

The quantum hardware is constructed and programmed to suppress such excitations from an instantaneous ground state to a higher energy state during an early stage of the computation. In addition, the quantum hardware is also constructed and programmed to assist relaxation from higher energy states to lower energy states or the ground state during a later stage of the computation. The robustness of finding the ground state of the Hamiltonian for solving the problem is improved.

According to an aspect, there is provided an apparatus comprising: quantum units; and couplers among the quantum units, each coupler being configured to couple a pair of quantum units such that a quantum Hamiltonian characterizing the quantum units and the couplers is:

$$H_{\text{tot}} = I(t) \sum_i \sigma_i^z + G(t) \left(\sum_{m \in \{x, y, z\}} \sum_i \varepsilon_{i,m} \sigma_i^m + \sum_{m \in \{x, y, z\}} \sum_{i < j} g_{ijm} \sigma_i^m \sigma_j^m \right) + P(t) \left(\sum_i h_i \sigma_i^z + \sum_{i,j} J_{ij} \sigma_i^z \sigma_j^z \right)$$

where $\varepsilon_{i,m}$ denotes disorders and g_{ijm} defines general two-body interaction parameters, N is the total number of pairs of quantum units, i represents the i^{th} pair of quantum unit, h_i and J_{ij} have real values that are associated with coupling strength between the quantum units of each pair of quantum units, and $I(t)$, $G(t)$, and $P(t)$ are time-dependent control parameters.

The details of one or more embodiments of the subject matter of this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will be apparent from the description, the drawings, and the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic perspective view of a quantum annealing processor within a Chimera connectivity of interacting qubits.

FIG. 2 is a schematic diagram showing the structures and interactions of two qubits in a quantum processor, where the interactions include x-x and x-z interactions of a quantum governor.

FIG. 2A is a schematic diagram showing a Josephson box, including a Josephson junction and a capacitor.

FIG. 3 is a schematic diagram showing the effect of a quantum governor on transitions among instantaneous energy states during a quantum annealing process

FIG. 4 is a schematic diagram showing the interplay of an initial Hamiltonian, a problem Hamiltonian, and a Hamiltonian of a quantum governor chosen for the problem Hamiltonian during a quantum annealing process.

FIG. 5 is a flow diagram of an example process for determining a quantum governor distribution.

FIG. 6 is a flow diagram of an example process for performing an artificial intelligence task.

CLAIMS

1. An apparatus comprising:

quantum units; and

couplers among the quantum units, each coupler being configured to couple a pair of quantum units such that a quantum Hamiltonian characterizing the quantum units and the couplers is:

$$H_{\text{tot}} = \sum_i I(t) \sigma_i^z + G(t) \left(\sum_{i,j \in \{x,y,z\}} \sum_i \varepsilon_{i,m} \sigma_i^m + \sum_{i,j \in \{x,y,z\}} \sum_{m,n} g_{ijmn} \sigma_i^m \sigma_j^n \right) + P(t) \left(\sum_i h_i \sigma_i^z + \sum_{i,j} J_{ij} \sigma_i^z \sigma_j^z \right)$$

where $\varepsilon_{i,m}$ denotes disorders and g_{ijmn} defines general two-body interaction parameters, N is the total number of pairs of quantum units, i represents the i^{th} pair of quantum unit, h_i and J_{ij} have real values that are associated with coupling strength between the quantum units of each pair of quantum units, and $I(t)$, $G(t)$, and $P(t)$ are time-dependent control parameters.

2. The apparatus of claim 1, wherein the quantum units comprises a first pair of superconducting quantum units, the first pair comprising:

a first superconducting quantum unit configured to have controllable quantum operators σ_i^i , where $i = x, y$, or z and represents a direction in Hilbert space;

a second superconducting quantum unit configured to have controllable quantum operators σ_j^j , where $j = x, y$, or z and represents a direction in the Hilbert space; and

wherein the couplers comprise:

a first coupler between the first and second superconducting units, wherein when a magnetic field is applied along the z direction, the first coupler couples the first superconducting unit with the second superconducting unit in a first coupling represented by $\sigma_i^x \sigma_j^x$; and

a second coupler between the first and second superconducting units, wherein when the magnetic field along the z direction is applied, the second coupler couples the first superconducting unit with the second superconducting unit in a second coupling represented by $\sigma_i^x \sigma_j^z + \sigma_j^x \sigma_i^z$.

3. The apparatus of claim 2, wherein the first superconducting quantum unit comprises a first superconducting qubit and the controllable quantum operators σ_I^j are binary, and the second superconducting quantum unit comprises a second superconducting qubit and the controllable quantum operators σ_2^j are binary.
4. The apparatus of claim 2, wherein the first coupler and the second coupler comprise inductive couplers.
5. The apparatus of claim 2, wherein the couplers comprise a third coupler between the first and second superconducting units, wherein when the magnetic field along the z direction is applied, the second coupler couples the first superconducting unit with the second superconducting unit in a third coupling represented by $\sigma_I^x \sigma_2^x$.
6. The apparatus of claim 2, wherein each pair superconducting quantum units has the same structure as the first pair of superconducting quantum unit recited in claim 2, wherein different pairs of superconducting quantum units are coupled through additional couplers.