Quantum Information and Quantum Computation

Academic and Research Staff
Professor Seth Lloyd, Professor Leonid Levitov, Professor Terry Orlando, Professor Jeffrey H. Shapiro, Dr. N.C. Wong

Visiting Scientists and Research Affiliates
Dr. Vittorio Giovanetti,[1] Dr. Lorenzo Maccone,[2] Professor Murray Gell-Mann[3]

Graduate Students
William Kaminsky, Si Hui Tan

Technical and Support Staff
Lori Hyke

Introduction

Quantum computers and communication systems are devices that store and process information on quantum systems such as atoms, photons, superconducting systems, etc. Quantum information processing differs from classical information processing in that information is stored and processed in a way that preserves quantum coherence. The Quantum Information Group is investigating methods for constructing quantum computers and quantum communication systems using atomic physics,quantum optics, and superconducting systems. In addition, the group is investigating applications of quantum information processing including novel quantum algorithms and communication protocols.

1. W.M. Keck Center for Extreme Quantum Information Theory (xQIT)

Sponsors
W.M.Keck Foundation

Project Staff
Professor Seth Lloyd, Professor Jeffrey H. Shapiro, Professor Scott Aaronson, Professor Edward Farhi, Professor Jeffrey Goldstone, Professor Leonya Levitov, Professor Sanjoy Mitter, Professor Jean-Jacques Slotine, Professor Peter Shor,

Over the last half century, the components of computers have gotten smaller by a factor of two every year and a half, the phenomenon known as Moore's law. In current computers, the smallest wires and transistors are coming close to a size of one hundred nanometers across, a thousand times the diameter of an atom. Quantum mechanics is the theory of physics that describes the behavior of matter and energy in extreme conditions such as short times and tiny distances. As transistors and wires become smaller and smaller, they inevitably begin to behave in intrinsically quantum mechanical ways.

Quantum computers store and process information at the level of individual quanta--atoms, photons, and electrons. Even if Moore's law persists, commercial quantum computers are not yet due on the shelves for another few decades; nonetheless, prototype quantum computers consisting of a small number of atoms and quantum communication systems that use single photons have been built and operated.

[1] Researcher, Scuola Normale Superiore, Pisa.
[2] Researcher, Universita di Pavia.
[3] Professor, Santa Fe Institute.

Researchers at the W.M. Keck Center for Extreme Quantum Information Theory (xQIT) are Working to investigate the limits of computation and communication. We are working to uncover the abilities of quantum computers to solve hard problems. We are investigating the capacities of noisy quantum channels. We have shown how quantum channel capacity can be enhanced using entanglement. We have derived limits on the capacities of broadband quantum channels with and without entanglement assistance. Finally, we are investigating the ultimate physical limits to the accuracy of sensing and measurement.

2. Superconducting Quantum Computers

Sponsors
NEC

Project Staff
Professor Seth Lloyd, Professor Leonid Levitov, Professor Terry Orlando, Professor J.E. Mooij, Haidong Yuan, William Kaminsky

Superconducting systems present a variety of opportunities for quantum information processing. In collaboration with Delft Institute of Technology, we demonstrated the first macroscopic quantum superposition of circulating supercurrents, and have designed devices in which such systems function as quantum bits in a quantum computer. We are currently collaborating with Delft and NEC to investigate mechanisms of errors and decoherence in superconducting quantum bits and are designing experiments to demonstrate quantum logic operations, quantum algorithms and quantum entanglement using superconducting systems. We have presented novel designs for quantum computers that compute while remaining in their ground state. We have shown how adiabatic methods can be used to perform coherent quantum computation.

Publications

Journal Articles Published

Lloyd, S, `Almost Certain Escape from Black Holes in Final State Projection Models,' Phys. Rev. Lett. 96, 061302 (2006); quant-ph/0406205.

Bennett, C.H., A.W. Harrow, S. Lloyd, `Universal quantum data compression via gentle tomography,' Phys. Rev. A73, 032336 (2006); quant-ph/0403078.

Giovannetti, V., S. Lloyd, S., L. Maccone, `Quantum metrology,' Phys. Rev. Lett. 96, 010401 (2006); quant-ph/0509179.

Pirandola, S., D. Vitali, P. Tombesi, S. Lloyd, `Macroscopic entanglement by entanglement swapping,' Phys. Rev. Lett. 97, 150403 (2006); quant-ph/0509119.

Giovannetti, V., S. Lloyd, L. Maccone, `Interferometric tunability of the absorption,' Optics Express14/19, 8622-8629 (2006); quant-ph/0602110.

Yuan, H., S. Lloyd, `Controllability of the coupled spin-half harmonic oscillator system,’ to appear in Phys. Rev. A..

Journal Articles, Submitted for Publication

Lloyd, S., `A theory of quantum gravity based on quantum computation,' submitted to Phys. Rev. A, quant-ph/0501135.

Lloyd, S., `Quantum limits to the measurement of spacetime geometry,'submitted to Phys. Rev. Lett.; quant-ph/0505064.

Pirandola, S., S. Mancini, S. Lloyd, S.L. Braunstein, `Continuous variable quantum cryptography using two-way quantum communication,' submitted to Nature Physics; quant-ph/0611167.