner self."

> Kundu, P. ..., Elinav, E., Pettersson, S. (2017). Cell, 171, 1481-1493.



At a Glance

Founded: **2004**

Program Directors:

Torsten Persson, Stockholm University, and Francesco Trebbi (Associate Director), University of British Columbia

Fellows, Advisors and CIFAR Azrieli Global Scholars:

31

Institutions represented:

16, in 6 countries

Meetings:

3; in Toronto, Canada and London, United Kingdom

Supporters:

BMO Financial Group, Jon and Laura Hantho, 1 anonymous donor

Institutions, Organizations & Growth

Takes an integrated approach to basic questions, such as what makes some countries rich and others poor; what makes some societies violent and others peaceful; what makes some states strong and others weak; always examining the crucial roles of different types of institutions.

The Institutions, Organizations & Growth program explored six core themes this year: economic trade, international trade, political economy of consolidated democracies, political economy of development, culture and economics, and history.

Traditionally, the program partners with leading institutions abroad to co-organize their summer program meetings. The June 2018 meeting was held in London and co-hosted by the London School of Economics & Political Science (LSE). The Fall 2017 and Spring 2018 meetings took place in Toronto.

The program also engaged in knowledge mobilization activities, such as the **Commission on State Fragility, Growth, and Development** event in London, UK on June 28, 2018, in advance of the program meeting at LSE. This high-profile event, co-organized by CIFAR, the **International Growth Centre**, and the **British Academy**, brought together leading academics, policy-makers, NGOs and key community members to discuss the theme of "Escaping the Fragility Trap."

Research Highlights

Informed by central issues around the legitimacy and effectiveness of the state, which have been core discussion points in the program, Senior Fellow **Tim Besley** (LSE) developed and presented several key papers on a model of state action that requires reciprocal behaviour by the government towards its citizens. These papers ultimately formed the basis of his July 2018 Presidential Address to the Econometric Society, one of the most prestigious professional associations in economics worldwide.

Senior Fellows Joseph Henrich (Harvard University) and Avner Greif (Stanford

University), engaged in a catalyst project titled, "Christianity in late Antiquity: Effects of divinely-sanctioned social norms on the social structure of Medieval Europe." This CIFAR-supported collaborative project, which helped support a co-supervised postdoctoral fellow, shows that the spread of the Church systematically altered family structures over centuries, resulting in a shift of people's psychology towards the more individualistic and analytic.

Senior Fellow **Daniel Diermeier** (University of Chicago) completed a book on private politics, which examines private interest actions by activists and NGOs that target companies in order to regulate the latter's behaviour. The book develops a comprehensive theoretical framework for the study of corporate campaigns and addresses key questions on the consequences of corporate campaigns for society.



At a Glance

Founded: 2004

Program Directors:

Yoshua Bengio, Université de Montréal; Yann LeCun, New York University and Facebook AI Research; and Hugo Larochelle (Associate Program Director), Université de Sherbrooke and Google

Fellows, Advisors and CIFAR Azrieli Global Scholars:

47

Institutions represented:

31, in 7 countries

Meetings:

2; in Long Beach, CA, United States and Vancouver, Canada

Research Partners:

Brain Canada Foundation through the Canada Brain Research Fund, Facebook, Google Inc., Inria

Supporters:

Bristol Gate Capital Partners, Facebook, Céline and Jacques Lamarre

Learning in Machines & Brains

Aims to contribute to the understanding of the computational and mathematical principles that enable intelligence through learning, be it in brains or in machines.

A core research direction fueling the Learning in Machines & Brains program is deep learning which studies algorithms that discover multiple levels of representation of observed data. Whereas much progress has been made in supervised learning, major challenges remain for unsupervised learning and reinforcement learning, which are believed to be key to future progress in Al.

This year, the program held two meetings and added six new members. The December 2017 program meeting was held before the Conference on Neural Information Processing Systems (NIPS). Program members discussed topics including causality and meta-learning (learning to learn) and training neural networks to understand the world in which they operate. In April 2018, program members met prior to the International Conference on Learning Representations (ICLR). This meeting included discussions of the common learning mechanisms underlying artificial models and biological brains. Part of this meeting also explored ways to ensure artificial intelligence systems reliably behave outside their specified domain.

From June 28 - July 5, 2017 the program also held their largest ever Deep Learning and Reinforcement Learning Summer School in Montreal, QC. More than 1,100 applications were received for this opportunity and successful participants included 271 trainees and researchers from 23 countries.

Research Highlights

Program members have made substantial progress on bridging the gap between our understanding of biological neurons and deep learning, and how learning mechanisms such as backpropagation could be implemented in the brain. This work is supported by CIFAR's catalyst program and involves ongoing collaborations between Global Scholar **Joel Zylberberg** (University of Colorado Denver), Fellow **Blake Richards** (University of Toronto) and Program Co-Director **Yoshua Bengio** (Université de Montréal).

- > Guerguiev, J., Lillicrap, T.P., & Richards, B.A. (2017). *eLife*, 6: e22901
- > Sacramento, J., Costa, R.P., Bengio, Y., & Senn, Y. (2017). arXiv:1801.00062

In 2014, program members **Aaron Cour**ville and **Yoshua Bengio** developed a ground-breaking approach, generative adversarial networks, for image classification. This year, interactions between Associate Fellow **Pascal Vincent** and Yoshua Bengio (both Université de Montréal) led to a new perspective on these previous findings with implications for unsupervised learning.

> Huang, G., Berard, H., Touati, A., Gidel, G., Vincent, P., & Lacoste-Julien, S. (2018). *ICLR*. arXiv:1708.02511

Richard Zemel (University of Toronto) and **Hugo Larochelle** (Université de Montréal; Google) have been investigating ways of making an Al system faster at learning (i.e. using much less data). Specifically, their method improves the ability of a computer to recognize new objects in images from only a handful of pictures of that object, instead of thousands.

> Ren, M., Triantafillou, E., Ravi, S., Snell, J., Swersky, K., Tenenbaum, J.B., Larochelle, H., & Zemel, R.S. ICLR 2018, arXiv:1803.00676

Molecular Architecture of Life

Understanding the complex molecular processes that underlie all living systems.

At a Glance

Founded: 2014

Program Directors:

Dwayne Miller, Max Planck Institute for the Structure & Dynamics of Matter/ University of Toronto, and Oliver Ernst, University of Toronto

Fellows, Advisors and CIFAR Azrieli Global Scholars:

18

Institutions represented:

15, in 6 countries

Meetings:

2; in Hamburg, Germany, and Toronto, Canada The Molecular Architecture of Life program aims to understand the structure-function relationships and dynamics of biological molecules under conditions that reflect that of living cells. Key areas of focus are DNA and its compaction, the proteasome and protein degradation, and G-protein-coupled receptors (GPCRs), proteins that account for more than 50 per cent of current drug targets in the human body.

The program held two meetings this year. The first meeting took place in Hamburg, Germany in October 2017 in partnership with the Center for Free-Electron Laser Science (CFEL) and the Max Planck Institute for the Structure and Dynamics of Matter (MPSD). Program members and guests discussed approaches, methodologies and limitations for understanding biological function with discussion on the physics controlling DNA compaction and viral replication. Guests shared and discussed advances in imaging methods such as cryo-electron microscopy (cryo-EM) to coherent X-ray reconstruction. Integrating various techniques such as these will be necessary to develop a complete picture of any cellular process.

The second meeting was held in April 2018 in Toronto, Canada. This meeting centred on mass spectrometry (MS) and proteomics. Leading researchers presented on the latest advances in using MS to understand protein complexes, such as GPCRs, and discussed the potential for single-cell mass spectrometry. Newly-appointed CIFAR Azrieli Global Scholar **Huy Bui** (McGill University) presented his work using cryo-EM and tomography to understand the structure and function of cilia (cellular microtubules that aid in sensing and mechanical motion of cells).

Research Highlights

The research groups of Senior Fellows Krzysztof Palczewski (Case Western Reserve University) and Daniel Figeys (University of Ottawa) investigated the biological function of retinal pigmented epithelium (RPE) cells. RPE plays a critical role in shedding photoreceptors through a poorly understood process. Without this natural regulation, degenerative disorders within the retina can cause damage, and potentially lead to blindness. The research team discovered a number of important pathways and signaling mechanisms within the eye that help regulate this process. A CIFAR catalyst project helped to support this work and resulted in publication.

> Figeys D, Palczewski K et al. (2017). J Biol Chem, 292, 19826.

Program Co-Director **Oliver Ernst** established a research collaboration with **Autodesk** to develop software for visualizing protein structures using virtual reality technology. The work has now been published in the journal *Nature Methods*.

> Balo AR, Wang M, and Ernst OP. (2017). Nature Methods, 14, 1122.



At a Glance

Founded: **2002**

Program Directors:

Aephraim Steinberg, University of Toronto, and David Poulin, Université de Sherbrooke

Fellows, Advisors and CIFAR Azrieli Global Scholars: **38**

Institutions represented: **22, in 9 countries**

Meetings:

2; in Niagara-on-the-Lake and Quebec City, Canada

Quantum Information Science

Unites computer scientists and physicists in an effort to harness the strange and fascinating properties of the quantum world, where the mere act of observing an object changes its nature, with the aim of building quantum computers.

The program explored the frontiers in quantum information science, including many of the latest advances related to quantum computing, quantum algorithms, many-body physics, and new technologies for sensing applications.

The fall meeting at Niagara-on-the-Lake, ON included presentations focused on quantum protocols, light-matter interactions, and quantum optics, as well as research with implications for quantum computing, quantum communication, and precision sensing. Fellow Thomas Jennewein (University of Waterloo) presented work on the Quantum Encryption and Science Satellite (QEYSSat) project, the Canadian Space Agency's upcoming mission to demonstrate secure quantum key distribution (technology in space. CIFAR Azrieli Global Scholar **Nir** Bar-Gill (The Hebrew University of Jerusalem) highlighted his latest work studying spin systems in diamonds. CIFAR Fellow Debbie Leung (University of Waterloo) described recent work on communication through quantum channels compared to classical channels in different noise regimes.

The spring meeting in Quebec City, QC focused on understanding tensor networks as presented by meeting guests Glen Evenbly (Université de Sherbrooke) and Guifre Vidal (Perimeter Institute) - and their use in understanding strongly entangled quantum systems. CIFAR Fellow Joseph Emerson (University of Waterloo) and meeting guest Stacey Jeffery (CWI) presented work on error testing, benchmarking and verifying results from quantum computers that will not be able to be tested on classical machines. CIFAR Azrieli Global Scholar Gerhard Kirchmair (University of Innsbruck) described work related to manipulation and control of laser light using cavities mechanically controlled using oscillating cantilevers, and Senior Fellow **Raffi Budakian** (University of Waterloo) highlighted advances in his group related to magnetic resonance imaging (MRI) with nanometer scale precision.

Research Highlights

CIFAR Fellow **Alexandre Blais** (Université de Sherbrooke) co-authored a paper looking at a real-world example of a material that could be used in future quantum computers, and was able to demonstrate a route to scalable quantum circuits. The work was initiated by a connection made at a CIFAR program meeting, and the approach is based on work by Fellow **Michel Pioro-Ladrière** (Université de Sherbrooke).

> Blais et al. (2018). Science, 359, 1123.

Senior Fellow **Andrew Childs** (University of Maryland) co-authored a study exploring how to use near-term quantum computers, which will initially have limited processing power. The results provide a detailed blue-print for what could be the first practical application of quantum computers.

> Childs et al. (2017). arXiv:1711.10980

Fellows **William Coish** (McGill University) and **Michel Pioro-Ladrière** found that the conversion of an electron's magnetic moment into electrical charge can be amplified to perform the most accurate measurements ever achieved on such quantum systems – approaching 99.9 per cent – which is believed to be sufficient to reach the so-called fault-tolerant regime. The work grew out of conversations with a guest at a CIFAR program meeting.

- > Pioro-Ladrière et al. (2017). Nature Commun., 8, 1029.
- Coish, Pioro-Ladrière et al. (2018). Phys. Rev. X, 8, 021046.



Quantum Materials

Discovers and explores new or unusual materials whose unique properties, like superconductivity, could revolutionize technology.

At a Glance

Founded: 1987, as the Superconductivity program

Program Directors: Louis Taillefer, Université de Sherbrooke

Fellows, Advisors and CIFAR Azrieli Global Scholars:

68

Institutions represented:

33, in 7 countries

Meetings:

2; in Half Moon Bay, CA, United States and Montreal, Canada

Partners:

Gordon & Betty Moore Foundation The Quantum Materials program is at the forefront of materials discovery and fundamental physics, exploring some of the most unusual and exotic properties of frontier materials including high-temperature superconductors, spin liquids, semi-metals (such as graphene), and topological materials.

The program held its Fall 2017 meeting in Half Moon Bay, California in partnership with the **Gordon and Betty Moore Foundation** (GBMF), providing an opportunity to celebrate the collaboration between the GBMF's Emergent Phenomena in Quantum Systems (EPiQS) Initiative and CIFAR's Quantum Materials program. The meeting focused on the themes of iron-based superconductors, spin liquids, strongly correlated matter, and topological materials.

The June 2018 meeting in Montreal, QC, was preceded by the program's annual summer school, where 74 graduate students and postdoctoral fellows from around the world learned from top tier researchers and networked with peers. The program meeting that followed explored developments including the exciting discovery of superconductivity in graphene. Guest speaker Pablo Jarillo-Herrero (MIT) and Liang Fu (MIT) discussed the result.

Research Highlights

The nature of the pseudogap phase in cuprate superconductors is one of the major challenges of physics today. Work by members of the program has shed light on this phenomenon, including work by Program Director **Louis Taillefer** (Université de Sherbrooke) and his team demonstrating that the pseudogap phase is a generalized property across many different cuprate superconductors. The results are supported by theoretical work by Associate Fellow **Subir Sachdev** (Harvard University) and Senior Fellow **André-Marie Tremblay** (Université de Sherbrooke).

- > Taillefer et al. (2017) Phys Rev B, 95, 224517
- > **Sachdev** et al. (2017) *Phys Rev* B, 96, 075103
- > Tremblay et al. (2017) Phys Rev B 96, 125139

Since 2009, program members have reported on a number of quantum materials with electrical resistivities that depend linearly on temperature, at low temperatures, a phenomenon that has puzzled physicists for years. Recent results by Associate Fellow **Cyril Proust** (Laboratoire National des Champs Magnetiques Intenses) and **Louis Taillefer** have shown this extends to another material known as Bi-2212. The limit of this effect, known as the Planckian limit, is now seen as a universal property of metals, and poses a tremendous challenge to theorists.

> Fournier, Taillefer, Proust et al. (2018) arXiv:1805.02512

A major effort within the program is the realization of a quantum spin liquid – a solid material whose electronic properties act more like a liquid – with potential applications for information processing and storage. Associate Fellow **Robert Cava** (Princeton University) discovered a promising new material this year, NaCaNi2F7, which appears to behave like a spin liquid, according to recent results by Cava and Associate Fellow **Collin Broholm** (Johns Hopkins University). The research was inspired by discussions with Senior Fellows **Michel Gingras** (University of Waterloo) and **Bruce Gaulin** (McMaster University).

> **Cava**, **Broholm** et al. (2017). arXiv: 1711.07509



Successful Societies

Explores the roots and effects of social inequalities and asks the question: What makes a society successful?

At a Glance

Founded: **2002**

Program Directors:

Michèle Lamont, Harvard University, and Paul Pierson, University of California, Berkeley

Fellows, Advisors and CIFAR Azrieli Global Scholars:

21

Institutions represented:

17, in 4 countries

Meetings:

3; in Toronto, Canada; La Jolla, CA, United States; and Paris, France

Supporters:

BMO Financial Group, 1 anonymous donor The Successful Societies program held three meetings this year: Fall 2017 in Toronto, Winter 2018 in La Jolla, California, and Spring 2018 in Paris, France (in collaboration with **Sciences Po**). Members used the meetings to plan a special issue to be published with *Dædalus*. Tentatively titled "Inequality as a Multidimensional Process; An Interdisciplinary Agenda." it is expected to be published in Fall 2019.

As the program will close in 2019-20, several program members have successfully put forward Letters of Intent (LOIs) for CIFAR's 2018 Global Call for Ideas. **Irene Bloemraad** (University of California, Berkeley) and **Will Kymlicka** (Queen's University) are co-leads of the shortlisted LOI titled "Boundaries, Solidarities and Collective Action;" **Patrick Le Galès** (Sciences Po) has teamed up with Michael Storper (UCLA, Sciences Po, LSE) and Julie-Anne Boudreau (INRS) on a shortlisted LOI titled "Urban Governance and City-Ness."

On May 2, 2018, Irene Bloemraad gave the third annual **David Dodge CIFAR Lecture** in Toronto, on the topic of populism. This was a timely lecture in terms of public engagement and knowledge mobilization, especially in these times of "boundary-making" politics.

Research Highlights

Program Co-Director **Michèle Lamont** (Harvard University) published "Addressing Recognition Gaps: Destigmatization and the Reduction of Inequality" in the *American Sociological Review*, which built on the work of the Successful Societies Program over the last 15 years. Lamont discusses the role of institutions and cultural repertoires in sustaining collective well-being and extending cultural membership to the largest number. The article follows Lamont's 2018 Presidential Address to the American Sociological Association.

> Lamont, Michèle (2018). American Sociological Review, 83, 419-444.

Irene Bloemraad (University of California, Berkeley), published an article that advances a conceptual understanding of citizenship as membership through claims-making. This moves existing debates from mere typologizing towards a relational approach to dynamics of recognition within contexts of structured agency. Citizenship as claims-making may require a reassessment of boundary approaches and a more serious commitment to mixed-methods research. This is a defining challenge for future scholarship.

> **Bloemraad, Irene** (2018). Journal of Ethnic and Migration Studies, 44, 4–26.

Will Kymlicka (Queen's University), in collaboration with Keith Banting (Queen's University) co-edited *The Strains of Commitment: The Political Sources of Solidarity in Diverse Societies*, published by Oxford University Press in 2017. The volume focuses on the forces and sources of inclusion, a shift from the dominant focus on exclusionary measures in the extant literature. It was informed by Kymlicka's participation in the Successful Societies program, and several chapters were discussed at one of the program meetings. Founding Program Co-Director **Peter Hall** (Harvard University) also contributed one of the chapters.

Financial Overview

Financial Overview

CIFAR's revenue totaled \$30 million for the year, an increase of \$7.3 million (32%) over 2017. The year-over-year increase consisted of \$5.7 million for the Pan-Canadian AI Strategy and \$1.8 million from the governments of Canada, Ontario, British Columbia, Alberta and Quebec.

CIFAR expenses totaled \$30 million, an increase of 7.2 million (32%), of which direct program spending totaled \$26.2 million, up \$6.3 million (32%), for the 14 research programs supported within the year, knowledge mobilization efforts, the CIFAR Azrieli Global Scholars Program and the Pan-Canadian Al Strategy. Nonprogram spending totaled \$2.6 million, down \$0.3 million (10%) for advancement, governance and administration to support the organization.

CIFAR concluded the year with a strong balance sheet. Total assets at the end of the year totaled \$34 million, represented primarily by cash and short-term deposits (\$2.1 million), accounts receivable (\$2.8 million), equipment and leasehold improvement (\$1.7 million) and investments (\$28 million). Net assets after accounting for liabilities were \$20.9 million.

The audited financial statements for the year ended June 30, 2018 are available at **cifar.ca/accountability**.

30,037,999 22,762,737 22,762,737 Individuals Partnerships Foundations Federal: PCAIS Provincial Federal: Operational

2017

Expenses

28,812,722 23,359,925 Advancement Advancement Next Generation Knowledge Mobilization & Communications Pan-Canadian Al Strategy Knowledge Creation

2018

Revenue

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Statement of Operations

Year ended June 30, 2018

	2018 (000s)	2017 (000s)
Revenue		
Program contributions		
Government funding		
Federal		
Operational funding	7,000	5,680
Pan-Canadian Al Strategy	5,723	87
Provincial	7,044	6,595
	19,767	12,362
Partnerships		
Research organizations	2,643	2,415
Universities and others	245	258
	2,888	2,673
Private sector		
Corporations	853	1,053
Foundations	3,488	3,568
Individuals	1,779	1,753
	6,120	6,374
Investment income	1,263	1,353
	30,038	22,762
Expenses		
Program expenses		
Knowledge creation	15,161	15,637
Pan-Canadian Al Strategy	6,018	87
Knowledge mobilization and communications	2,803	2,914
Next generation	2,250	1,285
	26,232	19,923
Non-program expenses	2,581	2,868
	28,813	22,791
Surplus (deficiency) of revenue over expenses from operations	1,225	(29)
Unrealized gain (losses) on investments	(40)	1,790
One-time investment gain	311	_
	1,496	1,761

Condensed Balance Sheets

Year ended June 30, 2018

	2018 (000s)	2017 (000s)
Assets		
Cash	2,110	1,439
Investments	9,000	3,844
Accounts receivable	2,777	4,025
Prepaid expenses	230	298
	14,117	9,606
Investments	18,688	16,585
Property, equipment and leasehold improvements	1,566	1,686
Intangible assets	120	147
	34,491	\$28,024
Liabilities		
Accounts payable and accrued liabilities	5,139	4,194
Deferred revenue	5,708	3,513
Deferred tenant allowance	40	40
	10,887	7,747
Deferred revenue	2,393	520
Deferred tenant allowance	321	363
	13,601	8,630
Net assets		
Invested in property, equipment, leasehold improvements and intangible assets	1,325	1,430
Externally restricted endowment fund	474	474
Internally restricted reserve	10,000	11,000
Unrestricted	9,091	6,490
	20,890	19,394
	34,491	28,024

Appendices

Appendix A: Major Awards and Honours Received July 2017 to June 2018

In 2017/2018, CIFAR fellows and advisors received 90 major awards and honours.

Awards

Award	CIFAR Fellow or Advisor	CIFAR Program
Alfred P. Sloan Research Fellowship (USA)	 > Gabriela Schlau-Cohen (Massachusetts Institute of Technology) 	 CIFAR Azrieli Global Scholars/ Bio-inspired Solar Energy
Andrew Carnegie Fellowship (USA)	> Prerna Singh (Brown University)	> Successful Societies
Bloomberg 50 (USA)	 Geoffrey Hinton (Google; University of Toronto) 	> Learning in Machines & Brains
Bloomberg Ones to Watch (USA)	> Kyunghyun Cho (New York University)	 CIFAR Azrieli Global Scholars/ Learning in Machines & Brains
Breakthrough Prize in Fundamental Physics (USA)	 Mark Halpern (University of British Columbia) 	> Gravity & the Extreme Universe
	 > Gary Hinshaw (University of British Columbia) 	> Gravity & the Extreme Universe
	> Lyman Page (Princeton University)	> Gravity & the Extreme Universe
	> David Spergel (Princeton University)	> Gravity & the Extreme Universe
Calvó-Armengol International Prize in Economics (Spain)	> Melissa Dell (Harvard University)	 Institutions, Organizations & Growth
Canada's Top 40 Under 40	> Graham Taylor (University of Guelph)	 CIFAR Azrieli Global Scholars/ Learning in Machines & Brains
CAP/DCMMP Brockhouse Medal (Canada)	 Andrea Damascelli (University of British Columbia) 	> Quantum Materials
CAREER Award (National Science Foundation, USA)	> Judy Cha (Yale University)	 CIFAR Azrieli Global Scholars/ Quantum Materials
	 Nathaniel Gabor (University of California, Riverside) 	 CIFAR Azrieli Global Scholars/Bio- inspired Solar Energy
CNRS Silver Medal (France)	> Patrick Le Galès (Sciences Po)	> Successful Societies
Cottrell Scholar Award (Research Corporation for Science Advancement, USA)	 Nathaniel Gabor (University of California, Riverside) 	 CIFAR Azrieli Global Scholars/Bio- inspired Solar Energy
Daniel M. Wegner Theoretical Innovation Prize (Society for Personality & Social Psychology, USA)	> Joseph Henrich (Harvard University)	> Institutions, Organizations & Growth
Dannie Heineman Prize for Astrophysics (American Institute of Physics & American Astronomical Society)	 Vicky Kalogera (Northwestern University) 	> Gravity & the Extreme Universe

Discovery Accelerator Supplement (Natural Sciences & Engineering Research Council, Canada)	 David Hawthorn (University of Waterloo) 	> Quantum Materials
E. W. R. Steacie Memorial Fellowship (Natural Sciences & Engineering Research Council, Canada)	> Joelle Pineau (McGill University)	> Learning in Machines & Brains
Early Career Award (International Social Cognition Network)	 Kristin Laurin (University of British Columbia) 	 CIFAR Azrieli Global Scholars/ Successful Societies
Early Career Research Contributions Award (Society for Research in Child Development, USA)	> Katherine McAuliffe (Boston College)	 CIFAR Azrieli Global Scholars/ Azrieli Program in Brain, Mind & Consciousness
Early Investigator Award (Society of Experimental Psychologists, USA)	 Nicholas Turk-Browne (Yale University) 	 Azrieli Program in Brain, Mind & Consciousness
Early Researcher Award (Government of Ontario, Canada)	> Blake Richards (University of Toronto)	> Learning in Machines & Brains
Ernst Jung Gold Medal for Medicine (Jung Foundation for Science and Research, Germany)	 Wolfgang Baumeister (Max Planck Institute of Biochemistry) 	> Molecular Architecture of Life
European Research Council Consolidator Grant	 Ami Citri (Hebrew University of Jerusalem) 	 CIFAR Azrieli Global Scholars/ Child & Brain Development
George W. Beadle Award (Genetics Society of America)	 Philip Hieter (University of British Columbia) 	> Genetic Networks
Gerhard Herzberg Canada Gold Medal for Science and Engineering (Natural Sciences & Engineering Research Council, Canada)	> Lewis Kay (University of Toronto)	> Molecular Architecture of Life
Google Focused Research Award (USA)	 > Alán Aspuru-Guzik (University of Toronto) 	> Bio-inspired Solar Energy
Hamburg Prize for Theoretical Physics (Germany)	> Andrew Millis (Columbia University)	> Quantum Materials
Howard Hughes Medical Institute Professor (USA)	 Margaret McFall-Ngai (University of Hawaii, Manoa) 	> Humans & the Microbiome
Jeremy Knowles Award (Royal Society of Chemistry, UK)	 Christopher Chang (University of California, Berkeley) 	> Bio-inspired Solar Energy
John Rae Prize (Canadian Economics Association)	 Siwan Anderson (University of British Columbia) 	 Institutions, Organizations & Growth
John Simon Guggenheim Fellowship	> Peter Hall (Harvard University)	> Successful Societies
	> Aniruddh Patel (Tufts University)	 Azrieli Program in Brain, Mind & Consciousness
Killam Prize for the Social Sciences (Canada Council for the Arts)	 Janet Werker (University of British Columbia) 	 > Azrieli Program in Brain, Mind & Consciousness/Child & Brain Development
Killam Research Fellowship (Canada Council for the Arts)	> Yong Baek Kim (University of Toronto)	> Quantum Materials
L'Oréal-UNESCO For Women in Science Award	 Janet Rossant (Hospital for Sick Children, Toronto) 	> Humans & the Microbiome
Lagrange Prize in Continuous Optimization (Mathematical Optimization Society & Society for	 Mark Schmidt (University of British Columbia) 	> Learning in Machines & Brains
Industrial and Applied Mathematics)	> Francis Bach (Inria)	> Learning in Machines & Brains

Lars Onsager Prize (American Physical Society)	> Subir Sachdev (Harvard University)	> Quantum Materials
Lee Osheroff Richardson Science Prize for North and South America (Oxford Instruments)	> Kate Ross (Colorado State University)	> Quantum Materials
Longuet-Higgins Prize (IEEE Computer Society)	> Josef Sivic (Inria)	> Learning in Machines & Brains
Maria Sklodowska-Curie Medal (Polish Chemical Society)	 Krzysztof Palczewski (Case Western Reserve University) 	> Molecular Architecture of Life
Medal for Distinguished Contributions in Biomedical Science (New York Academy of Medicine)	 Nancy Adler (University of California, San Francisco) 	> Child & Brain Development
New Innovator Award (National Institutes of Health, USA)	 > Gabriela Schlau-Cohen (Massachusetts Institute of Technology) 	> Bio-inspired Solar Energy
Paul Kayser International Award in Retina Research (Retina Research Foundation, USA)	 Krzysztof Palczewski (Case Western Reserve University) 	> Molecular Architecture of Life
Prix du Québec – Prix Marie-Victorin	 Yoshua Bengio (Université de Montréal) 	> Learning in Machines & Brains
Prix du Québec – Prix Wilder- Penfield	 Michel Bouvier (Université de Montréal) 	> Molecular Architecture of Life
Ruane Prize for Outstanding Achievement in Child & Adolescent Psychiatric Research (Brain & Behavior Research Foundation, USA)	> Charles Nelson (Harvard University)	> Child & Brain Development
Rutherford Memorial Medal in Physics (Royal Society of Canada)	 > Ingrid Stairs (University of British Columbia) 	> Gravity & the Extreme Universe
SAGE Young Scholar Award (Society for Personality & Social Psychology and SAGE Publications, USA)	> Kristin Laurin (University of British Columbia)	 CIFAR Azrieli Global Scholars/ Successful Societies
Simons Investigator (Simons Foundation, USA)	> Ue-Li Pen (University of Toronto)	> Gravity & the Extreme Universe
Sloan Fellowship	 Mark Schmidt (University of British Columbia) 	> Learning in Machines & Brains
Thousand Young Talents Award (China)	> Luyi Yang (University of Toronto)	 CIFAR Azrieli Global Scholars/ Quantum Materials
TRIPODS Award (National Science Foundation, USA)	 Zaid Harchaoui (University of Washington) 	> Learning in Machines & Brains
W. B. Lewis Medal (Canadian Nuclear Society)	 Arthur McDonald (Queen's University) 	> Gravity & the Extreme University
Whole Child Award (Simms/Mann Institute, USA)	 W. Thomas Boyce (University of California, San Francisco) 	> Child & Brain Development
Wiley Prize in Psychology (British Academy)	 Stanislas Dehaene (Collège de France) 	 > Azrieli Program in Brain, Mind & Consciousness
Wolf Prize for Agriculture (Wolf Foundation, Israel)	 Gene Robinson (University of Illinois, Urbana-Champaign) 	> Child & Brain Development
Wolf Prize for Physics (Wolf	 Charles Bennett (IBM Corporation) 	> Quantum Information Science
	 > Gilles Brassard (Université de Montréal) 	> Quantum Information Science

Honours

Honour	CIFAR Fellow or Advisor	CIFAR Program
Corresponding Fellow of the British Academy	> Peter Hall (Harvard University)	> Successful Societies
Corresponding Member of the Australian Academy of Science	 Richard Ellis (University College London) 	> Gravity & the Extreme Universe
Distinguished Fellow of the American Economic Association	> Joel Mokyr (Northwestern University)	> Institutions, Organizations & Growth
Distinguished Fellow of the International Society for Computational Biology	> Olga Troyanskaya (Princeton University)	> Genetic Networks
Fellow of the American Academy of Arts and Sciences	 Leon Balents (University of California, Santa Barbara) 	> Quantum Materials
Fellow of the American Association for the Advancement of Science	 > Alán Aspuru-Guzik (University of Toronto) 	> Bio-inspired Solar Energy
Fellow of the American Physical Society	 Johnpierre Paglione (University of Maryland) 	> Quantum Materials
Fellow of the Association for the Advancement of Artificial Intelligence (USA)	> Joelle Pineau (McGill University)	> Learning in Machines & Brains
Fellow of the Royal Society of	> Yoshua Bengio (Université de Montréal)	> Learning in Machines & Brains
Canada	 > Gary Hinshaw (University of British Columbia) 	> Gravity & the Extreme Universe
	> Mario Leclerc (Université Laval)	> Bio-inspired Solar Energy
	> Barry Sanders (University of Calgary)	> Quantum Information Science
	> Robert Zatorre (McGill University)	 > Azrieli Program in Brain, Mind & Consciousness
Inductee to the Canadian Medical Hall of Fame	 Brett Finlay (University of British Columbia) 	> Humans & the Microbiome
Member of the European Academy of Sciences	 > Tanja Weil (Max Planck Institute for Polymer Research) 	> Molecular Architecture of Life
Member of the U.S. National Academy of Sciences	 > Lars Bildsten (University of California, Santa Barbara) 	> Gravity & the Extreme Universe
	 Vicky Kalogera (Northwestern University) 	> Gravity & the Extreme Universe
	 Matias Zaldarriaga (Institute for Advanced Study) 	> Gravity & the Extreme Universe
Knighthood (UK)	 > Timothy Besley (London School of Economics & Political Science) 	> Institutions, Organizations & Growth
Order of Canada – Officer	 Raymond Laflamme (University of Waterloo) 	> Quantum Information Science
	 Neil Turok (Perimeter Institute for Theoretical Physics) 	> Gravity & the Extreme Universe
	> Janet Werker (University of British Columbia)	 > Azrieli Program in Brain, Mind & Consciousness/Child & Brain Development

Canada 150 Research Chair	 Alán Aspuru-Guzik (University of Toronto) 	> Bio-inspired Solar Energy
Canada Research Chair (In total, CIFAR researchers hold 34 Canada Research Chairs and 4 Canada Excellence Research Chairs.)	 Michel Gingras (University of Waterloo) Anna Goldenberg (Hospital for Sick Children, Toronto) Will Kymlicka (Queen's University) Lisa Saksida (Western University) 	 > Quantum Materials > Child & Brain Development > Successful Societies > Azrieli Program in Brain, Mind & Consciourness
	 > Edward Sargent (University of Toronto) > Graham Taylor (University of Guelph) 	 > Bio-inspired Solar Energy > CIFAR Azrieli Global Scholars/ Learning in Machines & Brains
	 > Christopher Wiebe (University of Winnipeg) > Luyi Yang (University of Toronto) 	 > Quantum Materials > CIFAR Azrieli Global Scholars/

Appendix B: Board, Councils & Execuitve

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D. Lorne Tyrrell	Department of Medical Microbiology & Immunology, University of Alberta

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Mario Mariniello	Digital Adviser to the European Political Strategy Centre, European Commission	
Doina Precup	CIFAR Senior Fellow and Associate Professor, School of Computer Science, McGill University and DeepMind	
Meredith Whittaker	Co-Director at AI Now Institute, New York University	

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Appendix D: Program Advisors, Fellows & Global Scholars

Azrieli Program in Brain, Mind & Consciousness

Name	Appointment
Tim Bayne (Monash University, Australia)	Senior Fellow
Craig Chapman (University of Alberta, Canada)	CIFAR Azrieli Global Scholar
Axel Cleeremans (Université libre de Bruxelles, Belgium)	Senior Fellow
Stanislas Dehaene (Collège de France; INSERM-CEA, France)	Senior Fellow
Daniel Dennett (Tufts University, United States)	Advisor
Alona Fyshe (University of Victoria, Canada)	CIFAR Azrieli Global Scholar
Melvyn Goodale (Western University, Canada)	Ivey Fellow and Program Co-Director
Atsushi Iriki (RIKEN Brain Science Institute, Japan)	Senior Fellow
Sheena Josselyn (Hospital for Sick Children, Canada)	Senior Fellow
Nancy Kanwisher (Massachusetts Institute of Technology, United States)	Advisor
Robert Kentridge (Durham University, United Kingdom)	Senior Fellow
Sid Kouider (École Normale Supérieure, France)	Senior Fellow
Rafael Malach (Weizmann Institute of Science, Israel)	Tanenbaum Fellow
Marcello Massimini (University of Milan, Italy)	Senior Fellow
Jason Mattingley (University of Queensland, Australia)	Senior Fellow
Katherine McAuliffe (Boston College, United States)	CIFAR Azrieli Global Scholar
David Menon (University of Cambridge, United Kingdom)	Advisor
Adrian Owen (Western University, Canada)	Koerner Fellow and Program Co-Director
Aniruddh Patel (Tufts University, United States)	Senior Fellow
Isabelle Peretz (Université de Montréal, Canada)	Associate Fellow
Mu-ming Poo (Chinese Academy of Sciences, China)	Associate Fellow
Lisa Saksida (Western University, Canada)	Senior Fellow
Anil Seth (University of Sussex, United Kingdom)	Senior Fellow
David Sherry (Western University, Canada)	Advisor
Catherine Tallon-Baudry (École normale supérieure, France)	Senior Fellow
Laurel Trainor (McMaster University, Canada)	Senior Fellow
Nicholas Turk-Browne (Yale University, United States)	Senior Fellow
Sandra Waxman (Northwestern University, United States)	Associate Fellow
Janet Werker (University of British Columbia, Canada)	Advisory Committee Chair
Robert Zatorre (McGill University, Canada)	Senior Fellow

Bio-inspired Solar Energy

Name	Appointment
Fraser Armstrong (University of Oxford, United Kingdom)	Advisor
Alán Aspuru-Guzik (University of Toronto, Canada)	Senior Fellow
Curtis Berlinguette (University of British Columbia, Canada)	Senior Fellow
Christopher Chang (University of California, Berkeley, United States)	Senior Fellow
Richard Cogdell (University of Glasgow, United Kingdom)	Advisory Committee Chair
Catherine Drennan (Massachusetts Institute of Technology, United States)	Senior Fellow
Nathaniel Gabor (University of California, Riverside, United States)	CIFAR Azrieli Global Scholar
Sharon Hammes-Schiffer (Yale University, United States)	Senior Fellow
Shaffiq Jaffer (Total American Services, United States)	Advisor
Mario Leclerc (Université Laval, Canada)	Senior Fellow
Karl Leo (Dresden University of Technology, Germany)	Senior Fellow
Thomas Mallouk (Pennsylvania State University, United States)	Senior Fellow
Daniel Nocera (Harvard University, United States)	Advisor
Ted Sargent (University of Toronto, Canada)	Senior Fellow and Heffernan Program Director
Gabriela Schlau-Cohen (Massachusetts Institute of Technology, United States)	CIFAR Azrieli Global Scholar
Greg Scholes (Princeton University)	Senior Fellow
Rienk Van Grondelle (Vrije University Amsterdam, The Netherlands)	Senior Fellow
Aleksandra Vojvodic (University of Pennsylvania, United States)	Fellow
Jeffrey Warren (Simon Fraser University)	CIFAR Azrieli Global Scholar
Vivian Yam (University of Hong Kong)	Advisor
Peidong Yang (University of California, Berkeley)	Senior Fellow

Child & Brain Development Program

Name	Appointment
Nancy Adler (University of California, San Francisco, United States)	Advisor
Elisabeth Binder (Max Planck Institute of Psychiatry, Germany)	Advisor
W. Thomas Boyce (University of California, San Francisco, United States)	Senior Fellow and Program Co-Director
Ami Citri (The Hebrew University of Jerusalem, Israel)	CIFAR Azrieli Global Scholar
David Clayton (Queen Mary, University of London, United Kingdom)	Senior Fellow
Brian Dias (Emory University, United States)	CIFAR Azrieli Global Scholar
Paul Frankland (Hospital for Sick Children, Toronto, Canada)	Fellow
Anna Goldenberg (Hospital for Sick Children, Toronto, Canada)	Fellow
Megan Gunnar (University of Minnesota, United States)	Associate Fellow
Takao Hensch (Harvard University, United States)	Senior Fellow
Daniela Kaufer (University of California, Berkeley, United States)	Fellow
Michael Kobor (University of British Columbia, Canada)	Senior Fellow
Bryan Kolb (University of Lethbridge, Canada)	Senior Fellow
Joel Levine (University of Toronto at Mississauga, Canada)	Senior Fellow

Thom McDade (Northwestern University, United States)	Senior Fellow
Michael Meaney (McGill University, Canada)	Senior Fellow
Sara Mostafavi (University of British Columbia, Canada)	Fellow
Charles Nelson (Harvard University, United States)	Senior Fellow
Candice Odgers (Duke University, United States)	Fellow
Kieran O'Donnell (McGill University, Canada)	CIFAR Azrieli Global Scholar
Gene Robinson (University of Illinois at Urbana-Champaign, United States)	Advisor
Michael Rutter (King's College London, United Kingdom)	Advisory Committee Chair
Marla Sokolowski (University of Toronto, Canada)	Weston Fellow and Program Co-Director
Stephen Suomi (National Institutes of Health, United States)	Senior Fellow
Janet Werker (University of British Columbia, Canada)	Senior Fellow

Genetic Networks Program

Name	Appointment
Brenda Andrews (University of Toronto, Canada)	Senior Fellow
Charles Boone (University of Toronto, Canada)	Senior Fellow and Program Co-Director
David Botstein (California Life Company, United States)	Advisory Committee Chair
Hannah Carter (University of California, San Diego, United States)	CIFAR Azrieli Global Scholar
Aravinda Chakravarti (Johns Hopkins University, United States)	Senior Fellow
Maitreya Dunham (University of Washington, United States)	Senior Fellow
Douglas Fowler (University of Washington, United States)	CIFAR Azrieli Global Scholar
Andrew Fraser (University of Toronto, Canada)	Fellow
Brendan Frey (University of Toronto, Canada)	Senior Fellow
Philip Hieter (University of British Columbia, Canada)	Senior Fellow
Timothy Hughes (University of Toronto, Canada)	Senior Fellow
Jason Moffat (University of Toronto, Canada)	Senior Fellow
Chad Myers (University of Minnesota, United States)	Fellow
Frederick Roth (University of Toronto, Canada)	Senior Fellow and Program Co-Director
Stephen Scherer (Hospital for Sick Children, Toronto, Canada)	Senior Fellow
Olga Troyanskaya (Princeton University, United States)	Senior Fellow
Marian Walhout (University of Massachusetts, United States)	Senior Fellow
Robert Waterston (University of Washington, United States)	Advisor

Gravity & the Extreme Universe Program

Name	Appointment
Lars Bildsten (University of California, Santa Barbara, United States)	Associate Fellow
Roger Blandford (Stanford University, United States)	Advisor
J. Richard Bond (University of Toronto, Canada)	Senior Fellow
Mark Chen (Queen's University, Canada)	Senior Fellow
Matthew Choptuik (University of British Columbia, Canada)	Associate Fellow

Matt Dobbs (McGill University, Canada)	Senior Fellow
Richard Ellis (University College London, United Kingdom)	Associate Fellow
Gabriela Gonzalez (Louisiana State University, United States)	Advisor
Daryl Haggard (McGill University, Canada)	CIFAR Azrieli Global Scholar
Mark Halpern (University of British Columbia, Canada)	Senior Fellow
Gary Hinshaw (University of British Columbia, Canada)	Senior Fellow
Gilbert Holder (University of Illinois at Urbana-Champaign, United States)	Senior Fellow
Werner Israel (University of Victoria, Canada)	Distinguished Fellow
Vicky Kalogera (Northwestern University, United States)	Senior Fellow
Victoria Kaspi (McGill University, Canada)	R. Howard Webster Foundation Fellow and Program Director
Luis Lehner (University of Waterloo, Canada)	Senior Fellow
Arthur McDonald (Queen's University, Canada)	Associate Fellow
Robert Myers (Perimeter Institute for Theoretical Physics, Canada)	Associate Fellow
Julio Navarro (University of Victoria, Canada)	Senior Fellow
Barth Netterfield (University of Toronto, Canada)	Senior Fellow
Lyman Page (Princeton University, United States)	Advisor
Ajith Parameswaran (International Center for Theoretical Sciences, India)	CIFAR Azrieli Global Scholar
John Peacock (University of Edinburgh, United Kingdom)	Associate Fellow
Ue-Li Pen (University of Toronto, Canada)	Senior Fellow
Harald Pfeiffer (University of Toronto, Canada)	Associate Fellow
E. Sterl Phinney (California Institute of Technology, United States)	Associate Fellow
Frans Pretorius (Princeton University, United States)	Senior Fellow
Scott Ransom (National Radio Astronomy Observatory, United States)	Senior Fellow
Joseph Silk (University of Oxford, United Kingdom)	Associate Fellow
Eva Silverstein (Stanford University, United States)	Advisor
David Spergel (Princeton University, United States)	Associate Fellow
Ingrid Stairs (University of British Columbia, Canada)	Senior Fellow
Scott Tremaine (Institute for Advanced Study, United States)	Advisory Committee Chair
Neil Turok (Perimeter Institute for Theoretical Physics, Canada)	Associate Fellow
William Unruh (University of British Columbia, Canada)	Associate Fellow
Simon White (Max Planck Institute for Astrophysics, Germany)	Advisor
Matias Zaldarriaga (Institute for Advanced Study, United States)	Senior Fellow

Humans & the Microbiome

Name	Appointment
Katherine Amato (Northwestern University, United States)	CIFAR Azrieli Global Scholar
Martin Blaser (New York University, United States)	Advisor
Thomas Bosch (Kiel University, Germany)	Senior Fellow
Stanislav Dusko Ehrlich (King's College London, United Kingdom)	Advisor
Eran Elinav (Weizmann Institute of Science, Israel)	Senior Fellow
Brett Finlay (University of British Columbia, Canada)	Senior Fellow and Program Co-Director

Tamara Giles-Vernick (Institut Pasteur, France)	Senior Fellow
Philippe Gros (McGill University, Canada)	Trottier Fellow
Karen Guillemin (University of Oregon, United States)	Senior Fellow
Frédéric Keck (Musée du quai Branly, France)	Fellow
Alexander Kwarteng (Kwame Nkrumah University of Science and Technology, Ghana)	CIFAR Azrieli Global Scholar
Margaret Lock (McGill University, Canada)	Advisor
Corinne Maurice (McGill University, Canada)	CIFAR Azrieli Global Scholar
Margaret McFall-Ngai (University of Hawaii at Manoa, United States)	Advisory Committee Chair
Melissa Melby (University of Delaware, United States)	Advisor
Mark Nichter (University of Arizona, United States)	Advisor
Sven Pettersson (Karolinska Institutet, Sweden)	Senior Fellow
Hendrik Poinar (McMaster University, Canada)	Senior Fellow
Tobias Rees (McGill University, Canada)	Fellow
Janet Rossant (Hospital for Sick Children, Toronto, Canada)	Senior Fellow and Program Co-Director
Philippe Sansonetti (Institut Pasteur and Collège de France, France)	Senior Fellow
Eric Wieschaus (Princeton University, United States)	Advisor
Liping Zhao (Rutgers University, United States)	Senior Fellow

Institutions, Organizations & Growth

Name	Appointment
Daron Acemoglu (Massachusetts Institute of Technology, United States)	Senior Fellow
Philippe Aghion (Collège de France, France)	Senior Fellow
George Akerlof (Georgetown University, United States)	Senior Fellow
Siwan Anderson (University of British Columbia, Canada)	Associate Fellow
Natalie Bau (University of Toronto, Canada)	CIFAR Azrieli Global Scholar
Roland Benabou (Princeton University, United States)	Senior Fellow
Timothy Besley (London School of Economics & Political Science, United Kingdom)	Senior Fellow
Matilde Bombardini (University of British Columbia, Canada)	Fellow
Robert Boyd (Arizona State University, United States)	Advisor
Melissa Dell (Harvard University, United States)	Associate Fellow
Daniel Diermeier (University of Chicago, United States)	Senior Fellow
Mauricio Drelichman (University of British Columbia, Canada)	Fellow
James Fearon (Stanford University, United States)	Senior Fellow
Patrick Francois (University of British Columbia, Canada)	Senior Fellow
Thomas Fujiwara (Princeton University, United States)	Associate Fellow
Avner Greif (Stanford University, United States)	Senior Fellow
Elhanan Helpman (Harvard University, United States)	Distinguished Fellow
Joseph Henrich (Harvard University, United States)	Senior Fellow
Kim Hill (Arizona State University, United States)	Senior Fellow
Matthew Jackson (Stanford University, United States)	Senior Fellow
Ruixue Jia (University of California, San Diego, United States)	Associate Fellow

Sara Lowes (Bocconi University, Italy)	CIFAR Azrieli Global Scholar
Joel Mokyr (Northwestern University, United States)	Advisory Committee Chair
Roger Myerson (University of Chicago, United States)	Advisor
Torsten Persson (Stockholm University, Sweden)	Senior Fellow and Program Director
Marit Rehavi (University of British Columbia, Canada)	Fellow
Raul Sanchez de la Sierra (University of California, Berkeley, United States)	CIFAR Azrieli Global Scholar
Kenneth Shepsle (Harvard University, United States)	Advisor
Guido Tabellini (Bocconi University, Italy)	Senior Fellow
Francesco Trebbi (University of British Columbia, Canada)	Fellow and Associate Program Director
Daniel Trefler (University of Toronto, Canada)	Senior Fellow

Learning in Machines & Brains

Name	Appointment
Pieter Abbeel (University of California, Berkeley, United States)	Advisor
Francis Bach (Inria, France)	Senior Fellow
Marc Bellemare (McGill University, Canada)	Fellow
Yoshua Bengio (Université de Montréal, Canada)	Senior Fellow and Program Co-Director
Leon Bottou (Facebook Al Research, France)	Advisor
Kyunghyun Cho (New York University, United States)	CIFAR Azrieli Global Scholar
Aaron Courville (Université de Montréal, Canada)	Fellow
Nando De Freitas (University of Oxford, United Kingdom)	Senior Fellow
James DiCarlo (Massachusetts Institute of Technology, United States)	Associate Fellow
Rob Fergus (New York University, United States)	Senior Fellow
Ila Fiete (University of Texas at Austin, United States)	Senior Fellow
David Fleet (University of Toronto, Canada)	Senior Fellow
Brendan Frey (University of Toronto, Canada)	Senior Fellow
Surya Ganguli (Stanford University, United States)	Associate Fellow
Zaid Harchaoui (University of Washington, United States)	Associate Fellow
Geoffrey Hinton (Google and University of Toronto, Canada)	Distinguished Fellow, Advisor and Founding Program Director
Aapo Hyvärinen (University College London, United Kingdom)	Associate Fellow
Konrad Körding (University of Pennsylvania, United States)	Associate Fellow
Simon Lacoste-Julien (Université de Montréal, Canada)	Fellow
Hugo Larochelle (Google and Université de Sherbrooke, Canada)	Fellow and Associate Program Director
Yann LeCun (Facebook Al Research, United States)	Senior Fellow and Program Co-Director
Honglak Lee (University of Michigan, United States)	Associate Fellow
Christopher Manning (Stanford University, United States)	Associate Fellow
Roland Memisevic (Twenty Billion Neurons Inc., Canada)	Fellow
Andrew Ng (Stanford University, United States)	Associate Fellow
Bruno Olshausen (University of California, Berkeley, United States)	Senior Fellow
Pietro Perona (California Institute of Technology, United States)	Advisor

Joelle Pineau (McGill University, Canada)	Senior Fellow
Doina Precup (McGill University, Canada)	Senior Fellow
Blake Richards (University of Toronto, Canada)	Fellow
Ruslan Salakhutdinov (Carnegie Mellon University, United States)	Fellow
Mark Schmidt (University of British Columbia, Canada)	Associate Fellow
Bernhard Schölkopf (Max Planck Institute for Intelligent Systems, Germany)	Advisory Committee Chair
Terrence Sejnowski (The Salk Institute for Biological Studies, United States)	Advisor
Sebastian Seung (Princeton University, United States)	Advisor
Eero Simoncelli (New York University, United States)	Associate Fellow
Josef Sivic (Inria, France)	Senior Fellow
Ilya Sutskever (OpenAl, United States)	Associate Fellow
Richard Sutton (University of Alberta, Canada)	Associate Fellow
Graham Taylor (University of Guelph, Canada)	CIFAR Azrieli Global Scholar
Antonio Torralba (Massachusetts Institute of Technology, United States)	Associate Fellow
Pascal Vincent (Université de Montréal, Canada)	Associate Fellow
Yair Weiss (The Hebrew University of Jerusalem, Israel)	Senior Fellow
Max Welling (University of Amsterdam, The Netherlands)	Senior Fellow
Christopher Williams (University of Edinburgh, United Kingdom)	Associate Fellow
Richard Zemel (University of Toronto, Canada)	Senior Fellow
Joel Zylberberg (University of Colorado, Denver, United States)	CIFAR Azrieli Global Scholar

Molecular Architecture of Life

Name	Appointment
Robert Austin (Princeton University, United States)	Advisor
Wolfgang Baumeister (Max Planck Institute of Biochemistry, Germany)	Senior Fellow
Michel Bouvier (Université de Montréal, Canada)	Senior Fellow
Khanh Huy Bui (McGill University, Canada)	CIFAR Azrieli Global Scholar
Oliver Ernst (University of Toronto, Canada)	Senior Fellow and Program Co-Director
Daniel Figeys (University of Ottawa, Canada)	Senior Fellow
Sihyun Ham (Sookmyung Women's University, South Korea)	Senior Fellow
Lewis Kay (University of Toronto, Canada)	Senior Fellow
Brian Kobilka (Stanford University, United States)	Advisor
Ming Lei (Shanghai Institute of Precision Medicine, China)	Senior Fellow
Dwayne Miller (Max Planck Institute for the Structure and Dynamics of Matter, Germany and University of Toronto, Canada)	Senior Fellow and Program Co-Director
Krzysztof Palczewski (Case Western Reserve University, United States)	Senior Fellow
Lois Pollack (Cornell University, United States)	Advisor
David Stuart (University of Oxford, United Kingdom)	Advisory Committee Chair
Mikko Taipale (University of Toronto, Canada)	CIFAR Azrieli Global Scholar
John Vederas (University of Alberta, Canada)	Senior Fellow
Tanja Weil (Max Planck Institute for Polymer Research, Germany)	Senior Fellow
Paul Wiseman (McGill University, Canada)	Senior Fellow

Quantum Information Science

Name	Appointment
Scott Aaronson (Massachusetts Institute of Technology, United States)	Associate Fellow
Nir Bar-Gill (The Hebrew University of Jerusalem, Israel)	CIFAR Azrieli Global Scholar
Charles Bennett (IBM Corporation, United States)	Advisor
Alexandre Blais (Université de Sherbrooke, Canada)	Fellow
Gilles Brassard (Université de Montréal, Canada)	Senior Fellow
Raffi Budakian (University of Waterloo, Canada)	Senior Fellow
Harry Buhrman (Centrum voor Wiskunde en Informatica, The Netherlands)	Advisor
Paola Cappellaro (Massachusetts Institute of Technology, United States)	Associate Fellow
Andrew Childs (University of Maryland, United States)	Senior Fellow
Giulio Chiribella (University of Oxford, United Kingdom)	CIFAR Azrieli Global Scholar
Richard Cleve (University of Waterloo, Canada)	Senior Fellow
William Coish (McGill University, Canada)	Fellow
David Cory (University of Waterloo and Perimeter Institute for Theoretical Physics, Canada)	Advisory Committee Chair
Joseph Emerson (University of Waterloo, Canada)	Fellow
Daniel Gottesman (Perimeter Institute for Theoretical Physics, Canada)	Senior Fellow
Patrick Hayden (Stanford University, United States)	Senior Fellow
Peter Høyer (University of Calgary, Canada)	Associate Fellow
Thomas Jennewein (University of Waterloo, Canada)	Fellow
Gerhard Kirchmair (University of Innsbruck, Austria)	CIFAR Azrieli Global Scholar
Raymond Laflamme (University of Waterloo and Perimeter Institute for Theoretical Physics, Canada)	Senior Fellow and Founding Program Director
Debbie Leung (University of Waterloo, Canada)	Fellow
Hoi-Kwong Lo (University of Toronto, Canada)	Associate Fellow
Alexander Lvovsky (University of Calgary, Canada)	Fellow
Michele Mosca (University of Waterloo and Perimeter Institute for Theoretical Physics, Canada)	Senior Fellow
Michel Pioro-Ladrière (Université de Sherbrooke, Canada)	Fellow
David Poulin (Université de Sherbrooke, Canada)	Senior Fellow and Program Co-Director
Robert Raussendorf (University of British Columbia, Canada)	Fellow
Barry Sanders (University of Calgary, Canada)	Senior Fellow
Aephraim Steinberg (University of Toronto, Canada)	Senior Fellow and Program Co-Director
Barbara Terhal (RWTH Aachen University, Germany)	Associate Fellow
Wolfgang Tittel (University of Calgary, Canada)	Senior Fellow
Thomas Vidick (California Institute of Technology, United States)	CIFAR Azrieli Global Scholar
Andreas Wallraff (ETH Zürich, Switzerland)	Associate Fellow
John Watrous (University of Waterloo, Canada)	Senior Fellow
Gregor Weihs (University of Innsbruck, Austria)	Fellow
Amir Yacoby (Harvard University, United States)	Associate Fellow
Andrew Yao (Tsinghua University, China)	Advisor
Bei Zeng (University of Guelph, Canada)	Fellow

Quantum Materials

Name	Appointment
Ian Affleck (University of British Columbia, Canada)	Senior Fellow
Yoichi Ando (University of Cologne, Germany)	Associate Fellow
Leon Balents (University of California, Santa Barbara, United States)	Associate Fellow
Alexandre Blais (Université de Sherbrooke, Canada)	Fellow
Immanuel Bloch (Max Planck Institute for Quantum Optics, Germany)	Associate Fellow
Doug Bonn (University of British Columbia, Canada)	Senior Fellow
Collin Broholm (Johns Hopkins University, United States)	Associate Fellow
David Broun (Simon Fraser University, Canada)	Fellow
Raffi Budakian (University of Waterloo, Canada)	Senior Fellow
Jules Carbotte (McMaster University, Canada)	Senior Fellow and Founding Director
Robert Cava (Princeton University, United States)	Associate Fellow
Judy Cha (Yale University, United States)	CIFAR Azrieli Global Scholar
Andrea Damascelli (University of British Columbia, Canada)	Senior Fellow
J. C. Séamus Davis (Cornell University, United States)	Advisory Committee Chair
Eugene Demler (Harvard University, United States)	Associate Fellow
Steve Dodge (Simon Fraser University, Canada)	Associate Fellow
lan Fisher (Stanford University, United States)	Associate Fellow
Joshua Folk (University of British Columbia, Canada)	Fellow
Patrick Fournier (Université de Sherbrooke, Canada)	Fellow
Marcel Franz (University of British Columbia, Canada)	Senior Fellow
Bruce Gaulin (McMaster University, Canada)	Senior Fellow
Antoine Georges (Collège de France, France)	Advisor
Guillaume Gervais (McGill University, Canada)	Fellow
Michel Gingras (University of Waterloo, Canada)	Senior Fellow
Richard Greene (University of Maryland, United States)	Advisor
David Hawthorn (University of Waterloo, Canada)	Fellow
Jennifer Hoffman (Harvard University, United States)	Associate Fellow
Randall Hulet (Rice University, United States)	Associate Fellow
Harold Hwang (Stanford University, United States)	Associate Fellow
Takashi Imai (McMaster University, Canada)	Senior Fellow
Stephen Julian (University of Toronto, Canada)	Senior Fellow
Catherine Kallin (McMaster University, Canada)	Senior Fellow
Hae-Young Kee (University of Toronto, Canada)	Senior Fellow
Bernhard Keimer (Max Planck Institute for Solid State Research, Germany)	Associate Fellow
Yong Baek Kim (University of Toronto, Canada)	Senior Fellow
Steven Kivelson (Stanford University, United States)	Associate Fellow
Gabriel Kotliar (Rutgers University, United States)	Associate Fellow
Lindsay LeBlanc (University of Alberta, Canada)	Fellow
Karyn Le Hur (École Polytechnique and CNRS, France)	Associate Fellow

Ruixing Liang (University of British Columbia, Canada)	Senior Fellow
Gilbert Lonzarich (University of Cambridge, United Kingdom)	Associate Fellow
Graeme Luke (McMaster University, Canada)	Senior Fellow
Joseph Maciejko (University of Alberta, Canada)	Fellow
Andrew Mackenzie (Max Planck Institute for Chemical Physics of Solids, Germany)	Advisor
Yoshiteru Maeno (Kyoto University, Japan)	Associate Fellow
Jochen Mannhart (Max Planck Institute for Solid State Research, Germany)	Advisor
Andrew Millis (Columbia University, United States)	Associate Fellow
Kathryn Moler (Stanford University, United States)	Associate Fellow
Johnpierre Paglione (University of Maryland, United States)	Associate Fellow
Arun Paramekanti (University of Toronto, Canada)	Fellow
Cedomir Petrovic (Brookhaven National Laboratory, United States)	Associate Fellow
Cyril Proust (Laboratoire National des Champs Magnetiques Intenses, France)	Associate Fellow
Kate Ross (Colorado State University, United States)	CIFAR Azrieli Global Scholar
Subir Sachdev (Harvard University, United States)	Associate Fellow
George Sawatzky (University of British Columbia, Canada)	Senior Fellow
Douglas Scalapino (University of California, Santa Barbara, United States)	Associate Fellow
Jeff Sonier (Simon Fraser University, Canada)	Associate Fellow
Louis Taillefer (Université de Sherbrooke, Canada)	Senior Fellow and Program Director
Hidenori Takagi (Max Planck Institute for Solid State Research, Germany)	Advisor
Joseph Thywissen (University of Toronto, Canada)	Fellow
Thomas Timusk (McMaster University, Canada)	Senior Fellow
Senthil Todadri (Massachusetts Institute of Technology, United States)	Associate Fellow
André-Marie Tremblay (Université de Sherbrooke, Canada)	Senior Fellow
John Wei (University of Toronto, Canada)	Associate Fellow
Hai-Hu Wen (Nanjing University, China)	Associate Fellow
Christopher Wiebe (University of Winnipeg, Canada)	Fellow
Luyi Yang (University of Toronto, Canada)	CIFAR Azrieli Global Scholar
Fei Zhou (University of British Columbia, Canada)	Fellow

Successful Societies

Name	Appointment
Irene Bloemraad (University of California, Berkeley, United States)	Senior Fellow
Gérard Bouchard (Université du Québec à Chicoutimi, Canada)	Advisor
Wendy Espeland (Northwestern University, United States)	Advisor
Peter Gourevitch (University of California, San Diego, United States)	Advisory Committee Chair
David Grusky (Stanford University, United States)	Senior Fellow
Peter Hall (Harvard University, United States)	Associate Fellow and Founding Program Co-Director
Jane Jenson (Université de Montréal, Canada)	Associate Fellow
Kristi Kenyon (University of Winnipeg, Canada)	CIFAR Azrieli Global Scholar

Will Kymlicka (Queen's University, Canada)	Senior Fellow
Michèle Lamont (Harvard University, United States)	Senior Fellow and Program Co-Director
Kristin Laurin (University of British Columbia, Canada)	CIFAR Azrieli Global Scholar
Patrick Le Galès (Sciences Po, France)	Advisor
Hazel Markus (Stanford University, United States)	Advisor
Paul Pierson (University of California, Berkeley, United States)	Senior Fellow and Program Co-Director
Francesca Polletta (University of California, Irvine, United States)	Senior Fellow
Paige Raibmon (University of British Columbia, Canada)	Senior Fellow
Vijayendra Rao (World Bank, Malaysia)	Advisor
William Sewell (University of Chicago, United States)	Associate Fellow
Prerna Singh (Brown University, United States)	Fellow
Leanne Son Hing (University of Guelph, Canada)	Senior Fellow
Anne Wilson (Wilfrid Laurier University, Canada)	Fellow

Appendix E: Performance Measurement: Understanding CIFAR's Impact

As a learning-based organization that strives to achieve the highest standards of excellence in supporting frontier scientific research and discovery, CIFAR recognizes the importance of regular performance measurement and evaluation. Through rigorous assessment and monitoring of programs and activities, CIFAR can ensure it is achieving the best possible outcomes for its researchers and stakeholders. CIFAR is dedicated to understanding and evaluating the impact of its research networks and programs, both nationally and internationally as well as across different sectors (including academia, industry, and policy/gov-ernment).

To do this, CIFAR developed and expanded upon a Performance Measurement and Evaluation Strategy Framework (PMESF) in May 2018. Aligned with CIFAR's Strategic Plan (2018-2022), the PMESF forms the basis for performance measurement and internal monitoring for the organization and serves as a foundation for future evaluation. It provides accountability for relevance, alignment and performance of the organization, and serves as a guiding reference and tool to learn from, assess, and improve upon performance, effectiveness and efficiency.

Part of the development of the PMESF included the creation of a logic model/theory of change, which is shown below. The model helps build a shared understanding of the organization and performance expectations, and illustrates the various circles of partners and stakeholders and the process by which CIFAR can achieve its vision of "new knowledge for a better world".

Evaluation and performance measurement activities are on track and ongoing, with annual tracking and analysis of indicators for 2018/2019 set to be completed by summer 2019.





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