CONSTRUCTING AND PROGRAMMING QUANTUM HARDWARE FOR ROBUST QUANTUM ANNEALING PROCESSES

CLAIM OF PRIORITY

This application claims priority under 35 USC §119(e) to U.S. Patent Application Serial No. 61/985,348, filed on April 28, 2014, and 61/924,207, filed on January 6, 2014, the entire contents of which are hereby incorporated by reference.

BACKGROUND

This specification relates to constructing and programming quantum hardware for quantum annealing processes that can perform reliable information processing at non-zero temperatures.

SUMMARY

According to a first aspect of the present invention, there is provided a method comprising:

for a quantum processor solving a machine learning optimization problem,

encoding, by one or more processors, the machine learning optimization problem into an energy spectrum of a quantum Hamiltonian H_{total} that characterizes the quantum processor, wherein the quantum processor is controllable such that H_{total} evolves from an initial quantum Hamiltonian H_i over time to a problem quantum Hamiltonian H_p, wherein an energy spectrum of H_p encodes a solution to the machine learning optimization problem, and wherein a quantum state evolves from a ground state of H_i towards a ground state of H_p as H_{total} evolves from H_i to H_p;

outputting a first set of control parameters based on the encoding for programming the quantum processor and parameterization of H_{total};

deriving, by the one or more processors, an additional quantum Hamiltonian H_{QG}, such that when combined with H_{total}, H_{QG} limits evolution of the quantum state into the ground state of H_p as H_{total} evolves to H_p without diagonalizing H_p;

outputting a second set of control parameters based on the derived H_{QG} for programming the quantum processor to reflect the parameterization of H_{total}; and

receiving, by the one or more processors from the quantum processor, an output associated with a state of the quantum state at the end of the evolution.

According to a second aspect of the present invention, there is provided an apparatus comprising:

a quantum processor for solving a machine learning optimization problem; and

a control system for programming the quantum processor, wherein the control system comprises one or more processors configured to:

encode the machine learning optimization problem into an energy spectrum of a quantum Hamiltonian H_{total} that characterizes the quantum processor, wherein the quantum processor is controllable such that H_{total} evolves from an initial quantum Hamiltonian H_i over time to a problem quantum Hamiltonian H_p, wherein an energy spectrum of H_p encodes a solution to the machine learning optimization problem, and wherein a quantum state evolves from a ground state of H_i towards a ground state of H_p as H_{total} evolves from H_i to H_p;

output a first set of control parameters based on the encoding for programming the quantum processor and parameterization of H_{total};

derive an additional quantum Hamiltonian H_{QG}, such that when combined with H_{total}, H_{QG} limits evolution of the quantum state into the ground state of H_p as H_{total} evolves to H_p without diagonalizing H_p;

output a second set of control parameters based on the derived H_{QG}; and

receive, from the quantum processor, an output associated with a state of the quantum state at the end of the evolution.

Artificial intelligent tasks can be translated into machine learning optimization problems. To perform an artificial intelligence task, quantum hardware, e.g., a quantum processor, is constructed and programmed to encode the solution to a corresponding machine optimization problem into an energy spectrum of a many-body quantum Hamiltonian characterizing the quantum hardware. For example, the solution is encoded in the ground state of the Hamiltonian. The quantum hardware performs adiabatic quantum computation starting with a known ground state of a known initial Hamiltonian. Over time, as the known initial Hamiltonian evolves into the Hamiltonian for solving the problem, the known ground state evolves and remains at the instantaneous ground state of the evolving Hamiltonian. The energy spectrum or

the ground state of the Hamiltonian for solving the problem is obtained at the end of the evolution without diagonalizing the Hamiltonian.

Sometimes the quantum adiabatic computation becomes non-adiabatic due to excitations caused, e.g., by thermal fluctuations. Instead of remaining at the instantaneous ground state, the evolving quantum state initially started at the ground state of the initial Hamiltonian can reach an excited state of the evolving Hamiltonian.