QUANTUM INFORMATION SCIENCE

Attempts 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.

Researchers in this program continued to provide important new insights and advances that probed deeper into the fundamental properties of quantum systems and quantum communication. New results looking at the fundamental nature of quantum encoding and decoding, improved methods of error correction, new ways of creating super-resolution in optical imaging, and improved data storage and extraction methods in quantum computing and quantum memory are helping to spur the design of revolutionary new technologies.

Two program meetings were held in 2016/2017. The first, held in Vancouver, included discussions on quantum processor networks, new solid-state quantum architectures, interfacing different technologies (such as optical- and silicon-based systems) and the intersection of quantum information systems with machine learning. The second program meeting, held in Banff, focused on topics such as quantum memories for atomic clocks, quantum ideas in classical cryptography, and improved algorithms and fault tolerance in quantum processing. Both meetings also included discussions about the upcoming 2018 program review, as well as important new directions and emerging areas of scientific research that could help define the future of the program and the field.

Other events during the year included a Quantum Cavities workshop held in Orford, QC, in June 2017 in partnership with the Institut quantique (Université de Sherbrooke), and a tour of the D-Wave facilities in Burnaby, BC, in Fall 2016 by program members and invited researchers from different theoretical and experimental communities. With strong interest in new quantum technologies (including "cloud quantum computing") from industry leaders such as IBM, Google, Microsoft and Intel, rapid growth in industrial investment is starting to change the quantum information landscape. New quantum-based technologies have the potential to be the driving force of the economy in the 21st century.

RESEARCH HIGHLIGHTS

The "no cloning theorem" in quantum mechanics prevents quantum information from being replicated through space, which is the basis of the enhanced security provided by quantum information and telecommunication systems. However, this has implications for encoding and decoding processes, which require the use of quantum error correcting codes. Sparked by discussions at a program meeting, Senior Fellows **Barry Sanders** (University of Calgary) and **Patrick Hayden** (Stanford University) investigated the theory behind "when and where" qubits (or quantum bits, the quantum information carrier) can exist in spacetime and how they can be decoded and analyzed during information transmission. Their work looked at using continuous variable error correction to replicate quantum information and to protect against natural erasure of quantum information.

- **Hayden P** et al. 2016. Spacetime replication of continuous variable information. New J Phys. 18: 083043.

A fundamental limit in the resolution of optical imaging, first defined by Lord Rayleigh in 1879, prevents far-away objects (or very small objects) from being resolved if the objects are too close together. This has implications for the resolution of optical telescopes, microscopes and cameras. However, two recent studies by program members **Alex Lvovsky** (University of Calgary) and **Aephraim Steinberg** (University of Toronto) have demonstrated practical examples of optical systems that can beat this limit. By analyzing not only the intensity of the light but also the phase of the light, the precise separation between two overlapping spots can be achieved with resolution approaching the quantum limit. The results could lead to a new paradigm in super-resolution imaging.

- Yang F, Lvovsky AI et al. 2016. Far-field linear optical superresolution via heterodyne detection in a higher order local oscillator mode. Optica. 3: 1148-1152.
- Tham WK, Ferretti H, Steinberg AM. 2017. Beating Rayleigh's curse by imaging using phase information. Phys Rev Lett. 118: 070801.

AT A GLANCE

FOUNDED: 2002

MOST RECENT RENEWAL: 2012

PROGRAM DIRECTORS: Raymond Laflamme, University of Waterloo and Perimeter Institute for Theoretical Physics

FELLOWS, ADVISORS AND CIFAR AZRIELI GLOBAL SCHOLARS: 38

INSTITUTIONS REPRESENTED: 20, in 8 countries

FIELDS AND SUBFIELDS REPRESENTED: computer science, including quantum computing and theory of computation; quantum, condensed matter, mathematical and atomic physics; optics; electronic and information engineering; applied mathematics

MEETINGS: 2; in Vancouver and Banff, Canada

RELEVANT KNOWLEDGE USERS: industry (e.g., communication/cyber security, microelectronics, quantum computing); government (e.g., departments of national security, aerospace, defense)

TO LEARN MORE: www.cifar.ca/research/quantum-information-science/

In 1982, Richard Feynman proposed the concept of a quantum computer for simulating quantum mechanical systems. While very efficient quantum algorithms have been developed for investigating closed systems in this way (i.e., systems that do not interact with the external world), little work has been done to investigate this simulation problem for open systems. Following discussions at the Quantum Information Science program meetings, two research teams — one involving Senior Fellow **Richard Cleve** (University of Waterloo) and the other Senior Fellow **Andrew Childs** (University of Maryland) — have both presented landmark results and offered efficient simulation algorithms for certain classes of noise models in open systems. The results represent a major step forward toward realizing Feynman's original idea of a quantum simulator.

- **Childs AM**, Li T. Efficient Simulation of spare markovian quantum dynamics. In: ArXiv e-prints (Apr 2017). arXiv:1611.05543
- **Cleve R,** Wang C. 2017. Efficient quantum algorithms for simulating Lindblad evolution. Proceedings of the 44th International Colloquium on Automata, Languages and Programming (ICALP). Accepted for publication.

Other Notable Publications and Outputs

- Beaudoin F, Lachance-Quirion D, Coish WA, Pioro-Ladrière M et al. 2016. Coupling a single electron spin to a microwave resonator: controlling transverse and longitudinal couplings. Nanotechnology. 27: 464003.
- Raussendorf R et al. 2017. Symmetry-protected topological phases with uniform computational power in one dimension. Phys Rev A. Accepted for publication (arXiv:1609.07549).
- Yang Y, Chiribella G, Hayashi M. 2016. Optimal compression for identically prepared qubit states. Phys Rev Lett. 117: 090502.

IDEAS EXCHANGE

Program Director **Ray Laflamme** (University of Waterloo) presented at the Canadian Association for Security and Intelligence Studies Cyber Symposium in Ottawa in September. He spoke on cryptology in the age of quantum computing to a group of about 175 leaders from academia in the field of security and intelligence, and government leaders including representatives from the RCMP, Public Safety, Finance, Health and Immigration.

CIFAR Fellow **Wolfgang Tittel** (University of Calgary) led a two-day workshop on the technological and sector challenges and opportunities around development of quantum networks. The workshop brought together a number of fellows from the program, along with leaders in academia, industry and government.

GLOBAL ACADEMY

The program welcomed its first three CIFAR Azrieli Global Scholars in 2016/2017: **Nir Bar-Gill** (Hebrew University of Jerusalem), **Giulio Chiribella** (University of Hong Kong) and **Gerhard Kirchmair** (University of Innsbruck). All three presented their latest research at the October 2016 program meeting.

Together with the Institut quantique (Université de Sherbrooke) and other partners, the program supported the 16th Canadian Summer School on Quantum Information and 12th Canadian Student Conference on Quantum Information, held in Orford, QC from May 28 to June 9, 2017. Fellows **David Poulin**, **Alexandre Blais** and **Michel Pioro-Ladrière** (all Université de Sherbrooke) organized the school, and invited lecturers included Fellows Gilles Brassard (Université de Montréal) and Andreas Wallraff (ETH Zurich).