Quantum Information and Quantum Computation

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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

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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

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photons have been built and operated.

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.

This year we were able to make significant progress both in the area of quantum algorithms and in the area of quantum communications. We constructed a new quantum algorithm for finding solutions to linear sets of equations: the algorithm provides an exponential speedup over classical algorithms. In quantum communication we were able to prove the long-standing bosonic channel minimum output entropy conjecture, thereby resolving the important practical question of the capacity of the bosonic channel with linear amplification and loss, and with Gaussian noise.

In addition, we uncovered significant effects of quantum coherence in the process of photosynthetic energy transport.

2. Superconducting Quantum Computers

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Superconducting systems present a variety of opportunities for quantum information processing. 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. We have developed techniques for the control of complex superconducting circuits and are applying them to two- and three-qubit devices.

Publications

Journal Articles Published

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F. De Martini, V. Giovannetti, S. Lloyd, L. Maccone, E. Nagali, L. Sansoni, F. Sciarrino, "Experimental Quantum Private Queries with Linear Optics," *Phys. Rev. A* ***80,*** 010302(R) (2009); arXiv:0902.0222.

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