

Institute for Quantum Information

Activities – 2002-2003

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), Leonard Schulman (co-PI, Associate Professor of Computer Science), Jeff Kimble (Valentine Professor of Physics), Hideo Mabuchi (Associate Professor of Physics and Control and Dynamical Systems), and Alexei Kitaev (Professor of Physics and Computer Science). Other affiliated Caltech faculty include John Doyle (Professor of Control and Dynamical Systems, Electrical Engineering, and Bioengineering), Michael Roukes (Professor of Physics), Axel Scherer (Neches Professor of Electrical Engineering, Applied Physics and Physics), and Kip Thorne (Feynman Professor of Theoretical Physics). Administration of the IQI is supervised by Ann Harvey (IQI Administrative Assistant).

In 2002-03, nine IQI postdoctoral scholars were in residence: Dave Bacon, Sougato Bose, Andrew Doherty, Luming Duan, JM Geremia, Sean Hallgren, Patrick Hayden, Debbie Leung, and Guifre Vidal. In 2003-04, Doherty, Duan, and Hallgren will depart, while Sergei Bravyi, Robert Raussendorf, and Jennifer Sokol 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 long-term visitors for 2002-03 were Eric Rains (Center for Communications Research, three months), Ben Schumacher (Kenyon College, ten months), Michael Nielsen (University of Queensland, six months), and Michael Vyalyi (University of Moscow, six months).

Twenty-two other senior and postdoctoral scholars visited the IQI for one week or longer in 2002-2003: Howard Barnum (Los Alamos), Stephen Bartlett (Macquarie University), Robin Blume-Kohout (Los Alamos), Todd Brun (Institute for Advanced Study), Jens Eisert (Imperial College), Geza Giedke (Max Planck Institute), Daniel Gottesman (Perimeter Institute), Michael Keyl (TU-Braunschweig), Allen Knutson (Berkeley), Masato Koashi (SOKEN), Jose Latorre (Barcelona), Dominic Mayers (Sherbrooke), Gerard Milburn (Queensland), Cris Moore (New Mexico), Ashwin Nayak (Waterloo), Jonathan Oppenheim (Hebrew University), Daniel Terno (Perimeter Institute), Ashish Thapliyal (Berkeley), Frank Verstraete (KU Leuven), John Watrous (Calgary), Michael Westmoreland (Dennison), and Michael Wolf (Max Planck Institute). Fourteen students from other institutions also visited for at least one week: Sergey Bravyi (Landau Institute), Michael Bremner (Queensland), Matthew Buckley (Kenyon), Andrew Childs (MIT), Jennifer Dodd (Queensland), Aram Harrow (MIT), Henry Haselgrove (Queensland), Yasser Omar (Oxford), Robert Raussendorf (Munich), Dirk Schlingeman (TU-Braunschweig), Peter Stelmachovic (Slovak Academy of Sciences), David Schwab (Cornell), Salvador Venegas-Andraca (Oxford), and Pawel Wocjan (Karlruhe). There were many shorter-term visitors.

Research Activities

IQI researchers are among the world leaders on both the theoretical and experimental sides of QIS. Preskill's group studies the 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. 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 87 from the beginning of the project through mid-May, 2003) 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: John Preskill's course on quantum computing (Ph/CS 219) 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, Preskill, Mabuchi, Doyle, Schulman, and Kitaev are training graduate students working on both the theoretical and experimental sides of QIS – a total of over 20 students. These students benefit greatly from the interdisciplinary spirit of the IQI. As already noted, many students from outside Caltech have visited the IQI and collaborated with our researchers. Mabuchi, Preskill, and Schulman also sponsor undergraduate research programs in quantum information science. Finally Mabuchi leads a project in science and media for which undergraduates develop educational materials related to QIS.

Budget Discussion

The IQI budget for the first three years was \$3.35 million. These funds were allocated as follows (amounts are approximate):

Postdoctoral scholars	45%
Students	13%
Visitor salaries	10%
Visitor support	10%
Staff	10%
Faculty salaries	8%
Equipment and miscellaneous	4%

Invited Talks

IQI participants have presented many invited talks at seminars and conferences during 2002-03. Here is an incomplete list:

Charlene Ahn, Continuous quantum error correction via quantum feedback control, Centre for Quantum Computation Technology seminar, University of Queensland, 15 Aug 2002.

Dave Bacon, Fifth Annual Meeting of the Southwest Quantum Information and Technology Network (SQuInT), Santa Fe, NM (2003).

Dave Bacon, MSRI Quantum Algorithms and Complexity Conference, Banff, Alberta (2002).

Dave Bacon, Quantum Information and Computation Summer School Research Seminar, University of Queensland, Australia (2002).

Dave Bacon, The Sixth International Conference on Quantum Communication, Measurement, and Computing, MIT (2002).

Dave Bacon, Quantum Technologies Seminar, Jet Propulsion Laboratory (2002).

Sougato Bose, Schemes to Probe Quantum Mechanical Behaviour of Macroscopic Objects, Third Conference of the ESF programme Quantum Information Theory and Quantum Computing: Advances in Quantum Information Processing: From Theory to Experiment, Ettore Majorana Center, Erice, Sicily, Italy, 15–22 Mar 2003.

Sougato Bose, Schemes to Probe Quantum Mechanical Behaviour of Macroscopic Objects, Yang Institute of Theoretical Physics, State University of New York at Stony Brook, 26 Mar 2003.

Sergey Bravyi and Alexei Kitaev, Quantum Invariants of 3-Manifolds and Quantum Computation, 987th AMS Meeting, Special Session on Topological Quantum Computation, San Francisco, 3 May 2003.

Sergey Bravyi, Schmidt theorem analogue for multipartite states, Landau Institute for Theoretical Physics, 7 Jun 2002.

Sergey Bravyi, Entropy of a multi-particle pure quantum state Landau Institute for Theoretical Physics, 12 Apr 2002.

Andrew Doherty, Quantum Entanglement and Non-locality: Semidefinite relaxations for problems in Quantum Information Processing, Workshop on Robustness Analysis Tools with Applications to the Biological and Physical Sciences, Kavli Institute of Theoretical Physics, 21 Mar 2003.

Andrew Doherty, Quantum Feedback and Measurement: Arranging for Theory to Visit the Laboratory, US-Australia Workshop on Solid State and Optical Approaches to Quantum Information Science, Newport Australia, 7 Jan 2003.

Andrew Doherty, Quantum Entanglement and Non-locality: Semidefinite relaxations for problems in Quantum Information Processing, 41st IEEE Conference on Decision and Control, Las Vegas, 13 Dec 2002.

Andrew Doherty, Local Hidden Variable Theories for Quantum States Quantum Information and Cryptography Workshop, MSRI, Berkeley, 8 Nov 2002.

Andrew Doherty, Distinguishing Separable and Entangled States SQuInT Conference, NIST, Boulder, 9 Mar 2002.

Luming Duan, Engineering many-body Hamiltonians with ultracold atoms in optical lattices, Joint IPAM/MSRI Workshop on Quantum Computing, UCLA, Oct 2002.

Luming Duan, Robust quantum communication and state engineering with atomic ensembles, The Feynman Festival, University of Maryland, Aug 2002.

Luming Duan, Quantum information processing with atomic ensembles, Santa Barbara, Quantum optics workshop, Santa Barbara, Jul 2002.

Luming Duan, Implementation of long-distance quantum communication, IQEC-CLEO/Europe, Moscow, Russia, June 2002.

Sean Hallgren, Polynomial-Time Quantum Algorithms for Pell's Equation and the Principal Ideal Problem, AMS Meeting, Baltimore, MD, Jan 2003.

Sean Hallgren, Polynomial-Time Quantum Algorithms for Pell's Equation and the Principal Ideal Problem, QIP 2003, Berkeley, CA, Dec 2002.

Sean Hallgren, Polynomial-Time Quantum Algorithms for Pell's Equation and the Principal Ideal Problem, MSRI workshop on Quantum Algorithms and Complexity, Banff, Canada, 2002.

Sean Hallgren, Quantum Algorithms for some Hidden Shift Problems, Foundations of Computational Mathematics (FoCM), Minneapolis, MN, 2002.

Patrick Hayden, American Mathematical Society Eastern Sectional Meeting, Boston, 5-6 Oct 2002.

Patrick Hayden, Workshop on Quantum Information and Cryptography, Mathematical Sciences Research Institute, 4-8 Nov 2002.

Patrick Hayden, 6th Annual Workshop on Quantum Information Processing, Mathematical Sciences Research Institute, 13-18 Dec 2002.

Patrick Hayden, Quantum Foundations in the Light of Quantum Information II, Centre de Recherches Mathematiques, Montreal, 13 Oct 2002 - 2 Nov 2002.

Patrick Hayden, Workshop on Quantum Cryptography, McGill-Bellairs Institute, Barbados, 28 Apr 2003 - 2 May 2003.

Jeff Kimble, Quantum Information Science—The Promise, the Problems, and the Plumbing, Frontiers of Science and Technology: Quantum Computation and Information, Lawrence Livermore National Laboratory, Livermore, CA, 9 Dec 2002.

Jeff Kimble, Experiments in Quantum Information Science—What’s the Point? Gordon Research Conference, Quantum Information Science, Ventura, CA, 23 Mar 2003.

Jeff Kimble, Quantum Teleportation—Fact and Fantasy, Loeb Lecture Series, Harvard University, Boston, MA, 10 Apr 2003.

Jeff Kimble, Cavity QED—The Plumbing, Loeb Lecture Series, Harvard University, Boston, MA, 15 Apr 2003.

Alexei Kitaev, Anyons in a spin model on the honeycomb lattice, Quantum Information Processing (QIP 2002), IBM T.J. Watson Research Center, Yorktown Heights, NY, 14–17 Jan 2002.

Alexei Kitaev, Quantum coin tossing, Quantum Information Processing (QIP 2003) MSRI, Berkeley, CA, 13–17 Dec 2002.

Alexei Kitaev, Anyons in a spin model on the honeycomb lattice, Annual Meeting of the American Mathematics Society, Baltimore, MD, 15–18 Jan 2003.

Alexei Kitaev, Topological quantum computation, 22nd Annual Western States Mathematical Physics Meeting, Caltech, Pasadena, CA, 17–18 2003.

Alexei Kitaev, Topological quantum computation, Sectional Meeting of the American Mathematics Society, San Francisco, CA, 3–4 May 2003.

Hideo Mabuchi, Research experiments and experimental teaching in quantum mechanics, Gordon Conference on Physics Research and Education: Quantum Mechanics, Mt. Holyoke, MA, 9–14 Jun 2002.

Carlo Mochon, Quantum computations using anyons from finite groups, AMS Special Session on Topological Quantum Computation, 3–4 May 2003.

Michael Nielsen, American Physical Society March Meeting, Austin, Texas, Mar 2003.

Michael Nielsen, Advances in Quantum Information Processing: From Theory to Experiment, Erice, Italy, Mar 2003.

Michael Nielsen, Gordon Conference on Quantum Information Science, Ventura, California Mar 2003.

John Preskill, Putting Weirdness to Work: Quantum Information and Quantum Computation, Annual Meeting of the American Mathematics Society, San Diego, CA, 2002.

John Preskill, Putting Weirdness to Work: Quantum Information and Quantum Computation, MSRI Annual Meeting, 2002.

John Preskill, Quantum Computation and the Future of Physics, Conference on the Theory of Computation and the Sciences, Berkeley, 9 May 2002.

John Preskill, Putting Weirdness to Work: Applications of Quantum Information, Lorentz Lecture, University of Leiden, 1 Oct 2002.

John Preskill, The power of quantum computing: Quantum speedups and quantum lower bounds, Lorentz Lecture, University of Leiden, 8 Oct 2002.

John Preskill, Battling decoherence: Quantum error correction and fault-tolerant quantum computation, Lorentz Lecture, University of Leiden, 15 Oct 2002.

John Preskill, Quantum cryptography: Quantum key distribution and its unconditional security, Lorentz Lecture, University of Leiden, 22 Oct 2002.

John Preskill, Quantum computation and the future of physics, Ehrenfest colloquium, University of Leiden, 23 Oct 2002.

John Preskill, Secure quantum key distribution with an uncharacterized source, Quantum Information Processing (QIP 2003) MSRI, Berkeley, CA, 16 Dec 2002.

John Preskill, Topologically protected quantum computation, American Physical Society March Meeting, Austin, Texas, 4 Mar 2003

John Preskill, How more is different: A quantum information perspective, Conference on glassy states of matter, Kavli Institute for Theoretical Physics, Santa Barbara, 23 May 2003.

Ben Rahn, Exact and Approximated Performance of Concatenated Quantum Codes, 6th International Conference on Quantum Communication, Measurement and Computing (QCMC'02), Cambridge, MA, 22 Jul 2002.

Ben Rahn, A Model Reduction Analysis of Concatenated Quantum Codes, CIMMS Workshop, Caltech, Pasadena, CA, 22 Mar 2002.

Leonard Schulman, Group representation theory and quantum algorithms, MSRI, Aug 2002.

- Ben Schumacher, Classical Information in Quantum Information Theory, ERATO Workshop on Quantum Information Science (EQIS 2002), Tokyo Sep 2002.
- Ben Schumacher, Interpretation problems and quantum information, Workshop on Quantum foundations in the light of quantum information, Centre de recherches mathematiques (CRM) Universite de Montreal, Nov 2002.
- Ben Schumacher, What is information?, Advances in quantum information processing: from theory to experiments, Ettore Majorana Center, Erice, Italy, Mar 2003.
- Ben Schumacher, CHB, T and Me, Charles H. Bennett 60th Birthday symposium, IBM Watson Research Lab, May 2003.
- Ben Toner, The communication cost of quantum correlations, Theory Seminar School of Physics, The University of Melbourne (Australia), 17 Sep 2002.
- Guifre Vidal, Interaction cost of non-local operations, Annual Meeting of the American Mathematical Society, San Diego, CA, 2002.
- Guifre Vidal, On the continuity of asymptotic measures of entanglement, Quantum Information EURESCO Conf., Sant Feliu, Barcelona, Spain, Apr 2002.
- Guifre Vidal, Entanglement in quantum phase transitions, Quantum Information and Cryptography, Mathematical Sciences Research Institute, Berkeley, Nov 2002.
- Guifre Vidal, Entanglement in quantum critical phenomena, Quantum Information Processing, Mathematical Sciences Research Institute, Berkeley, Dec 2002.
- Guifre Vidal, Efficient classical simulation of slightly entangled quantum computations, Perimeter Institute, Waterloo, Canada, Mar 2003.