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)

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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 aw 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.

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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. We are investigating the ultimate physical limits to the accuracy of sensing and measurement and have shown how entanglement can significantly enhance the sensitivity of imaging and detection, even in the presence of large amounts of noise and loss. Finally, we are studying alternative approaches to quantum gravity based both on quantum limits to the measurement of space and time, and on emergent solid-state approaches.

2. Superconducting Quantum Computers

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NEC

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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. 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

S. Pirandola, S. Mancini, S. Lloyd, and S.L. Braunstein, “Continuous variable quantum cryptography using two-way quantum communication,” to appear in *Nature Physics* (2008); quant-ph/0611167.

A.O. Niskanen, K. Harrabi, F. Yoshihara, Y. Nakamura, S. Lloyd, and J. S. Tsai, “Quantum Coherent Tunable Coupling of Superconducting Qubits,” Science 316: 723-726 (2007).

V. Giovannetti, S. Lloyd, and L. Maccone, “Quantum random access memory,” Phys. Rev. Lett. 100: 160501 (2008); arXiv:0708.1879.

V. Giovannetti, S. Lloyd, and L. Maccone, “Quantum private queries,” Phys. Rev. Lett. 100: 230502 (2008); arXiv:0708.2992.

S. Pirandola and S. Lloyd, “Computable bounds for the discrimination of Gaussian states,' Phys. Rev. A. 78: 012331 (2008).

M. Horodecki, S. Lloyd, and A. Winter, “Quantum coding theorem from privacy and indistinguishability,” Op. Sys. Inf. Dyn. 15: 47-69 (2008); arXiv:quant-ph/0702006.

S. Lloyd, “Quantum Information Matters,” Science 319 (5867): 1209-1211 (2008).

S. Lloyd, “Enhanced photodetection via quantum illumination,” Science 321: 1463-1465, 2008; arXiv:0803.2022.

Journal Articles, Submitted for Publication

S. Pirandola, S. Braunstein, S. Mancini, and S. Lloyd, “Quantum direct communication with continuous variables,” submitted to *Nature Physics*; arXiv:0802.0656.

M. Tsang, J. H. Shapiro, and S. Lloyd, “Quantum Theory of Optical Instantaneous Frequency and Bosonic Fluid Velocity,” submitted to *Phys. Rev. A*.; arXiv:0804.0463.

V. Giovannetti, S. Lloyd, L. Maccone, and J.H. Shapiro, “Sub-Rayleigh Quantum Imaging,” submitted to *Phys. Rev. Lett*.; arxiv:0804.2875.

M. Mohseni, P. Rebentrost, S. Lloyd, and A. Aspuru-Guzik, “Environment-Assisted Quantum Walks in Energy Transfer of Photosynthetic Complexes,” submitted to *J. Chem. Phys*.; arXiv:0805.2741.

S. Lloyd, “Robustness of Adiabatic Quantum Computing,” submitted to *Phys. Rev. Lett*.; arXiv:0805.2757.

S. Pirandola, S.L. Braunstein, and S. Lloyd, “Asymptotic security against collective Gaussian attacks,” submitted to *Phys. Rev. Lett.*; arXiv:0806.4207.