Caltech Establishes IQI: Institute for Quantum Information

by John Preskill

The Divisions of Physics, Mathematics, and Astronomy (PMA) and Engineering and Applied Science have jointly established the Institute for Quantum Information (IQI), supported by a five-year grant from the National Science Foundation. The goal of the IQI is to advance the foundations of quantum information science (QIS), an emerging field that draws on physics, mathematics, computer science, and engineering. Broadly speaking, QIS addresses how the principles of quantum physics can be harnessed to improve the acquisition, transmission, and processing of information.

QIS derives much of its intellectual vitality from three central ideas, all of relatively recent vintage. The first important idea is quantum computation. We have learned that a computer that operates on quantum states instead of classical bits can perform tasks that are beyond the capability of any conceivable classical computer. For example, finding the 200-digit prime factors of a 400-digit composite number would take billions of years on today's supercomputers. But for a quantum computer it would be an easy problem, not much harder than multiplying two numbers together to find their product. The boundary between "hard" and "easy"—between problems that someday will be solved and problems that never can be solved—is essentially different in a quantum world than in a classical world.

The second important idea is quantum cryptography. You can communicate privately with another party over the Internet, but the security of that communication is founded on assumptions about the computational resources that are available to a potential adversary. In contrast, if you were able to communicate by transmitting quantum states (like photon wave packets traveling in an optical fiber) instead of classical bits, you could achieve a higher level of privacy founded on fundamental laws of physics. Quantum

> Aside from its technological implications, QIS is an intellectually stimulating basic research field. Fundamental questions such as *What is the computational power of Nature?*, *Can measurement be reversed?*, and *How much information can we learn?* drive the field and inspire new research directions.

> "As with any revolutionary scientific insight, the long-term implications [of QIS] cannot be clearly anticipated, but we are confident that they will be profound. We also expect that the emergence of QIS will have an extensive eventual impact on how science is taught at the college and secondary level, and will bring a deeper understanding of quantum physics to a broad segment of the lay public."
> —*John Preskill, Professor of Theoretical Physics*

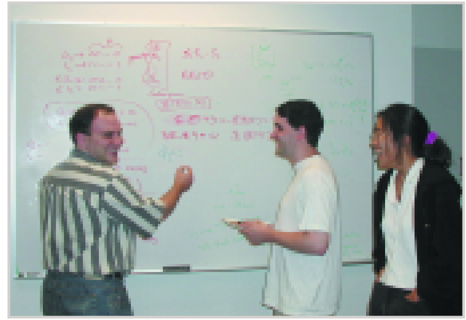
cryptography is based on the principle that it is impossible to collect information about the state of a quantum system without disturbing the state in a detectable way.

The third important idea is quantum error correction, which has greatly boosted our confidence that large-scale quantum computers really can be built and operated someday. The power of a quantum computer derives from its ability to process coherent quantum states, but such states are very easily damaged by uncontrolled interactions with the environment—a process called decoherence. Thus, quantum computers are much more susceptible to error than conventional digital computers. But we have learned that quantum states can be cleverly encoded so that the debilitating effects of decoherence, if not too severe, can be resisted. In principle then, even very intricate quantum systems can be stabilized and accurately controlled.

The scientific mission of the IQI is to elaborate and develop these ideas, and to otherwise illuminate the essential differences between quantum information and classical information. We aim to better understand the capabilities of quantum computers and to bridge the vast gap between the theory and practice of quantum information processing by conceiving new approaches to the physical manipulation of coherent quantum states.

A variety of Caltech groups in both the EAS and PMA Divisions have been engaged in QIS research for several years. The IQI consolidates, expands, and enhances these activities by providing a focal point for QIS research on the Caltech campus. Faculty, research staff, and students from both Divisions interact, promoting the communication and collaboration across disciplinary boundaries that will be essential to the further development of the field.

Central to the IQI's scientific program is a vigorous visitor's program that brings the world leaders of the QIS research community to Caltech for both long-term and short-term visits. Almost 40 visitors from the international research community have spent anywhere from several days to several months in residence at IQI since its inception. The IQI also supports post-doctoral scholars drawn from backgrounds spanning the disciplines relating to QIS. The visitors and postdocs affiliated with the IQI occupy space in the Steele and Jorgensen laboratories.



Graduate students (left to right) Andrew Landahl, Jim Harrington, and Charlene Ahn discussing the finer points of qubits.

EAS faculty connected with the IQI include John Doyle, Professor of Electrical Engineering; Michelle Effros, Associate Professor of Electrical Engineering; Axel Scherer, Neches Professor of Electrical Engineering, Applied Physics, and Physics; Leonard Schulman, Associate Professor of Computer Science. PMA faculty include Jeff Kimble, Valentine Professor and Professor of Physics; Hideo Mabuchi (PhD '98), Associate Professor of Physics; John Preskill, Professor of Theoretical Physics; Michael Roukes, Professor of Physics; and Kip Thorne (BS '62), Feynman Professor of Theoretical Physics.

In the 21st century, information technology will play an increasingly important role in our daily lives. We also anticipate that thinking about how information can be encoded and processed will facilitate progress in basic science. Though quantum theory is now over 100 years old, we are just beginning to learn some of the profound ways in which quantum information differs from classical information. The IQI aims to lead the quest for a deeper understanding of the role of information in fundamental physics.

More about IQI activities can be found at
http://www.iqi.caltech.edu