Progress towards Scalable Quantum Information Processing with Trapped Ions

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Abstract: Recent advances in trapped-ion quantum information processing include the combination of a complete set of scalable techniques as well as development of scalable trap technologies, high-fidelity operations, quantum networks, and quantum simulation.
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Quantum information processing (QIP) promises significant gains for some important computational tasks as well as the potential to simulate interesting physical systems. Storing quantum bits (qubits) in the internal states of trapped atomic ions is an interesting approach to QIP because of long coherence times and precise interaction with light fields for coherent control and entanglement generation. Recent advances in the field include the development and integration of techniques with the aim of facilitating the realization of large-scale quantum processors.

The Ion Storage Group at NIST has demonstrated a complete methods set for scalable ion-trap QIP, including robust qubit storage, single- and two-qubit logic gates, state initialization and readout, and quantum information transport [1]. We have used this methods set to realize the first programmable two-qubit quantum processor [2].

Various groups around the world have demonstrated high-fidelity operations, including 99.92(1)% for single-qubit operations [3], 99.3(1)% for two-qubit operations [4], and 99.991(1)% for readout [5].

Larger-scale processors will be required as the number of qubits increases, and recent efforts have focused on multidimensional trap arrays [6, 7] and integrated components such as optical fibers for light collection [8]. In addition, two remote trapped ions have been coupled through a photonic quantum network [9].

Trapped ions are also starting to be used as analog quantum simulators of systems such as quantum spins [10, 11] and the one-dimensional Dirac equation [12].

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