SYSTEMS, METHODS AND APPARATUS FOR LOCAL PROGRAMMING OF QUANTUM PROCESSOR ELEMENTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims benefit under 35 U.S.C. 119(e) to U.S. provisional patent application Ser. No. 60/868,654, filed Dec. 5, 2006, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

The present systems, methods and apparatus relate to scalable quantum computing and the local programming of quantum processor elements.

2. Description of the Related Art

A Turing machine is a theoretical computing system, described in 1936 by Alan Turing. A Turing machine that can efficiently simulate any other Turing machine is called a Universal Turing Machine (UTM). The Church-Turing thesis states that any practical computing model has either the equivalent or a subset of the capabilities of a UTM.

A quantum computer is any physical system that harnesses one or more quantum effects to perform a computation. A quantum computer that can efficiently simulate any other quantum computer is called a Universal Quantum Computer (UQC).

In 1981 Richard P. Feynman proposed that quantum computers could be used to solve certain computational problems more efficiently than a UTM and therefore invalidate the Church-Turing thesis. See e.g., Feynman R. P., "Simulating Physics with Computers", International Journal of Theoretical Physics, Vol. 21 (1982) pp. 467-488. For example, Feynman noted that a quantum computer could be used to simulate certain other quantum systems, allowing exponentially faster calculation of certain properties of the simulated quantum system than is possible using a UTM.

Approaches to Quantum Computation

There are several general approaches to the design and operation of quantum computers. One such approach is the "circuit model" of quantum computation. In this approach, qubits are acted upon by sequences of logical gates that are the compiled representation of an algorithm. Circuit model quantum computers have several serious barriers to practical implementation. In the circuit model, it is required that qubits remain coherent over time periods much longer than the single-gate time. This requirement arises because circuit model quantum computers require operations that are collectively called quantum error correction in order to operate. Quantum error correction cannot be performed without the circuit model quantum computer's qubits being capable of maintaining quantum coherence over time periods on the order of 1,000 times the single-gate time. Much research has been focused on developing qubits with coherence sufficient to form the basic information units of circuit model quantum computers. See e.g., Shor, P. W. "Introduction to Quantum Algorithms", arXiv.org:quant-ph/0005003 (2001), pp. 1-27. The art is still hampered by an inability to increase the coherence of qubits to acceptable levels for designing and operating practical circuit model quantum computers.

Another approach to quantum computation comprises using the natural physical evolution of a system of coupled quantum systems as a computational system. This approach

does not make critical use of quantum gates and circuits. Instead, starting from a known initial Hamiltonian, it relies upon the guided physical evolution of a system of coupled quantum systems wherein the problem to be solved has been encoded in the terms of the system's Hamiltonian, so that the final state of the system of coupled quantum systems contains information relating to the answer to the problem to be solved. This approach does not require long qubit coherence times. Examples of this type of approach include adiabatic quantum computation, cluster-state quantum computation, one-way quantum computation, quantum annealing and classical annealing, and are described, for example, in Farhi, E. et al., "Quantum Adiabatic Evolution Algorithms versus Simulated Annealing" arXiv.org:quant-ph/0201031 (2002), pp 1-16.

Embodiments of Quantum Computers

A quantum computer is any computing device that makes direct use of quantum mechanical phenomena, such as superposition and entanglement, to solve computational problems. To date, many different systems have been proposed and studied as physical realizations of quantum computers. Examples of such systems include the following devices: ion traps, quantum dots, harmonic oscillators, cavity quantum electrodynamics devices (QED), photons and nonlinear optical media, heteropolymers, cluster-states, anyons, topological systems, systems based on nuclear magnetic resonance (NMR), and systems based on spins in semiconductors. For further background on these systems, see Nielsen and Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, Cambridge (2000), pp. 277-352; Williams and Clearwater, *Explorations in Quantum Computing*, Springer-Verlag, New York, Inc. (1998), pp. 241-265; Nielsen, Micheal A., "Cluster-State Quantum Computation", arXiv.org:quant-ph/0504097v2 (2005), pp 1-15; and Brennen, Gavin K. et al., "Why should anyone care about computing with anyons?", arXiv.org:quant-ph/0704.2241 (2007), pp 1-19.

In brief, an example of an ion trap quantum computer is a computer structure that employs ions that are confined in free space using electromagnetic fields. Qubits may be represented by the stable electronic states of each ion. An example of a quantum dot quantum computer is a computer structure that employs electrons that have been confined to small regions where their energies can be quantized in such a way that each dot may be isolated from the other dots. An example of a harmonic oscillator is computer structure that employs a particle in a parabolic potential well. An example of an optical photon quantum computer is a computer structure in which qubits are represented by individual optical photons which may be manipulated using beam-splitters, polarization filters, phase shifters, and the like. An example of a cavity QED quantum computer is a computer structure that employs single atoms within optical cavities where the single atoms are coupled to a limited number of optical modes. An example of an NMR quantum computer is a computer structure in which qubits are encoded in the spin states of at least one of the nuclei in the atoms comprising a molecular sample. An example of a heteropolymer quantum computer is a computer structure that employs a linear array of atoms as memory cells, where the state of the atoms provides the basis for a binary arithmetic. An example of a quantum computer that uses electron spins in semiconductors is the Kane computer, in which donor atoms are embedded in a crystal lattice of, for example, silicon. An example of a topological quantum computer is a computer structure that employs two-dimensional "quasiparticles" called anyons whose world lines cross to