Quantum Information

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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. Quantum Internet

Sponsors
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A quantum internet consists of quantum computers connected by quantum communication channels. The problem of maintaining the coherence of quantum information as it is moved from atoms to photons, transported through space, and moved back from photons to atoms, is a difficult one. Exactly because quantum information provides additional opportunities for storing and processing information, it also provides additional opportunities for errors, loss, and the corruption of that information. We have developed designs for a quantum internet that allow the robust transmission of quantum information even in the presence of high levels of errors and loss. We are currently implementing those designs and are developing protocols and applications for the quantum internet. In addition, 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 communication.

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2. Secure Quantum Communication and Clock Synchronization

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Quantum mechanics offers a variety of opportunities both to protect information (quantum cryptography) and to improve the precision of measurement, positioning and timing techniques. We are developing the world's brightest source of narrow band entangled photons and are planning to use this source to demonstrate secure quantum communication via teleportation and to demonstrate the phenomenon of quantum magic bullets --- quantum systems that exploit entanglement to pass through potential barriers with a much higher degree of success than is allowed classically. In addition, we have developed and are implementing techniques that use quantum entanglement to surpass the shot noise limit for timing and positioning. We have shown how quantum entanglement can be exploited to cancel dispersion and to perform cryptographic ranging. We are applying these techniques to show how the structure of spacetime can be mapped out more accurately by exploiting intrinsically quantum dynamics.

3. Superconducting Quantum Computers

Sponsors
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Superconducting systems present a variety of opportunities for quantum information processing. In collaboration with Delft Institute of Technology, we have 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 investigating mechanisms of errors and decoherence in superconducting quantum bits and are designing experiments to demonstrate quantum logic operations 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.l

Publications

Journal Articles Published

Zanardi, P., and S. Lloyd, `Topological Protection and Quantum Noiseless Subsystems,' Phys. Rev. Lett 90, 067902 (2003).

Emerson, J. , and Y.S. Weinstein, S. Lloyd, D.G. Cory, Fidelity Decay as an Efficient Indicator of Quantum Chaos,' Phys. Rev. Lett. 89, 284102 (2002).

Weinstein, Y.S., and S. Lloyd, C. Tsallis, `The Edge of Quantum Chaos,' Phys. Rev. Lett. 89, 214101 (2002).

Lloyd, S., `The Power of Entanglement in Quantum Communication,’ to appear in Phys. Rev. Lett.

Weinstein, Y.S., and S. Lloyd, J.V. Emerson, D.G. Cory, `Experimental Implementation of the Quantum Baker's Map,’ Phys. Rev. Lett. 89, 157902 (2002).

Journal Articles, Submitted for Publication

Giovannetti, V., and S. Lloyd, L. Maccone, `The role of entanglement in dynamical evolution,’ submitted to Europhys. Lett.

Giovannetti, V., and S. Lloyd, L. Maccone, `Quantum limits to dynamical evolution,’ submitted to Phys. Rev. A.

Recht, B. and Y. Maguire, S. Lloyd, I.L. Chuang, N.A. Gershenfeld, `Using unitary operations to preserve quantum states in the presence of relaxation,’ submitted to Phys. Rev. Lett.

Weinstein, Y.S., and S. Lloyd, J.V. Emerson, D.G. Cory , `Fidelity Decay Saturation Level for Initial Eigenstates,’ submitted to Phys. Rev. Lett.

Meeting Papers, Presented

Lloyd, S. `The Power of Entangled Quantum Channels,’ QCMC, Cambridge, MA. 2002, Entanglement and Quantum Computation, Rio de Janeiro, 2002.

Meeting Papers, Published

Kaminsky, W.M., and S. Lloyd `Scalable Architecture for Adiabatic Quantum Computing of NP-Hard Problems,’ presentation at MQC2 Conference (Napoli, June 2002). Quantum Computing & Quantum Bits in Mesoscopic Systems (Kluwer Academic 2003).

Lloyd, S., `The Power of Entangled Quantum Channels,’ QCMC proceedings.