VECTOR INSTITUTE

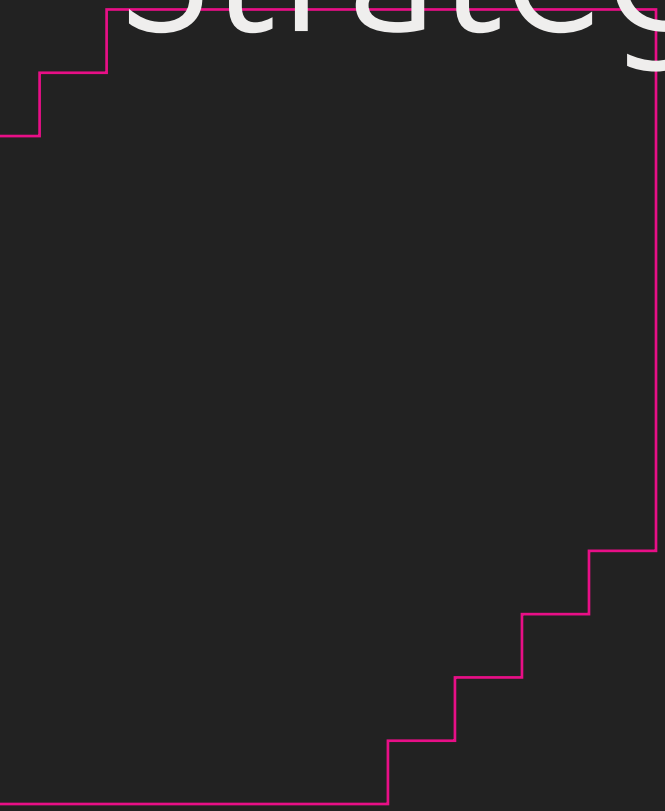
2020-23

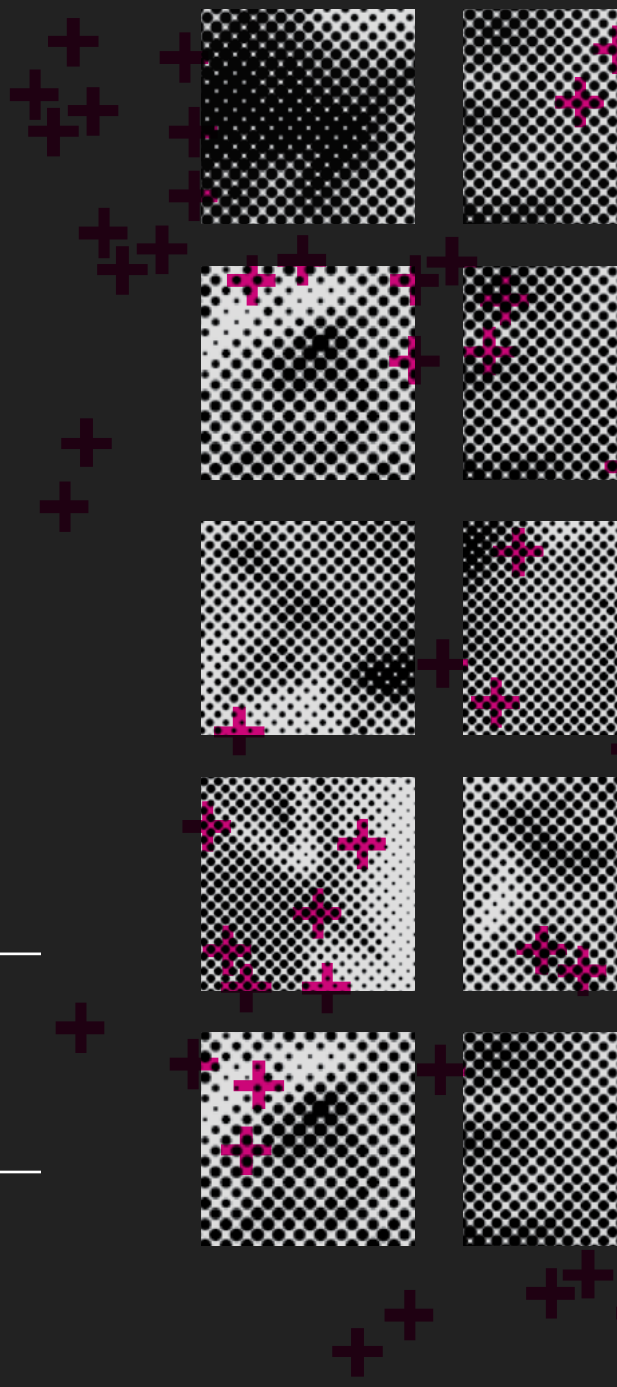
Three-year Strategy

TALENT.

DISCOVERY.

IMPACT.





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Message from the Board Chair

Technology innovation centres tend to have certain elements in common: talent, highly-ranked post-secondary institutions, renowned researchers in engineering and science, venture capital, supportive government policies, and strong social programs. Layer in relationships among academia, business, and entrepreneurs and a collaborative culture in which information flows freely, and the stage is set to create innovative companies, attract the talented and ambitious, and court serendipity. When a new important technology arises, the few regions that have these ingredients and capitalize on them can attain disproportionate long-term benefits.

AI is one of those technologies, and Ontario is positioned to be one of the global winners. When we launched Vector three years ago, we focused primarily on retaining and attracting talent to provide impetus. Few places in the world have a cluster of AI talent that is as large and diverse as Vector's – both in terms of breadth of expertise and international representation. Now, while maintaining that focus, we will ramp up our efforts to accelerate AI application and foster innovation in Canadian-based companies through industry programs.

Vector has already shown how this can be done. In one project conducted at Vector, sponsors learned how to cost-effectively replicate state-of-the-art systems that automate text and speech processing, which they can now incorporate into product development efforts. We will support Canadian

companies across the economy to be proactive about performing similar explorations of their own.

It's not just new, better products and operations that AI drives. AI's ability to enhance prediction creates opportunities for novel business models and platforms that facilitate entirely new economic activity. An increasing number of companies around the world are making AI a top strategic priority because they recognize this opportunity. Canadian companies also need to be prepared for that future. Ideally, Canadian companies play a large role in shaping it.

Commerce is only one arena in which we need bold AI application. The potential for AI to also drive health care discoveries is enormous. Look no further for an example than its use in combating COVID-19. In the early stages of the pandemic, software based on research led by Vector researcher Ali Punjani and supervised by University of Toronto and Vector Faculty Member David Fleet allowed researchers to create the first 3D images of the virus' spike protein at atomic resolutions. These images of the part of the virus that attaches to human cells provide important insights for vaccine or antiviral drug development. We're making such discoveries a priority by including health care as one of our five main research areas over the next three years.

The Vector Institute can also play a central role in improving delivery and administration in Canada's health care systems. Here too we've seen previews of what's possible. In one example, St. Michael's Hospital of Unity Health Toronto used machine learning in its emergency room (ER) to optimize nurse staffing and anticipate spikes in ER admissions, resulting in an estimated $1 million in annual cost savings. This is one application at one site using one hospital's data in one department. What could we achieve if we mobilized to apply AI to the large amounts of data in Canada's health systems and scaled applications to facilities throughout the province or country? Done prudently and with strong governance that prioritizes fairness, security, and privacy, AI could reveal patterns that are hidden in plain sight that contribute to health care cost savings, optimized resource allocation, and improved prevention, diagnosis, and treatment of ailments.

Finally, we can't ignore the larger context in which we've designed and will execute this strategy. That is the ongoing shift to the knowledge economy and its effects, which include the impacts of new technologies on people. Widespread adoption requires trust, and trust is earned with good governance. Vector researchers take this seriously, and are working in the lab and with industry on approaches to responsible AI deployment.

Now is the time to intensify our focus and resolve to make AI one of the main inputs of Canadian growth and quality-of-life improvements. We started early and focused on building talent. That was the right move, and we should be encouraged by what we've achieved. Now, we must run equally hard to achieve the next steps, and maximize the benefits for Canadian companies, institutions, and people.

Ed Clark
Board Chair

Message from the President and CEO

Our founders showed remarkable foresight when they crafted Vector's vision and mission. The priorities and objectives they defined are as pertinent today as they were on day one. Today, we're unveiling this new three-year strategy to guide our continued pursuit of those aspirations on top of the strong foundation that we've built since our founding.

I'm incredibly proud of our accomplishments over the past three years. When we started, there was no playbook for catalyzing productivity, application, and innovation through AI. But our founders, including our industry sponsors and the Ontario and federal governments, believed that building a critical mass of talented researchers and establishing strong relationships among business, academia, and public institutions were the key first steps. This, they believed, would attract the best students and practitioners, seed a growing labour pool of AI professionals for Canadian companies, and increase the application of AI in Canadian businesses and institutions for the betterment of the economy and society.

Since then, we've seen that belief validated. We've built a community of 400 incredibly talented researchers, some of whom have stayed in Canada to be part of the Vector community and others that were attracted to our country from prestigious institutions abroad for the same reason. Our researchers have engaged with industry sponsors on projects that explored state-of-the-art AI developments and their applications in business. We've

supported the embedding of accomplished AI scientists in Ontario's public health institutions to prepare them for applications that can improve health care systems and outcomes. All of this has put us in a position to pursue the ambitions detailed in the four pillars of the strategy that we present today.

Among those ambitions is establishing Vector as one of the world's top 10 AI research centres. Over the next three years, Vector research will focus on addressing fundamental questions in AI, with particular attention to those in five important areas: health care, sequential decision making, generative models, machine learning and AI theory, and security, privacy, and fairness. Work in these domains has the potential to deepen our understanding of AI, lead to applications that improve industry and quality of life, and move the field of responsible AI forward.

While we perform this fundamental research, we will also maintain the agility to apply our expertise and infrastructure when opportunities to benefit the lives of Canadians and the global community arise. This is precisely what we did when we repurposed our Spring 2020 high-performance computing infrastructure procurement for use in Ontario's Pandemic Threat Response platform to support analysis related to COVID-19 outbreaks, asymptomatic transmission, and resource allocation.

For our industry sponsors, our strategy involves massively scaling up the programs and projects that we've already seen work for them. Over the next three years, Vector experts will train 3,000 participants in programming and courses that focus on AI business and cutting-edge technical insights. We will also collaborate with sponsors to execute projects in areas such as natural language processing, computer vision, and health care. These will help our sponsors prepare people and establish processes to successfully implement AI projects that create value for their companies. We will also ramp up programs on commercialization of AI research and expand our AI Startup and Scaleup Program in which entrepreneurs and their teams share their experiences operating AI companies in exchange for machine learning training opportunities and relationships with Vector researchers.

We also intend to drive the effective and responsible implementation of AI in Ontario health care, giving health practitioners the best-available AI tools to improve systems and patient care. We're laying the groundwork for this by partnering to embed expertise in Ontario health institutions and preparing secure computing infrastructure designed specifically for health care projects.

Examples of embedded expertise include Vector Faculty Member and Canada CIFAR AI Chair Anna Goldenberg, who became the Hospital for Sick Children's first-ever Chair in Biomedical Informatics and Artificial Intelligence. At the Li Ka Shing Knowledge Institute of St. Michael's Hospital in Toronto, Vector Faculty Affiliate Muhammad Mamdani is Director of the Li Ka Shing Centre for Healthcare Analytics Research and Training (CHART) and Vector Faculty Member and Canada CIFAR AI Chair Frank Rudzicz is an Associate Scientist. Vector Faculty Member and Canada CIFAR AI Chair Bo Wang is the Lead Artificial Intelligence Scientist in the Peter Munk Cardiac Centre of the University Health Network and the Techna Institute, where he leads the AI team in developing new machine learning approaches to care for patients with heart and vascular diseases.

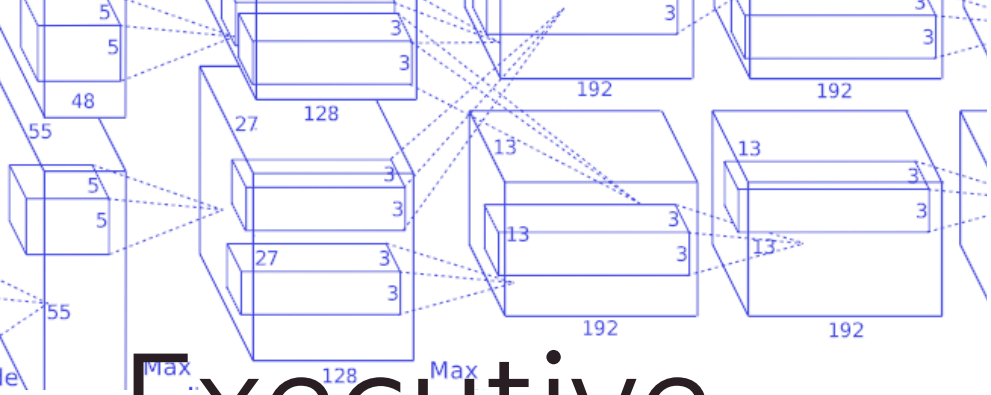
On the technology front, we partnered with ICES and HPC4Health at The Hospital for Sick Children to develop the Health Artificial Intelligence & Data Analysis Platform (HAIDAP), a secure high-performance computing environment that provides researchers with access to de-identified health data.

With this foundation in place, we will work with new and existing health partners to deploy machine learning tools to hospitals across Ontario and drive the development of a modern framework for health data governance that will allow discoveries to be made using health care data while maintaining security and safeguarding privacy.

Finally, we have a duty to help define and promote the responsible use of AI and contribute to addressing challenges that arise from accelerating innovation and application. We will publish and promote thought leadership by members of Vector's diverse community, who have informed perspectives on AI and its technical, ethical, economic, and sociological implications.

Three years ago, Vector began with a handful of founders who saw the potential for the Toronto region and Canada to become leading centres for AI talent and development and understood the benefits that could arise from that. The initial plan yielded promising results and set the stage to be compounded by growth in the region's AI community, benefits to Canadian companies, and improvements to the lives of Canadians.

Garth Gibson
President and CEO



Executive Summary

We have created a community of premier AI talent at the Vector Institute by attracting and retaining top machine learning and deep learning researchers. We have grown our research community from six founding Faculty Members to a diverse group of over 400 trained researchers and over 800 enrolled AI master's students to support labour force development. We have undertaken innovative AI implementation projects for industry and established knowledge-transfer programs that have built AI proficiency among professionals at Canadian organizations.

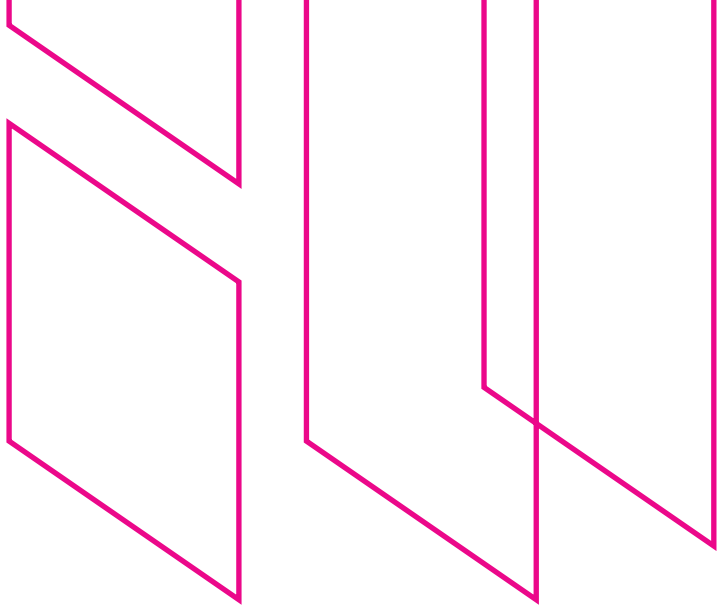
Our new three-year strategy builds on this foundation. Designed with input from researchers, industry, public institutions, and other stakeholders, this strategy expands successful programs, introduces new initiatives related to AI talent, commercialization, and application, and leads Canada towards the responsible and effective use of AI.

The strategy comprises four pillars. Over the next three years we will:

1. **Become a top 10 world-leading centre for machine learning and deep learning research.**
   We will grow our full-time faculty, add to our computing resources, and facilitate increased research collaboration. We will also continue to conduct leading-edge research across a wide range of machine learning and artificial intelligence topics, with significant advances in five areas: health care, sequential decision making, generative models, machine learning and AI theory, and security, privacy, and fairness.

2. **Expand partnerships with Canadian industry through programs for talent, training, and applied AI projects.**
   We will advance industry knowledge and AI application by increasing the number of industry collaboration projects, Face-to-Face meetings, and education programs that we operate. We will run 10 applied AI projects involving Vector industry sponsors, connect talent in the Vector community to industry jobs through targeted programs and the Digital Talent Hub, promote commercialization opportunities, and launch the Industry Affiliate program in which data science and AI practitioners from industry sponsors will work alongside Vector researchers.

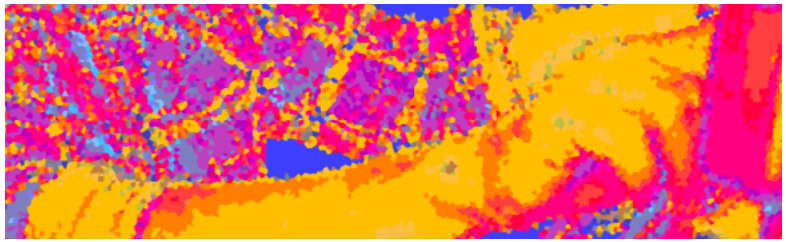
3. **Towards better whole-life health, enable effective & appropriate research access to health data.**
   We will initiate partnerships with health institutions to apply machine learning to health data. We will do this through projects that aim to improve health outcomes, decrease health care costs, and uncover new, valuable health-related insights. We will also continue to lead in the development of a modern governance framework for the Health Artificial Intelligence & Data Analysis Platform (HAIDAP), a secure high-performance computing environment for de-identified Ontario health data that will be central to the health projects. This governance framework will enable innovation while ensuring health data remains secure and privacy remains protected. We will also enable industries to contribute health-related insights and develop innovative health technologies and solutions that are necessary for modern health care.



4. **Contribute thought leadership about Ontario and Canada's role in AI, including economic and societal impacts.**
   We will convene experts and publish on topics related to AI and economic, social, health, and research issues. Our community of industry and scientific leaders, noted economists and entrepreneurs, prominent health care stakeholders, and others have unique, valuable perspectives on AI, management of its impacts on society, research directions, and new opportunities for industry. We will ensure those perspectives are shared for the benefit of the broader economy and society.

Through our three-year strategy, we will build on the foundation of talent and successful programs that we have developed. In doing so, we will continue to play a central role in growing Ontario as a hub of world-class AI research and talent, enhancing the competitiveness and productivity of Canadian companies, and informing best practices regarding the responsible use of AI.

Vision & Mission



Our Vision

The Vector Institute will drive excellence and leadership in Canada's knowledge, creation, and use of AI to foster economic growth and improve the lives of Canadians.

Our Mission

- We will lead Ontario's efforts to build and sustain AI-based innovation, growth and productivity in Canada by focusing on the transformative potential of deep learning and machine learning.
- We, together with our AI partners in other parts of Canada, will work with Canadian industry and public institutions to ensure that they have the people, skills, and resources to be best in class at the use of AI.
- We will support Canada's innovation clusters in AI and focus on helping startups grow to become Canadian-based global leaders.
- We will attract the best global talent focused on research excellence; our researchers and academic partners will be part of a vibrant community of innovative problem-solvers, working across disciplines on both curiosity-driven and applied research.

Accomplishments

The Vector Institute's establishment was a milestone in Canada's rich history of AI research and achievements — one that captured the attention of researchers, policy-makers, companies, and media around the world. Our mission, programs, and activities were informed by four deeply held convictions.

The founding researchers and organizations believed that:

- Canadian organizations should benefit from the extraordinary AI talent and research taking place in Canada;
- bringing the most talented AI researchers together in a highly collaborative environment would create a density that would draw high-performing researchers and commercial activity to the region, growing it as an AI hub;
- enabling collaboration among industry, researchers, entrepreneurs, and public institutions — with a focus on AI application and commercialization — would contribute to Canadian business productivity and competitiveness as well as to Canadians' lives; and
- a credible Canadian institution with Canadian values could take a leadership role in developing guidance on the responsible and beneficial use of AI.

We have demonstrated that these convictions are well-founded, with measurable and meaningful progress in talent attraction and development, industry-related research and application, knowledge transfer and upskilling, and health care initiatives.

Talent attraction and development

Our base of world-class talent encourages top researchers from around the world to come to Canada for the opportunity to collaborate and work in a diverse and vibrant ecosystem. Vector has focused on developing future generations of top AI talent by attracting and retaining prominent faculty and graduate researchers, developing a culture of collaboration, supporting Ontario AI master's programs to build industry-relevant curricula, and providing opportunities for graduate students, postdoctoral fellows, and interns to work alongside a variety of researchers with expertise in specific AI domains.

Here are some of the results:

- **Researchers:** Our community has grown to over 400 researchers, including over 250 Postdoctoral Fellows, graduate researchers and interns, 86 Faculty Affiliates, 34 Faculty Members, and 40 Postgraduate Affiliates. This community spans from coast to coast. We have also hosted 28 research interns from prestigious educational institutions in Africa, Asia, Europe, and North America to undertake projects and publish with leading Vector researchers.

- **Master's students:** We have recognized 22 AI master's programs with industry-relevant curricula in 11 post-secondary institutions across Ontario, and have drawn top master's candidates to these programs by awarding 250 Vector Scholarships in Artificial Intelligence to meritorious students. Since 2018, four new degree programs and 12 new AI concentrations within existing degree programs have been created. 800 AI master's students have enrolled across programs at Ontario universities and are beginning to enter the workforce.

Industry-related research and application

Our Industry Innovation projects bring industry and researchers together to apply state-of-the-art solutions to specific industry-related problems. Program participants benefit from collaboration with peers without sacrificing key business information or competitive advantages, and are able to conduct project experimentation on computing infrastructure that may otherwise be impractical or prohibitively expensive to access. Vector Industry Innovation projects include:

- **Financial industry collaboration projects:** Over 120 participants from 13 industry sponsor companies work with Vector researchers to develop governance frameworks for the responsible adoption of AI, with an emphasis on fairness, interpretability, and risk management. Other ongoing initiatives focus on developing strategies and algorithms to combat financial crime and using AI for social good.

- **Natural language processing (NLP) project:** 37 participants from 16 industry sponsors collaborate in various workstreams. These include workstreams related to training deep learning language models at scale to significantly reduce the cost of training NLP models while increasing the accessibility and benefits for businesses and researchers.

- **Model-based reinforcement learning project to reduce energy use costs:** Nine participants from three industry sponsors work with Vector researchers to explore ways that reinforcement learning can help them meet targets for carbon footprint reduction and energy efficiency.

The NLP project is "a tide that lifts all boats," according to Khalid Al-Kofahi, Vice President of Research and Development at Thomson Reuters' Center for AI and Cognitive Computing. He explains, "This is an area where it makes a lot of sense for industry to collaborate because we are establishing solutions for horizontal problems: how to scale deep learning models. Then each one of us, once we figure out a solution to that problem, can take that and adapt these models." Al-Kofahi continues, "We took these learnings and adapted them to different domains. ... [W] e are now exploring how to incorporate some of these models for some of our products. This is a win-win situation."

VECTOR'S INDUSTRY SPONSORS ARE LEADERS IN AI

While Vector's industry sponsors come from a variety of sectors — including health care, finance, insurance, education, retail, advanced manufacturing, and transportation — they have some important things in common. Leaders of these organizations understand that AI will have a material impact on their industries. They value being deeply involved in Canada's AI ecosystem. They share a vision of Canada leading AI research and application on the global stage.

27 Platinum, Gold, and Silver sponsors contribute direct funding to the Vector Institute, while 15 Bronze sponsors — comprised of AI startups and scaleup companies — contribute time and AI expertise to others in the Vector community. Vector sponsorship is a key element of each organization's AI strategy and vital to staying ahead of the curve competitively.

Sponsorship benefits include:

- opportunities to participate in collaborative industry projects
- one-on-one conversations with researchers through the Face-to-Face Program
- exclusive recruitment and executive networking opportunities
- access to Industry Affiliates to foster research collaboration, and
- comprehensive professional development.

Sponsors understand the transformational impact that AI will have on their industries and Canada, and have committed to proactively working with Vector to recruit talent, support the ecosystem, and enhance their capabilities to research, apply, and commercialize AI.

Knowledge transfer and upskilling

Our programs and courses have enabled professionals in executive and technical roles to quickly advance their AI knowledge. AI implementation, commercialization, and scale requires expertise and alignment among several levels and functions within an organization, and our courses facilitate this by catering to the experience and requirements of various professional roles and backgrounds. Examples of programs and courses include:

- **Business Insights Series:** This series provides senior management professionals with frameworks for understanding AI opportunities, implementation, and scale.
- **Face-to-Face Program:** These one-on-one meetings allow industry sponsors to get advice and feedback from top researchers on highly-specific AI issues and ideas that exist within their organizations.
- **Endless Summer School:** These seminars distill and share the most important recent technical advances in robotics, NLP, generative models, privacy, and fairness, among other topics with the technical team leaders of industry sponsors.

FACE-TO-FACE PROGRAM

"It's like technically we have a direction we want to go, but we're not sure how to get there and we don't know what pitfalls we're going to encounter. Then we go to the [Face-to-Face program] and we have people who have different maps of the research space, and not only do they have maps, they have commentary about the different pathways to where we want to go. That's extremely helpful because we are not map makers, but they are." - Jimoh Ovbiagele, ROSS Intelligence co-founder.

ROSS Intelligence provides an AI-powered legal research service to lawyers, law firms, and law schools throughout North America.

Health care initiatives

We have engaged Ontario's health sector stakeholders to help practitioners use AI tools to improve the care and health of Canadians.

- **Health data analysis:** We partnered with the Institute for Clinical Evaluative Sciences (ICES) and HPC4Health to construct and update the Health AI Data Analysis Platform (HAIDAP) — a secure computing environment that allows researchers to use the best-available machine learning tools and methods to analyze de-identified population-level health data to generate more accurate health insights and predictions. This partnership enabled collaboration with ICES on the Risk Dashboard, a project that uses machine learning to identify populations and patients at risk of becoming highly reliant on the health care system.

USING AI TO IMPROVE OUR KNOWLEDGE OF DIABETES

Vector Faculty Affiliate Laura Rosella is using AI to help identify and prevent diabetes. She and her team developed the Diabetes Population Risk Tool, a machine learning algorithm that has provided evidence that risk factors for developing diabetes are not limited to obesity and inactivity, but include social isolation, chronic stress, and socioeconomic status, among other factors.

The tool has helped inform institutions – including the Region of Peel and Ottawa Public Health — about how targeted investments in communities and populations can contribute to individual health and impact health care system costs. She is also using deep learning to study the possibility that there are more types of diabetes than currently understood, opening the potential for more refined identification and treatment for people living with the disease.

- **Embedding talent:** Vector researchers are keen to affect measurable improvements to health care. To this end, we provided customized training to the Ministry of Health and the Canadian Institute for Health Information in order to equip health practitioners and policy-makers with the best-available AI tools and insights, and partnered with University Health Network (UHN) and the Peter Munk Cardiac Centre (PMCC) to use machine learning for cardiac care, health research, personalized medicine, and hospital operations. This initiative resulted in the UHN and PMCC hiring an award-winning machine learning scientist and Vector Faculty Member as Lead Artificial Intelligence Scientist.

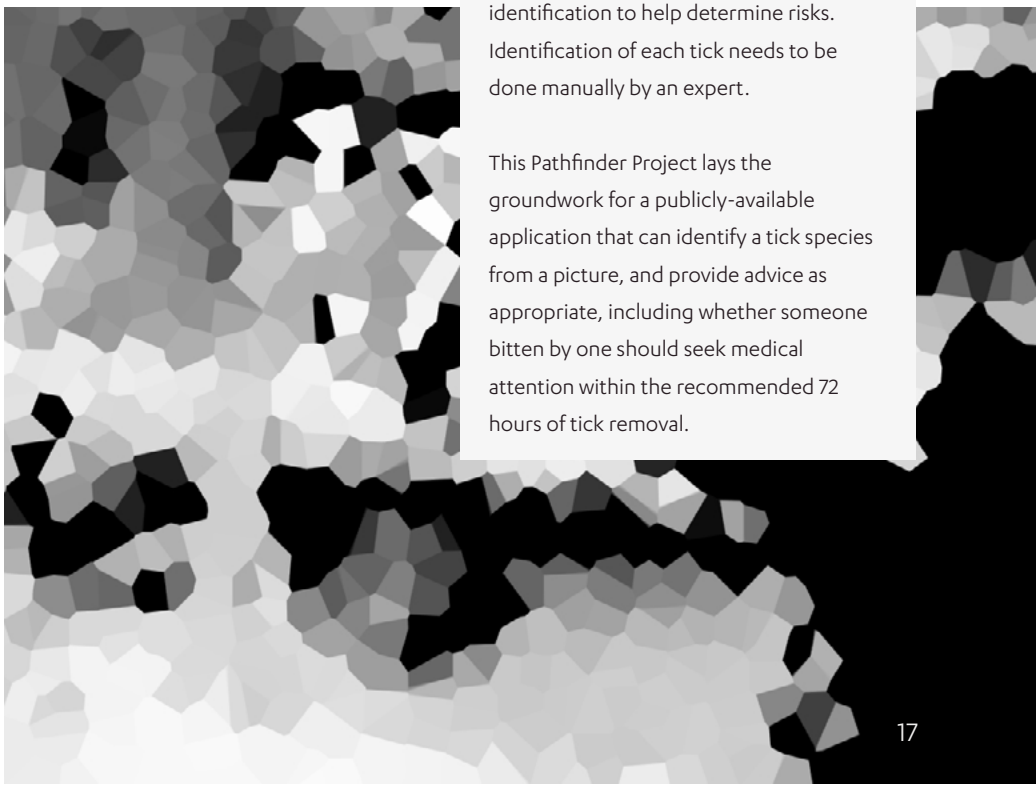
- **Pathfinder projects:** We initiated small-scale AI projects that serve as case studies for tackling health care challenges. Among these were an early warning system that predicts when patients should be transferred to the intensive care unit (ICU), a tool that improves the speed and accuracy of tick identification in order to combat Lyme disease, and a project to enable the early diagnosis of sepsis in newborns in the ICU.

VECTOR PATHFINDER PROJECTS: USING AI TO AUTOMATE TICK IDENTIFICATION

Pathfinder Projects involve the application of AI-assisted technologies in small-scale health-related projects that serve as case studies for broader application.

In one Pathfinder Project, Vector partnered with Public Health Ontario (PHO) to use computer vision to automate the identification and classification of various tick species.
Some tick species introduce the risk of spreading Lyme disease, and each year the PHO receives nearly 10,000 ticks for identification to help determine risks. Identification of each tick needs to be done manually by an expert.

This Pathfinder Project lays the groundwork for a publicly-available application that can identify a tick species from a picture, and provide advice as appropriate, including whether someone bitten by one should seek medical attention within the recommended 72 hours of tick removal.



We have built momentum across each of these domains. Our community has attracted and retained premier AI faculty and graduate researchers. Our projects, programs, and courses bring researchers and industry together and contribute to product development. Our partnerships are laying the groundwork for innovative, life-saving tools to improve health care in Ontario. Toronto's density of talent is increasing, and industry participants are becoming more sophisticated AI adopters and practitioners.

Our new three-year strategy is informed by these results. It expands research and talent recruitment, adds new programs and courses that will increase focus on AI application and development in industry and public institutions, and focuses on amplifying Vector's capabilities as one of most prominent, trusted, and advanced global centres of AI research, collaboration, and expertise in the world.

TORONTO'S AI COMMUNITY AND ECOSYSTEM HAS GROWN CONSIDERABLY SINCE THE VECTOR INSTITUTE'S ESTABLISHMENT.

Highlights:

- A projected 25,000 jobs will be created as a result of AI and tech-related investments and expansion announcements since Vector's launch in 2017, resulting from over $1 billion being invested in AI and technology operations in Canada.[1]
- Within three years of Vector's launch, there were 47 corporate AI and tech investment announcements in Canada, including by Google, Uber, NVIDIA, IBM, Microsoft, Thomson Reuters, Samsung, LG, Amazon, and others.
- Toronto has been measured to be the city with largest net gain of talent, with an excess of 57,600 technology jobs added over technology degrees granted between 2012-2018.[2]
- Toronto has the fastest growing technology labour pool in North America, increasing by 54 per cent in 2018.[3]
- Venture capital investment into Canadian AI companies has risen from $289 million in 2017 to $658 million in 2019. [4]

[1] Economic analysis prepared by Stokes Economics for the Vector Institute, December 12, 2018.
[2] CBRE report: "2019 Scoring Tech Talent"
[3] CBRE report: "2019 Scoring Tech Talent"
[4] PwC Canada & CB Insights. "MoneyTree Canada report H2 and FY 2019".

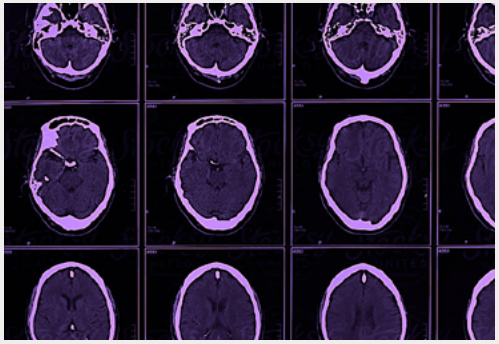
Vector researchers use AI to improve the world we live in

Optimizing nursing and emergency room staffing

Vector Faculty Affiliate Muhammad Mamdani and his team have employed algorithms to improve hospital administration. One model achieves over 90% accuracy at predicting the number of patients that will visit an emergency room on any given day. His team also developed an algorithm — now used at St. Michael's Hospital and St. Joseph's Hospital — that optimizes scheduling for regular and critical care nurses. This is estimated to save the hospitals over a million dollars per year.

Predicting cardiac arrest before it happens

Vector Faculty Member and Canada CIFAR AI Chair Anna Goldenberg's research as Chair of Biomedical Informatics and AI at Toronto's Hospital for Sick Children involves the development of an algorithm that uses a patient's medical data to predict cardiac arrests five minutes before they occur. The model has achieved 70% accuracy, adding a key tool for medical practitioners to use in their efforts to save lives.



Detecting Alzheimer's disease through subtle changes in speech

Vector Faculty Member and Canada CIFAR AI Chair Frank Rudzicz and his team created Ludwig, a robot equipped with an algorithm that can detect signs of Alzheimer's disease or dementia through analysis of an individual's speech patterns, opening the potential for early diagnosis and treatment.

Ensuring AI is fair by design

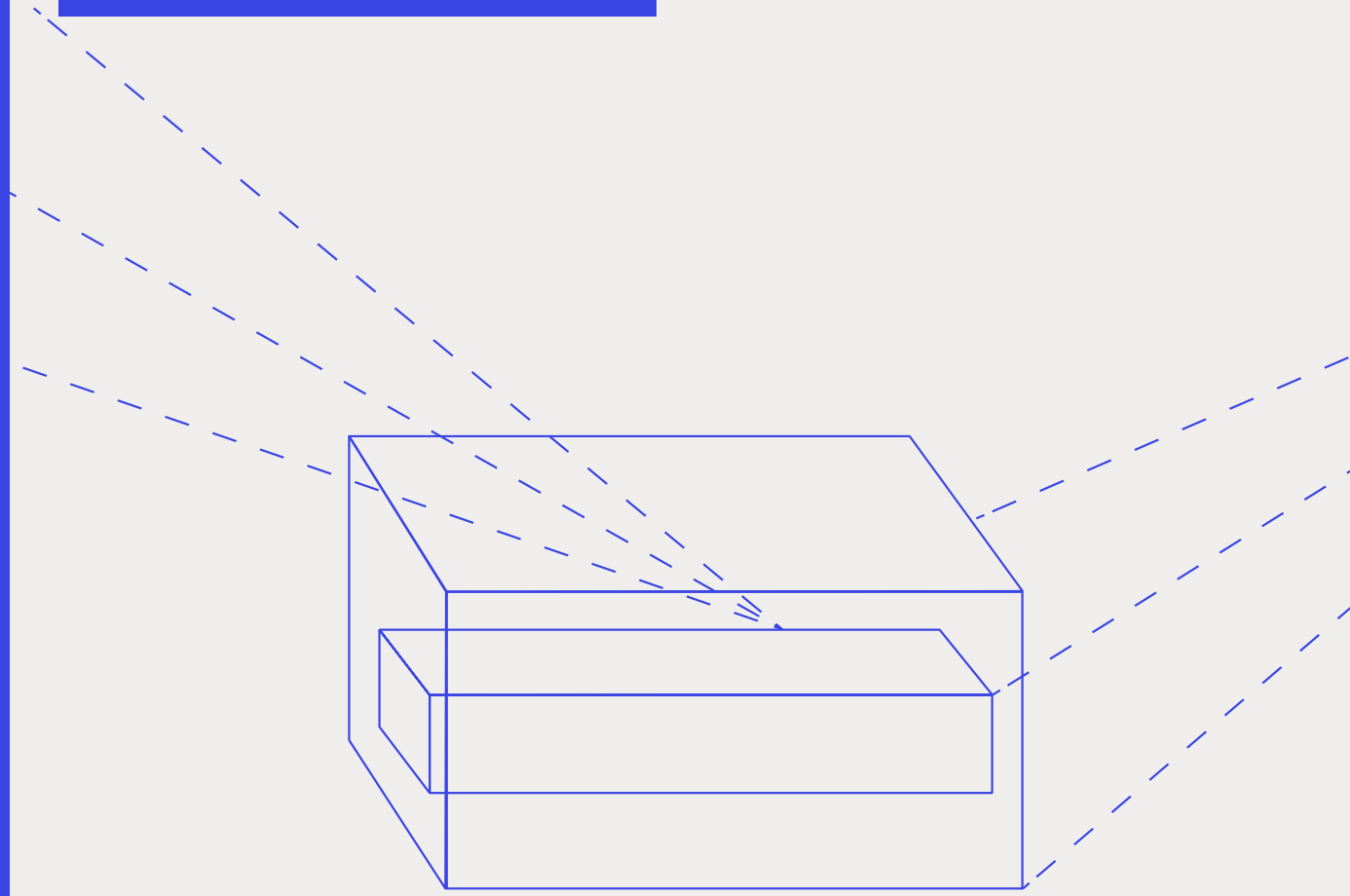
Vector Research Director Richard Zemel is a top expert on fairness in machine learning and automated decisions, a field that seeks to ensure AI models don't inadvertently incorporate stereotypes and prejudices that may be latent in our culture and systems. This research is key to ensuring AI models do not reinforce existing biases when they are used to inform decisions relating to justice, employment, and creditworthiness, among myriad other domains.

Highlights of Vector community members' recognition and accomplishments

- Vector Founder Geoffrey Hinton: co-recipient of the 2018 ACM A.M. Turing Award, computing's highest award, recognizing "major contributions of lasting importance to computing.", 2018 Companion of the Order of Canada, 2019 Honda Prize, 2019 Toronto Region Builder Award
- Vector Faculty Member & Canada CIFAR AI Chair Alán Aspuru-Guzik: Canada 150 Research Chair in Theoretical and Quantum Computing
- Vector Faculty Member & Canada CIFAR AI Chair Shai Ben-David: Best Paper award at NeurIPS 2018
- Vector Faculty Member & Canada CIFAR AI Chair Juan Carrasquilla: Google Quantum Research Award 2019
- Vector Faculty Member & David Duvenaud: Best Paper award at NeurIPS 2018; Google Faculty Award 2019
- Vector Faculty Member & Canada CIFAR AI Chair Sanja Fidler: Connaught New Researcher Award
- Vector Faculty Member & Canada CIFAR AI Chair Animesh Garg: Best Conference Paper award at IEEE ICRA 2019; Best Paper Award Robot Learning Workshop, NeurIPS 2019
- Vector Faculty Affiliate & Canada CIFAR AI Chair Marzyeh Ghassemi: 2018 MIT Technology Review 'Top 35 Innovators Under 35 list'
- Vector Faculty Member & Canada CIFAR AI Chair Anna Goldenberg: Varma Family Chair in Biomedical Informatics and Artificial Intelligence 2018
- Vector Faculty Member & Canada CIFAR AI Chair Sheila McIlraith: Fellow of the Association of Computing Machinery 2019
- Vector Faculty Member & Canada CIFAR AI Chair Toniann Pitassi: Fellow of the Association of Computing Machinery 2018
- Vector Faculty Member & Canada CIFAR AI Chair Frank Rudzciz: Connaught Innovation Award 2018; Best Paper award at eTELEMED 2020
- Vector Faculty Member & Canada CIFAR AI Chair Marzyeh Ghassemi: 2018 Canada's Top 40 Under 40
- Vector Faculty Member & Canada CIFAR AI Chair Bo Wang: PMCC Innovation Award 2019
- Vector Faculty Member & Research Director

Richard Zemel: Best Paper Award at CoRL 2019

- Vector Faculty Affiliate Ajay Agrawal: published critically acclaimed bestselling book Prediction Machines - The Simple Economics of Artificial Intelligence.
- Vector Faculty Affiliate Timothy Barfoot: Best Paper Award at HEART 2019
- Vector Faculty Affiliate Vaughn Betz: Google Faculty Research Award 2019
- Vector Faculty Affiliate Michael Brown: Best Paper Award at CIC27 2019
- Vector Faculty Affiliate Tom Chau: Governor General's Innovation Award 2018
- Vector Faculty Affiliate Gillian Hadfield: Appointed as the Inaugural Schwartz Reisman Chair in Technology and Society 2019
- Vector Faculty Affiliate Graeme Hirst: Fellow of the Association of Computational Linguistics 2019
- Vector Faculty Affiliate Kyros Kultulakos: Best Paper Award at CVPR 2019
- Vector Faculty Affiliate Laura Rosella: Connaught Global Challenge Award 2018
- Vector Faculty Affiliate Jeffrey S. Rosenthal: Best Paper Award, Canadian Journal of Statistics 2019
- Vector Faculty Affiliate Scott Sanner: Google Faculty Research Award 2019
- Vector Faculty Affiliate Yu Sun: Connaught Innovation Award 2019
- Vector Faculty Affiliate Grace Yi: Canada Research Chair in Data Science 2019



Strategy Development Approach

To develop the three-year strategy, we consulted researchers, industry, institutions, and entrepreneurs in one-on-one interviews, surveys, and facilitated discussions. We wanted to understand the challenges and opportunities they face, the Vector programs they feel have the most impact, and the role they feel Vector should play regarding important AI issues facing the world.

Here is what we heard:

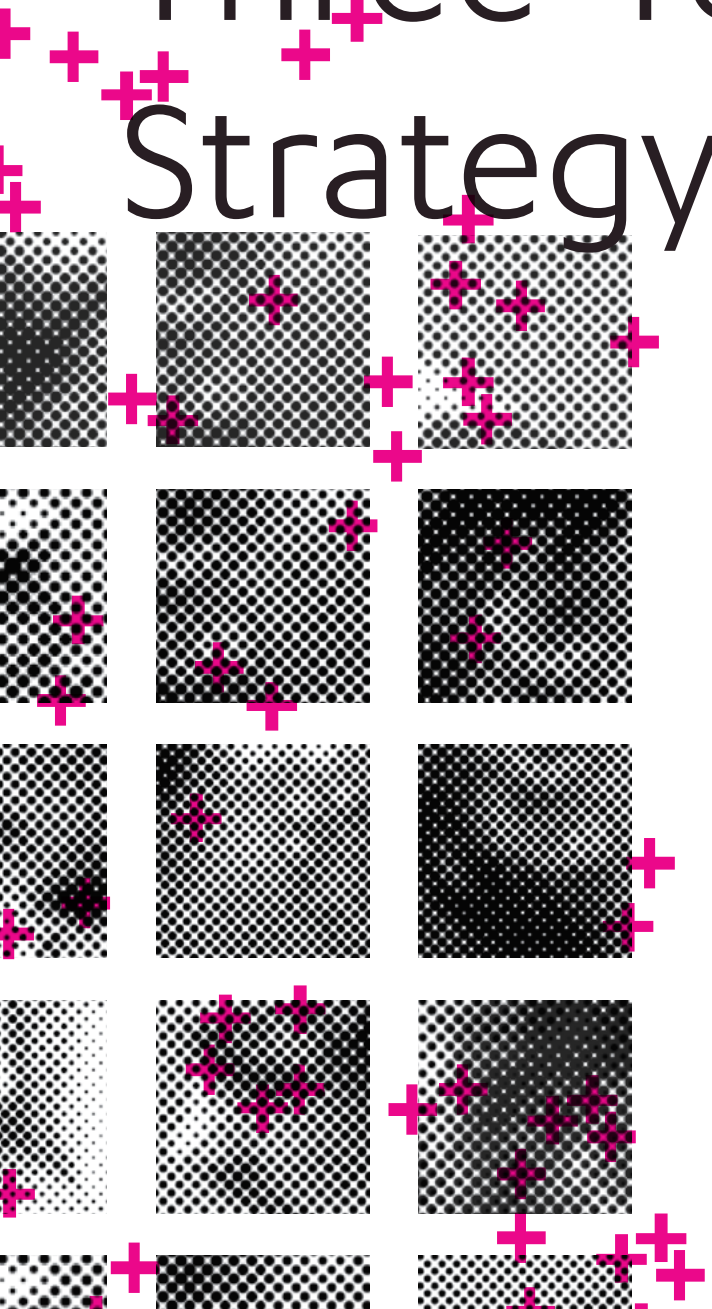
- Initiatives related to industry collaboration projects, talent development, and professional development are highly valuable.
- Attracting top talent to Canada, training post-secondary students, and upskilling industry professionals is extremely important and should be expanded.
- Collaboration between Vector researchers and industry sponsors should be increased.
- Vector, as an independent not-for-profit institute, can be a clarifying voice in a context of misleading information and competing perspectives related to AI.
- Vector cements Toronto's position on the global AI map and should continue to do so.

We also heard calls for new initiatives and activities. These include suggestions to:

- Develop domain-specific expert subgroups within Vector that can be consulted for common industry goals and issues.
- Engage regulatory bodies, safety assessors, and safety consultants in order to educate on "safe AI".
- Offer broader educational programming.
- Explore convening a table on major AI issues such as fairness, industry application, and regulatory evolution.

This strategy is informed by the perspectives shared by our stakeholders.

Three-Year Strategy



Through execution of our three-year strategy, we will build on the foundation of talent, research, and collaboration that we have established; continue to promote Toronto as a premier destination for AI researchers, students, practitioners, and businesses; invest in projects and knowledge-transfer activities focused on enhancing AI commercialization and application in industry and health care; and contribute to the responsible deployment of AI in the global economy and society. We will achieve this by focusing on four strategic pillars:

1. **Become a top 10 global centre for machine learning and deep learning research.**

2. **Expand partnerships with Canadian industry through programs for talent, training, and applied AI projects.**

3. **Towards better whole-life health, enable effective & appropriate research access to health data.**

4. **Contribute thought leadership about Ontario and Canada's role in AI, including economic and societal impacts.**

1. Become a top 10 global centre for machine learning and deep learning research.

The Vector Institute will be one of the top ten most renowned AI research centres in the world. To achieve this, we will grow our full-time faculty, add to our computing capacity, and facilitate increased research collaboration. We will:

Expand our top tier faculty and facilities

We will continue to add prominent researchers to our faculty, increasing the amount of outstanding work produced and the number of students trained in Canada. Through these actions, we will build Vector's appeal to the world's most talented AI practitioners and companies. We will also invest in boosting our computing infrastructure to enable our faculty and graduate researchers to conduct more advanced computational research.

Celebrate and promote results from Vector researchers

We will translate our researchers' technical work and communicate its real-world impact. We will also support our researchers' efforts to publish at top conferences and gain exposure at other credible research institutions throughout the world. Sharing our researchers' work along with practical insights — including those related to responsible AI, privacy, fairness, and explainability — will enhance Vector's impact as a focal point in a premier AI community of professionals and academics.

Build a highly visible and engaged alumni network

We will build and organize an alumni network that creates long-term value for professionals, faculty, affiliates, and students in the Vector community. To support the network, we will track alumni expertise and researchers' progression throughout academic institutions and industry. This network will capture and foster Vector's culture of collaboration, contribute to attracting top talent, and provide a compounding source of knowledge, mentorship, and partnership opportunities for its members and Vector's broader network of companies and institutions.

Leading research breakthroughs that will improve the lives of Canadians

We will lead on making impactful transformations in the real world. We will continue to retain research excellence in deep learning and machine learning, and build on discovering, developing, and delivering results. Our research will balance long-term fundamental research questions with the agility and ability to pursue targets of opportunity on socio-economic issues to benefit the lives of Canadians and the global community. Specific areas that Vector researchers will focus on in the next three years include:

HEALTH CARE

AI has the potential to make an enormous impact in the health care domain through improved disease diagnosis, enhanced efficiency in health care-providing facilities, and new drug discovery, among other possibilities. Realizing the potential in each of these categories and responsibly improving health care for Canadians requires addressing the challenges that exist for each through thoughtful research and collaboration.

One challenging research question concerns a shift from the standard formulation of health care problems as classification problems – for example, the binary classification of whether a person is 'ill' or 'not ill' – to one of outlier detection, as many conditions – particularly critical ones like sepsis and cardiac arrest – are relatively rare.

A second research avenue involves transferring a combination of clinical practice information from electronic medical records and clinical knowledge from ontologies and publications into models that can perform well on novel tasks and new patient populations. These methods will improve the ability to learn from cross-site data, such as CAT scans, that are shared among institutions and obtained with different equipment at different hospitals.

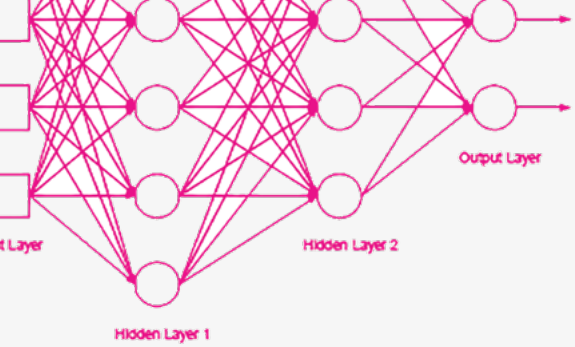
A third research avenue involves determining how models that operate on longer time scales and require estimation and optimization of the cumulative effects of decisions over time may be leveraged to identify suboptimal treatment decisions that may lead to avoidable deaths. Advances such as these will help translate key breakthroughs in published research and put them into practice for the benefit of Canadians.

SEQUENTIAL DECISION MAKING

Sequential decision making – deciding how to act – is central to daily living and at the core of intelligence. From large-scale logistics planning to in-home robots and cognitive assistants, advances in this area will support humans in making good short and long-term decisions that align with their values and improve their day-to-day lives. Our researchers will continue to explore machine learning algorithms that enable AI agents and systems to smoothly interact with humans in complex and dynamic settings, including those in health care, energy allocation, finance, retail, and manufacturing industries and applications.

One key research challenge in this area involves enabling AI agents or robots – machines that can physically interact with the world – to operate in human-centric environments that are less structured than those that robots operate in today. Such environments include roads, homes, shopping centers, and hospitals. This will involve advances in perception and sensing as well as in action and control, which pertains to enabling agents to learn how to deal with new situations.

A second fundamental research question we will address concerns the emergent dynamics among large numbers of interacting intelligent agents. Novel tools could help reduce some of the greatest risks currently facing the planet, from pandemics to financial crises to climate change. Such research advances in sequential decision making will lead to smarter and more flexible AI agents.



GENERATIVE MODELS

Generative models can generate data based on the original data that they were trained on. For example, a generative model can generate sentences or images that are novel but similar to those it has already seen. An important goal for machine learning models is to learn a description of an entire data set it has seen, whether that data comprises images, sentences, sounds, or other data types. Generative models can facilitate outlier detection as well as uncertainty estimates – i.e. appropriate confidence in its predictions – and can produce representations that are useful in downstream tasks such as object and scene understanding as well as object recognition and tracking.

Current generative models focus on creating digital artifacts, particularly images and text. Vector researchers are expanding the scope of generative models to include designing physical environments and improving computational chemistry and materials design. Long-term research involves personalized generative designs of the places in which we live or work, the items we wear, and the ways in which we seek entertainment. This research will also provide better user-control over generative music and audio models, including more subtle elements of speech such as prosody and expression. This is part of a longer-term goal to build effective systems for computational creativity. These tools will ultimately empower artists that are not AI specialists – like musicians, composers, and filmmakers – to realize their visions.

Our research will address some of the key challenges and frontiers for generative models. For instance, Vector researchers are developing scalable methods for dealing with irregularly-sampled time series. This kind of data is commonly encountered in medical and business settings, and is currently beyond the capabilities of existing generative models. We will also develop models that operate over multiple time scales. This is much like natural phenomena, which have both short-scale features (e.g., the shape of a heartbeat) and longer-term dynamics (e.g., overall cardiovascular health). These developments will allow more accurate forecasts and answers to questions in almost all business and medical settings, leading to cheaper and more effective business planning, resource allocation, and medical treatment.

UNDERSTANDING MACHINE LEARNING AND AI

AI and machine learning techniques – particularly deep learning methods – are being widely deployed, including in several high-risk applications. Our understanding of deep learning is largely empirical at this point. Without a theoretical basis, it is unwise to deploy systems in situations in which large amounts of training data that is representative of use cases cannot be obtained.

As algorithms enter real-world applications, it is also important to have characterizations of situations in which they will perform well and those in which they will not. Vector researchers will advance the mathematical understanding of deep learning and AI algorithms, which can help boost model robustness, increase the efficiency of training models, and potentially lead to guarantees of algorithm accuracy. Our researchers will also design algorithms that provide good predictions along with confidence intervals for the predictions with improved, faster training. This will lead to positive societal and environmental impacts through a better understanding of exactly what is needed to train a model to achieve a specific accuracy.

SECURITY, PRIVACY & FAIRNESS

Security, privacy, and fairness of AI systems are salient issues not just for Canadians, but globally. The costs of security breaches for individuals and institutions are immense, and leakage of private data is rampant. In 2019, the Office of the Privacy Commissioner of Canada revealed that over the past year, 28 million out of 37.5 million Canadians had been affected by a data breach.[5] Canada is well-placed to become a leader in these areas, particularly in sectors such as finance and health care.

Our researchers will work on producing machine learning architectures that are designed to provide security and privacy, rather than retrofitting architectures to achieve security post-hoc. This will enable Canadian companies and the Canadian government to deploy machine learning in critical environments and create an important foundation for the future security and privacy of computer systems.

The ability to deploy trustworthy machine learning, capable of analyzing data in a respectful way with regard to privacy, fairness, and ethics will also have social benefits given the growing concern around certain applications of the technology, such as facial recognition. Strong privacy guarantees are crucial for applications in hospitals. Robust predictions are imperative when applied to critical infrastructure. Fair decision-making is necessary in the financial and health care sectors. Our research — which will also examine questions of trustworthiness and governance — will enable Canadian organizations to circumvent costs and construct trustworthy systems.

[5] Office of the Privacy Commissioner of Canada. "A full year of mandatory data breach reporting: What we've learned and what businesses need to know." October 2019.
https://www.priv.gc.ca/en/blog/20191031/

HARNESSING POTENTIAL: RESEARCH, TALENT AND COLLABORATION

Talent attraction

We will work in collaboration with recruitment and academic partners to continue to attract and retain researchers of the highest calibre in both curiosity-driven and applied research. **We will target up to eight new faculty member hires over the next two years**, with a focus on recruiting candidates who are either first-time academic appointments or established researchers from outside Canada. Equity, diversity, and inclusion will be important values guiding our recruitment efforts.

We will focus on recruiting researchers with expertise in natural language processing, robotics and active systems, reinforcement learning, ethics and privacy, advanced materials, systems, medical and health applications, and health imaging and image analysis. Areas of secondary focus include recommender systems and information retrieval, security, metallurgy and organic materials for energy, energy and sustainability, and applied manufacturing.

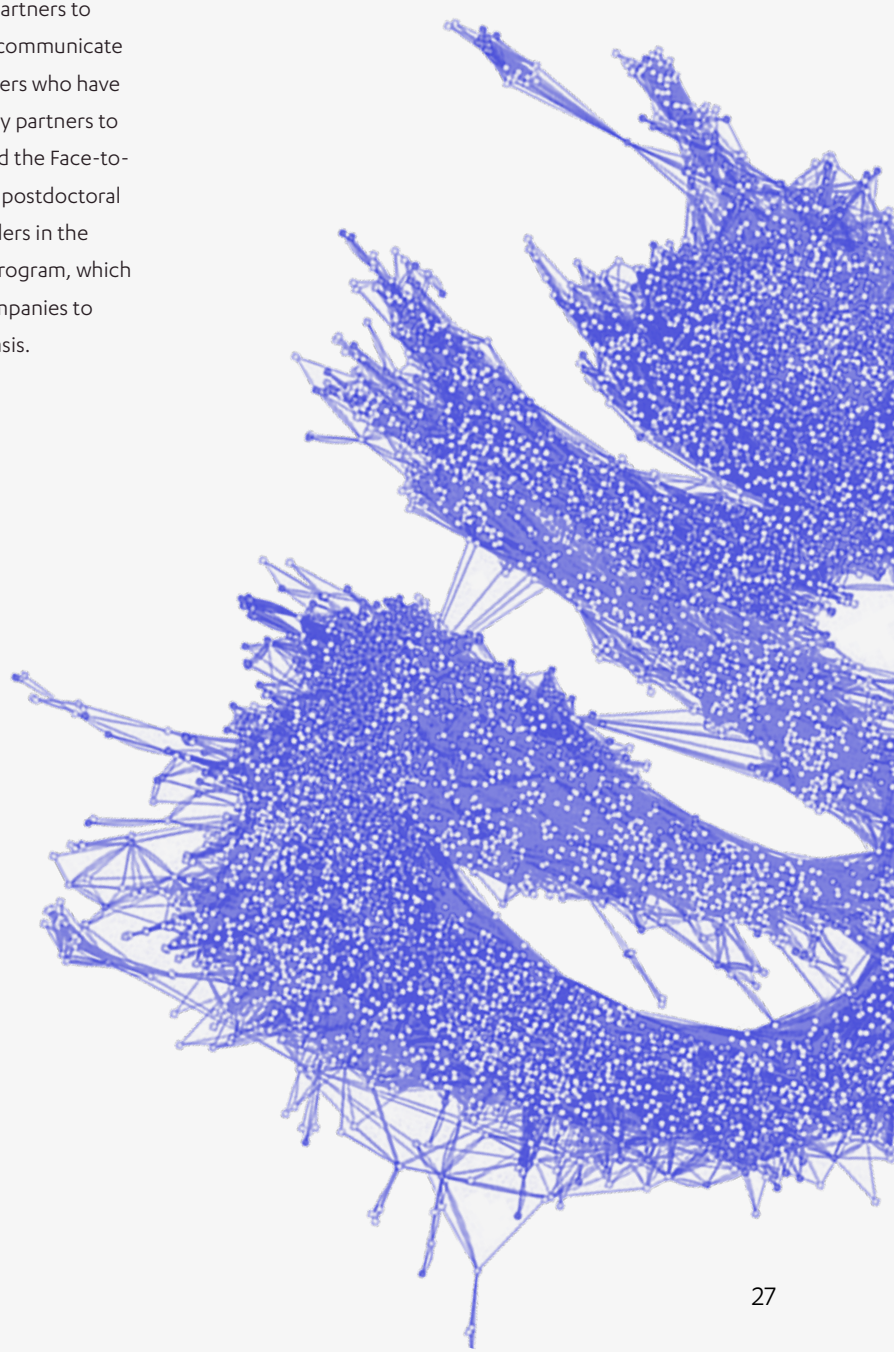
We will also attract visiting researchers through a new Visiting Faculty Researchers Program. This program will allow us to rapidly acquire expertise in key areas and raise Vector's international stature as a top research institute.

Increased collaboration among researchers

We will develop opportunities for greater collaboration among Vector researchers through joint industry projects, knowledge-transfer programs, and research. We will also create more opportunities for collaborative work and the cross-pollination of ideas among researchers and Industry Affiliates.

Industry

We will expand direct consultation with industry partners to identify the research areas that they value and to communicate when opportunities arise to partner with researchers who have expertise in those areas. We will also invite industry partners to join research discussions on various topics, expand the Face-to-Face program by providing new opportunities for postdoctoral fellows and Ph.D. students to advise technical leaders in the private sector, and launch the Industry Affiliates program, which will allow the best and brightest from sponsor companies to work alongside Vector researchers on a weekly basis.



2. Expand partnerships with Canadian industry through programs for talent, training, and applied AI projects.

Canadian companies across industry sectors must advance their AI knowledge, capabilities, and application to remain globally competitive. This advancement involves identifying use cases and commercialization opportunities, understanding state-of-the-art AI techniques, developing processes for AI implementation at scale, and accessing the talent and expertise required to execute projects. We will support industry to enhance its capabilities and expertise through expansion of our industry projects and programs. To do this, we will:

Create and run 10 applied AI projects for our industry sponsors

Our Industry Innovation team will increase the number of Collaborative Projects that allow companies to work alongside researchers to tackle industry problems. Among these will be the next phase of our NLP project and new projects related to computer vision, health care, and entity resolution. Each will be coordinated by a new industry project management office. Remaining project domains will be determined based on consultation with industry sponsors regarding the areas of greatest need and potential impact over the next three years. We will also introduce a new Project Management for AI program, providing companies with hands-on experience to develop the technical and non-technical abilities required to lead and navigate AI initiatives from ideation to modelling to implementation and scale. In addition, we will launch the Industry Affiliate program, which will provide expert data science and AI practitioners from Platinum sponsors with the opportunity to work alongside Vector researchers.

Expand professional development education and upskilling

We will increase our professional development education and upskilling program capacity to train 3,000 participants over the next three years. Our suite of programs and courses addresses all functions and levels within an organization, ramping up knowledge to enable the execution of sophisticated AI projects. Among the programs in our suite are Face-to-Face, Customized Workforce and Executive Training, and Business Insights. The Business Insights Series provides education to business

professionals through sessions that include *Introduction to AI: A high-level foundational intro to AI basics* and *Project Management* and *Agile for AI: A high-level introduction to managing AI projects*. Courses for technical professionals include Endless Summer School, a series of technical seminars focused on the latest machine learning advances, and AI Certificate Courses, a program for technical professionals that features mathematical foundations of AI, machine learning, deep learning, and reinforcement learning and the application of these concepts in case studies that tackle real business problems.

Connect Vector talent to industry jobs through targeted programs

Canadian organizations are competing for AI talent in a sellers' market. We will expand our talent programs to increase the opportunities for industry sponsors to competitively recruit, onboard, and retain talented researchers and practitioners. We will continue to host and participate in curated networking opportunities, such as AI careers fairs, where large concentrations of top local and international machine learning experts interface with Vector industry sponsors. We will also add industry-specific career events tailored for major sectors such as financial services, information and communications technology, health, and manufacturing, and host application-specific events that connect companies across sectors with experts in particular AI domains, such as NLP and computer vision. We will continue to promote the Digital Talent Hub, an online platform on which industry sponsors, universities, institutions, and startups advertise AI-related internship and employment opportunities in Canada to a curated pool of qualified machine learning candidates. Finally, we will monitor the talent pipeline coming out of university programs, along with the hiring needs of organizations, to identify gaps and areas of emerging growth and share these with university partners to inform curriculum development.

Enable commercialization opportunities for startup companies by complementing existing innovation ecosystem programs

Vector's AI Startup and Scaleup Program supports promising AI startups that have achieved product-market fit, have plans to scale, and view AI expertise as a foundation of their company. We will improve pathways for such startups and scaleups to participate in industry collaboration projects, gain opportunities to develop partnerships with existing sponsors, and benefit from our programs.

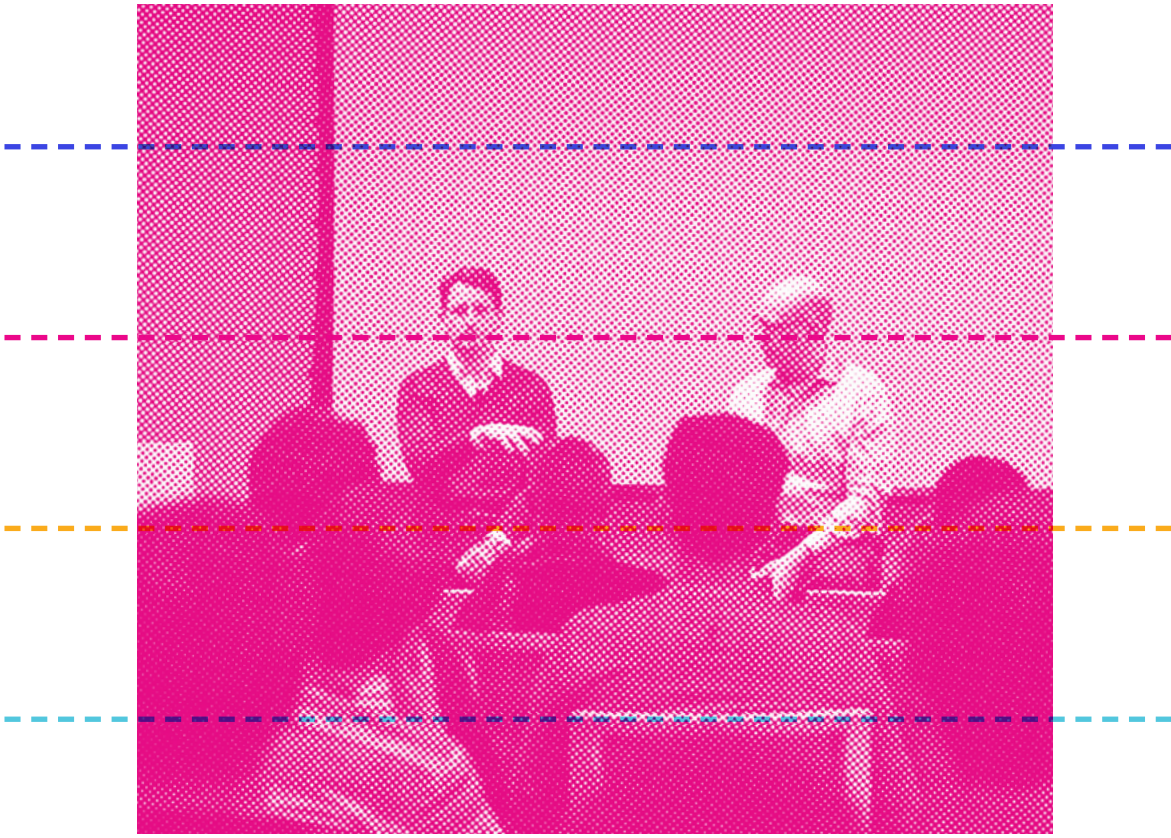
BRINGING AI EXPERTS TOGETHER WITH COMMERCIALIZATION SPECIALISTS

Vector's Industry Innovation team supports researchers with entrepreneurial ambitions through education on commercialization. In 2019, this involved hosting expert sessions on venture capital, law, intellectual property and AI, patent eligibility in the United States, contracts, and startups. These sessions were led by professionals in the field and researchers who have built AI-enabled commercial ventures.

Session presenters included:

- Jordan Jacobs, Radical Ventures
- Prashant Matta, Panache Ventures
- Madalin Mihailescu, Georgian Partners
- Filip Boskovic & Benjamin Mak of Ridout & Maybee LLP
- Stephen Piron, founder of Dessa

Furthermore, Vector has designed an Intellectual Property Policy to promote commercialization of research through education on IP protection, defense, and strategy, and to connect researchers with resources that support entrepreneurs and startup development.



3. Towards better whole-life health, enable effective & appropriate research access to health data.

We believe all Canadians deserve to benefit from modern health care solutions using the best technologies and tools available. We are uniquely positioned to convene and facilitate partnerships among scientists, government, and public health institutions to help health practitioners and policy-makers use the best-available AI tools to improve patient outcomes and health care delivery. Key to applying AI and working with de-identified Ontario health data is the development of a modern health data governance framework that protects privacy without stymying the adoption of innovative life-saving technologies. With a practical and enforceable framework in place, we will also take advantage of industry's ability to develop and scale new innovative technologies for modern health care and to contribute health-related insights. To advance AI application in health care, we will:

Initiate partnerships to improve health data research, beginning with the Unity Health Toronto's General Medicine Inpatient Initiative (GEMINI)

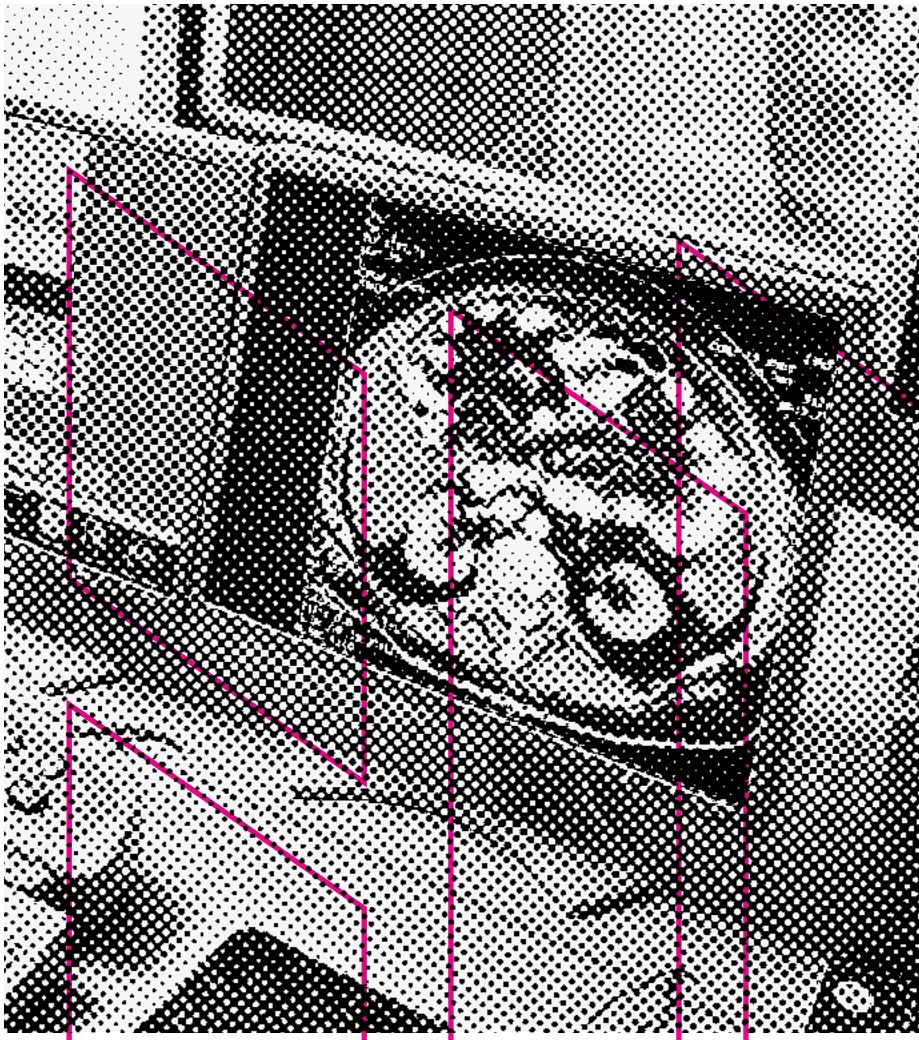
We will initiate partnerships to support new AI-based discoveries that will benefit health institutions and practitioners. This will begin with GEMINI, an initiative led by Unity Health Toronto's St. Michael's Hospital site to extract, standardize, and analyze data from electronic health records in order to improve patient care. Machine learning research enabled by this data partnership aims to improve health outcomes, develop methods to use resources more efficiently, and reduce hospital-acquired illnesses or complications in general internal medicine — a term used to classify hospital patients with a wide variety of health challenges and needs that are difficult to predict. Building on this, we will foster the deployment of AI technology in the health sector, facilitated by programs such as the Smart Health Analytics Lab to enable the scaling and deployment of machine learning tools to community hospitals across Ontario.

Take a leadership role in developing a modern framework for health data governance

We will continue to lead the development of a modern health data governance framework to ensure that health data research conducted on Vector's AI-optimized hardware, such as the HAIDAP, is secure and that privacy is protected.

Leverage Canadian industry capabilities towards innovative health technologies and insights for modern health care

Industry plays a vital role in developing and bringing to market innovative, sometimes life-saving health care solutions such as drugs, wearable technologies, medical equipment, or software used to deliver care. Moreover, service providers such as insurers, banks, and retailers capture behavioural and sociodemographic data that could deepen health care providers' understanding of factors that affect Ontarians' health. Using a modern health data governance framework, we will enhance industry capabilities by initiating two projects with our industry sponsors and providing them with the best-available AI tools to enable them to contribute to innovative health technologies, solutions, and insights.



4. Contribute thought leadership about Ontario and Canada's role in AI, including economic and societal impacts.

Our community includes industry and scientific leaders, noted economists and entrepreneurs, prominent health care stakeholders, and others who have unique and informed perspectives on important AI issues. Wider publication and distribution of their expertise and perspectives can add value to ongoing global conversations regarding AI and contribute to Canada's appeal as a centre of AI advancement. To maximize the impact of our community, we will:

Contribute to prominent publications on economic, social, and research issues

Our researchers and partners work to realize AI's promise for industry and society, but also acknowledge legitimate concerns relating to job displacement, fairness, explainability, safety, misinformation, regulations and standards, ethics, and privacy. Members of the Vector community are performing ground-breaking research to address these challenges. We will curate and convene their expert perspectives and insights, and contribute thought leadership that shapes and informs conversations regarding research, responsible AI, workforce development, economic competitiveness and productivity, and other important topics at the intersection of AI and society.

Support nation-building, leveraging national organizations and initiatives such as the CIFAR Pan-Canadian AI Strategy

In publications and events, we will continue to showcase and support Canada's AI leadership through the CIFAR Pan-Canadian AI Strategy and the accomplishments of organizations across Canada. We will widely share Canada's contributions with the world, from responsible AI frameworks to practical application in various business domains. We will also support and enhance alignment with our sibling organizations, Mila in Montreal and Amii in Edmonton. Furthermore, we will collaborate with the new **Schwartz-Reisman Institute for Technology and Society** to produce solution-oriented thought leadership regarding how AI can tackle pressing global problems.

VECTOR'S NEW HOME IN THE SCHWARTZ-REISMAN INNOVATION CENTRE

In late 2019, ground broke on the Schwartz-Reisman Innovation Centre, a new University of Toronto (UofT) complex that will become the work space of artificial intelligence researchers, biomedical scientists, and entrepreneurs in the UofT community. The establishment of the 750,000-square-foot centre was enabled by a record-setting $100-million donation by Gerald Schwartz and Heather Reisman.

Once construction is completed, the Vector Institute will take up residence in the complex, where it will cohabitate and collaborate with members of other disciplines. The new suite will overlook Queen's Park and significantly expand the size of the space in which Vector researchers and professionals conduct their work.

Afterword

April 29, 2020

The consultation and work for this strategic plan was spread over more than six months in 2019 and early 2020, before the COVID-19 pandemic came to Canada.

Since mid-March, our office has been empty as Vector personnel work from home under government emergency orders meant to help flatten the curve of cases and ensure that hospital intensive care unit resources are available to those most in need.

Social distancing measures taken across Canada are working to reduce the rate of contagion, but it appears that they will also prompt a deep economic contraction, and force plans and budgets throughout society to be revisited.

However, even at this time of medical emergency, social disruption, and economic distress, Vector will not retreat from its goals. In fact, the COVID-19 pandemic has reinforced the importance of pursuing our mission and carrying out our strategic plan.

Our community has a role to play in solutions and progress. In the context of COVID-19:

- we and our health partners are conducting effective and appropriate health research to address epidemic modelling and contact tracing, and using new health data platforms to enable novel, agile analysis;
- we and our industry partners are collaborating to model supply chain robustness and a staged reopening of our economy; and,
- we are accelerating the growth in supply of innovative modellers engaged in public health and economic recovery research.

We also have a moral imperative to engage in thought leadership with business, government, and institutional leaders to illuminate a path forward. This includes considering and communicating the economic and societal impacts of that path in ways that are accessible and understandable to all.

I am deeply proud of the COVID-19 initiatives Vector's researchers have launched, and of the partnerships with government, health care providers, universities, and businesses that empower this work. Vector is a place where brilliant, conscientious, and interesting people build teams to tackle important problems. I am honoured to serve at Vector, and I welcome you to join us on this voyage.

Garth Gibson
President and CEO
Vector Institute

Canada CIFAR Ontario

The Vector Institute is funded by the Province of Ontario, the Government of Canada through the Pan-Canadian AI Strategy administered by CIFAR, and industry sponsors from across the Canadian economy.

UNIVERSITY OF TORONTO

Special thanks to the University of Toronto for assistance in the start-up of the Vector Institute.

VECTOR INSTITUTE

Vector Institute

MaRS Centre, West Tower

661 University Ave., Suite 710

Toronto, ON M5G 1M1