

Institute for Quantum Information

Activities – 2003-2004

Personnel

The primary goal of the Institute for Quantum Information (IQI) is to carry out and facilitate research in Quantum Information Science (QIS). The IQI is an NSF-supported collaboration of Caltech's Divisions of Engineering and Applied Science and of Physics, Mathematics, and Astronomy. It is led by five Caltech faculty members: John Preskill (Director and PI, MacArthur Professor of Theoretical Physics), Alexei Kitaev (co-PI, Professor of Physics and Computer Science), Jeff Kimble (Valentine Professor of Physics), Hideo Mabuchi (Associate Professor of Physics and Control and Dynamical Systems), and Leonard Schulman (Associate Professor of Computer Science). Administration of the IQI is supervised by Ann Harvey (IQI Administrative Assistant).

In 2003-04, seven IQI postdoctoral scholars were in residence: Dave Bacon, Sergey Bravyi, Patrick Hayden, Debbie Leung, Robert Raussendorf, Jennifer Sokol, and Guifre Vidal; in addition, Dominic Mayers joined the IQI as a Senior Scientist in 2003. In 2004-05, Bacon and Hayden will depart, while Robin Blume-Kohout, Andrew Childs, Stefano Pironio, Frank Verstraete, and Pawel Wocjan will arrive. Some of these scholars are supported in part by sponsors other than NSF, including Caltech. About 30 Caltech students (both graduate and undergraduate) also participated in the project.

Visiting Scholars and Students

The IQI sponsors a vigorous visitor's program. Our year-long visitor for 2003-04 was Steven van Enk (Lucent), whose visit was partially sponsored by Caltech's newly launched Center for the Physics of Information (CPI). Jeffrey Goldstone (MIT) visited for three months; Michael Ben-Or (Hebrew University) and Michael Nielsen (Queensland) made extended visits during the summer of 2003.

Twenty-eight other senior and postdoctoral scholars visited the IQI for one week or longer in 2002-2003: Hans Briegel (Innsbruck), Nicolas Cerf (Brussels), Igor Devetak (IBM), Christopher Fuchs (Lucent), Akira Furusawa (Tokyo), Daniel Gottesman (Perimeter Institute), Leonid

Gurvits (LANL), Dieter Jaksch (Oxford), Masato Koashi (SOKENDAI, Japan), Julia Kempe (Paris), Christopher King (Northeastern), Alexander Klyachko (Bilkent University, Turkey), Jose LaTorre (Barcelona), Hoi-Kwong Lo (Toronto), Norbert Lütkenhaus (Erlangen-Nürnberg, Germany), Ashwin Nayak (Waterloo), Hui Khoon Ng (DSO National Labs of Singapore), Gerardo Ortiz (LANL), Scott Parkins (Auckland), Philippe Pouliot (Queen Mary), Deborah Santamore (Harvard), Rob Spekkens (Perimeter Institute), Daniel Terno (Perimeter Institute), Ben Travaglione (Cambridge), Jiri Vala (Berkeley), Vlatko Vedral (Imperial), Frank Verstraete (Max Planck Institute), and Andreas Winter (Bristol). Eleven students from other institutions also visited for at least one week: Scott Aaronson (Berkeley), Dominic Berry (Macquarie University, Australia), Andrew Childs (MIT), Chris Dawson (Queensland), Aram Harrow (MIT), Alex Hutton (Oxford), Lawrence Ip (Berkeley), Iordanis Kerenidis (Berkeley), David Poulin (Waterloo), David Schwab (Cornell), and Man-Hong Yung (Chinese University, Hong Kong). There were many shorter-term visitors as well.

Research Activities

IQI researchers are among the world leaders on both the theoretical and experimental sides of QIS. Preskill's group studies quantum information theory, quantum cryptography, and the theory of fault-tolerant control of quantum systems. Schulman's group develops new quantum algorithms that could outperform classical algorithms, and derives limits on the power of quantum computers. Kimble's group works on both the theory and practice of manipulating quantum information encoded in single atoms and in photons. Mabuchi's group is involved in both theoretical and experimental aspects of quantum control, quantum measurement, and quantum coding. Kitaev's group works on quantum complexity, quantum coding, and the interface of quantum information with quantum many-body theory. Senior Scientist Dominic Mayers studies the security of quantum cryptographic protocols. Our postdoctoral scholars and students are also very active in all of these areas of QIS. In addition affiliated faculty are active in adjacent areas: John Doyle in control theory, Kip Thorne in the theory of quantum nondemolition measurement, Axel Scherer in nanostructures and photonic crystals, and Michael Roukes in quantum-limited nanomechanical devices.

More details about our research accomplishments over the past year can be found in the Findings section of this Annual Report. Publications by IQI participants (a total of 132 from the beginning of the project through mid-May, 2004) are available at: <http://www.iqi.caltech.edu/publications.html>.

It is important to emphasize that the IQI is more than the sum of the research groups it includes. By providing a hub for the widespread research efforts at Caltech in quantum information science, and by facilitating interaction with the broader QIS community beyond Caltech, the IQI has created a unique research environment that strongly encourages work straddling the traditional boundaries between academic disciplines. This interdisciplinary attitude has many manifestations

in the discussion of our Findings.

Education and Training

IQI faculty have developed three innovative courses relating to quantum information science: A course on quantum computing (Ph/CS 219) taught by Alexei Kitaev and John Preskill, and Hideo Mabuchi's intermediate (Ph 125) and advanced (Ph 195) courses on quantum mechanics (which place strong emphasis on the information-theoretic underpinnings of the subject). These courses have frequently visited websites on which lecture notes and problem sets are posted. Links to these sites can be found at the IQI site: <http://www.iqi.caltech.edu/>.

IQI participants Kimble, Kitaev, Mabuchi, Preskill, and Schulman are training graduate students working on both the theoretical and experimental sides of QIS – a total of over 20 students. Five IQI students will receive Ph.D. degrees in 2004. As already noted, many students from outside Caltech have visited the IQI and collaborated with our researchers. The Caltech students and the visiting students benefit greatly from the interdisciplinary spirit of the IQI. Mabuchi, Preskill, and Schulman also sponsor undergraduate research programs in quantum information science.

Budget Discussion

The IQI budget for the first four years was \$4.2 million, of which \$850K is budgeted for the fourth year. Over four years, these funds were allocated as follows (amounts are approximate):

Postdoctoral scholars	42%
Students	14%
Faculty salaries	8%
Visitor salaries	8%
Visitor support	11%
Scientific staff	3%
Support Staff	10%
Equipment and miscellaneous	4%

Invited Talks

IQI participants have presented many invited talks at seminars and conferences during 2003-04. Here is an incomplete list:

Anura Abeyesinghe, Quantum Technologies Seminar, Jet Propulsion Laboratory (Feb 2004).

Charlene Ahn, Quantum error correction for continuously detected errors, International Conference in Physics and Control, St. Petersburg, Russia (Aug 2003).

Charlene Ahn, Protecting the unknown: forays into quantum error correction, Brigham Young University Colloquium (Oct 2003).

Charlene Ahn, Protecting quantum states through feedback control, 34th Winter Colloquium on The Physics of Quantum Electronics, Snowbird UT (Jan 2004).

Charlene Ahn, Quantum error correction for continuously detected errors, Perimeter Institute (Jan 2004); IBM, Yorktown NY (Mar 2004).

Dave Bacon, Transforms for Quantum Information Theory: or Schur-ly You're Joking, Mr. Bacon, Los Alamos Quantum Lunch Series (2003).

Dave Bacon, Quantum Computers that Fix Themselves, Quantum Information Processing Seminar, MIT (2003); Santa Fe Institute Seminar (2003); Oregon State Solid State Seminar (2004).

Dave Bacon, When Is Teleportation Quantum? Perimeter Institute Seminar (2004).

Dave Bacon, Tales from the Boundary of Physics and Computer Science, University of British Columbia Seminar (2004).

Dave Bacon, Quantum Computing (or how we learned to stop worrying and love quantum theory), University of Arizona (2004).

Sergey Bravyi, Quantum Invariants of 3-manifolds and quantum computation, AMS Special Session on Topological Quantum Computation, San Francisco (3 May 2003).

Sergey Bravyi, Entangled states and fault-tolerant quantum computation, Landau Institute for Theoretical Physics Annual Meeting, (26 Jun 2003).

Sergey Bravyi, Universal Quantum Computation Based on Magic States Distillation, Sixth Annual Meeting of the Southwest Quantum Information and Technology Network (SQuInT), San Diego (21 Feb 2004).

JM Geremia, An Introduction to Control Theory from Classical to Quantum Applications, Heidelberg Graduiertenkurse Physik (2003).

JM Geremia, Quantum Feedback Control in Cold Atoms, University of Arizona Optical Science Center, Tucson AZ (Dec 2003).

Jim Harrington, Robust quantum memory with local controls, Pan American Advanced Studies Institute and Workshop, Buzios, Brazil (Dec 2003); Quantum Computing Technologies Group, Jet Propulsion Laboratory (Nov 2003); LANL Quantum Institute (Mar 2004); University of New Mexico (Mar 2004).

Jim Harrington, Encoding a qudit into many oscillators, Sixth Annual SQuInT Workshop, San Diego CA (Feb 2004).

Patrick Hayden, ERATO Conference on Quantum Information Theory, Kyoto; McGill-Bellairs Workshop on Quantum Cryptography, Barbados; IBM Research; Los Alamos National Laboratory; McGill University, Perimeter Institute; University of Toronto; University of Waterloo.

Jeff Kimble, Quantum Optics with Cold Atoms – Cavity QED and Atomic Ensembles, Gordon Research Conference on Atomic Physics, Tilton NH (17 Jun 2003).

Jeff Kimble, Cavity QED by the Numbers, 16th International Conference on Laser Spectroscopy (ICOLS03), Palm Cove, Australia. (16 Jul 2003).

Jeff Kimble, A One-Atom Laser in a Regime of Strong Coupling, 87th OSA Annual Meeting/Laser Science XIX, Tucson AZ (8 Oct 2003); 34th Winter Colloquium on the Physics of Quantum Electronics (PQE), Snowbird UT (5 Jan 2004).

Jeff Kimble, The New Science of Quantum Information, Northwestern University Department of Physics Colloquium, Evanston IL (7 Nov 2003).

Jeff Kimble, Teleportation of Quantum States: Fact and Fantasy, AAAS Annual Meeting, Seattle WA (14 Feb 2004).

Jeff Kimble, Biedenharn Lectures on Quantum Information Science I, II, III and IV, University of Texas at Austin (26 Mar–6 Apr 2004).

Jeff Kimble, Recent Progress toward the Realization of Quantum Networks, Harvard University (19 Apr 2004).

Jeff Kimble, Cavity Quantum Electrodynamics, Workshop on Quantum Information Science and Emerging Technologies, NIST, Boulder CO (30 Apr 2004).

Alexei Kitaev, Topological quantum computation, Gordon Research Conference on Quantum Information Science, Ventura CA (Feb 22-27 2004); Texas A&M University Physics Colloquium (11 Mar 2004).

Debbie Leung, On state randomization and its applications, Quantum Information Workshop, Benasque Center for Science (9 Jul 2003).

Debbie Leung, Superdense coding of quantum states, Perimeter Institute (6 Aug 2003); EQIS-QIT ERATO Conference on Quantum Information Science, Kyoto (2 Sep 2003).

Debbie Leung, Quantum computation by measurements, EQIS ERATO Conference on Quantum Information Science Kyoto (4 Sep 2003); Quinf seminar, University of Toronto (21 Nov 2003).

Debbie Leung, Composability of quantum protocols and applications, Ganita Lab, University of Toronto (25 Nov 2003).

Debbie Leung, Composability of Quantum Key Distribution and Quantum Authentication, QIP 2004 - The 7-th Workshop on Quantum Info. Processing, Institute for Quantum Computing, Waterloo, Canada (17 Jan 2004).

Debbie Leung, Quantum Information Theory, Joint Applied Mathematics/IQC Colloquium, University of Waterloo (18 Nov 2003); Department of Combinatorics and Optimization, University of Waterloo (26 Jan 2004); Physics department, University of British Columbia (1 Mar 2004).

Debbie Leung, Resources in quantum information theory, EE department, University of Southern California (15 Feb 2004).

Debbie Leung, Quantum information theory – Quantum “information theory” or Quantum (information) theory? Information Science and Technology Seminar, Caltech (5 Mar 2004).

Debbie Leung, Unifying and Simplifying Measurement-based Quantum Computation Schemes, ERATO Tokyo office (16 Mar 2004).

Hideo Mabuchi, Physics with photons: from quantum to bio, Optics and electronics seminar, Stanford University (6-8 Apr 2003); Physics colloquium, University of Arizona (11 Apr 2003); Physics colloquium, Temple University (19-22 Apr 2003).

Hideo Mabuchi, Experiments in quantum feedback, SPIE Conference on Fluctuations and Noise, Santa Fe, NM (2 Jun 2003).

Hideo Mabuchi, Quantum optics and quantum information science, OSA Topical Meeting on Optics in Computing, Washington DC (20 Jun 2003).

Hideo Mabuchi, Microcavities: strong coupling of atoms and photons, PTAP, San Diego (Jul 2003).

Hideo Mabuchi, Feedback and robustness in quantum metrology, MaPhySto Workshop on quantum measurement and fluctuations, Aarhus (Aug 2003).

Hideo Mabuchi, Coherence in broadband atomic magnetometry, Tokyo University (Sep 2003).

Hideo Mabuchi, Continuous observation of open quantum systems: conditional spin squeezing and broadband atomic magnetometry, H. Mabuchi, US-Japan joint symposium on quantum coherence, Yatsugatake (Sep 2003).

Hideo Mabuchi, Quantum filtering and broadband atomic magnetometry, EURESCO conference on quantum optics, Granada (Sep 2003).

Hideo Mabuchi, Identification, modeling, and control of quantum and bio-molecular systems, New Horizons in Molecular Sciences and Systems, Okinawa (Oct 2003).

Hideo Mabuchi, Deterministic preparation of spin-squeezed states via real-time quantum feedback, Stanford-ENS joint symposium, Stanford CA (Dec 2003).

Hideo Mabuchi, Real-time quantum feedback control, SAMSI workshop on multiscale systems and modeling, Research Triangle Park (Jan 2004).

Hideo Mabuchi, Knowing what you know: estimation and control in nanoscale systems, Center for Bits and Atoms colloquium, MIT (Mar 2004).

Hideo Mabuchi, Quantum measurement and feedback control with cold atoms, Center for Ultra-cold Atoms seminar, MIT (Mar 2004).

John Preskill, Quantum Error Correction and Quantum Cryptography, 2003 PIMS-MITACS Summer School on Quantum Information Science, Calgary, Canada (26 Jun 2004).

John Preskill, Putting Weirdness to Work, AAAS Annual Meeting, Seattle WA (14 Feb 2004).

John Preskill, Superselection Rules and Quantum Protocols, Gordon Research Conference on Quantum Information Science, Ventura CA (25 Feb 2004).

John Preskill, Recent Progress in Quantum Information Science, Seven Pines Conference, Stillwater MN (8 May 2004).

Robert Raussendorf, Measurement-based quantum computation with cluster states, University of New Mexico (26 Mar 2004).

Robert Raussendorf, Fault-tolerant quantum computation using graph states, University of Innsbruck (28 Apr 2004).

Leonard Schulman, Physical limits of heat-bath algorithmic cooling, QIP 04 (Jan 2004); Los Alamos / U. New Mexico / Santa Fe Inst. (joint distinguished lecture series Apr 2004).

Ben Toner, Quantifying quantum nonlocality, University of Calgary (2 Jul 2003); JPL Quantum Technologies Seminar (5 Sep 2003); GAP-Optique, University of Geneva (7 Nov 2003).

Ben Toner, Nonlocal games, Sixth Annual Meeting of the Southwest Quantum Information and Technology network (SQuInT) (20–22 Feb 2004).

Ben Toner, Extending and Generalizing the Kochen-Specker theorem, Université de Montreal, Parts I and II (15-16 Apr 2004).

Guifre Vidal, Entanglement, quantum phase transitions and the simulation of quantum dynamics, Simons Conference on Quantum and Reversible Computation, Stony Brook (May 2003); Quantum Information and Communication, Benasque, Spain (Jul 2003); AMO seminar, Berkeley (Oct 2003).

Guifre Vidal, Entanglement, quantum critical phenomena and efficient simulation of spin systems, Quantum Information and Ordered Systems, Copenhagen, Denmark (Sep 2003).

Guifre Vidal, Entanglement and quantum computational speed-ups, Quantum seminar, Berkeley (Oct 2003).

Guifre Vidal, Quantum Information as a tool in Quantum Many-Body Physics, Physics Department, Stanford (Nov 2003); Physics Department, UC Santa Barbara (Dec 2003); Institute for Theoretical Physics, University of Innsbruck (Jan 2004); Institute of Quantum Electronics, ETH Zurich (Jan 2004); Quantum Optics Group, University of Geneva (Jan 2004); Max Planck Institute (Jan 2004); Niels Bohr Institute (Feb 2004); University of Southern California Condensed Matter Seminar (Feb 2004); MIT Condensed Matter Seminar (Feb 2004); UC Irvine Condensed Matter Seminar (Apr 2004).