**Gate-Model Quantum Computers**

**Abstract**

A computational problem fed into a gate-model quantum computer identifies an objective function with a particular computational pathway (objective function connectivity). The solution of the computational problem involves identifying a target objective function value that is the subject to be reached. A bottleneck in a gate-model quantum computer is the requirement of several rounds of quantum state preparations, high-cost run sequences, and multiple rounds of measurements to determine a target (optimal) state of the quantum computer that achieves the target objective function value. Here, we define a method for optimal quantum state determination and computational path evaluation for gate-model quantum computers. We prove a state determination method that finds a target system state for a quantum computer at a given target objective function value. The computational pathway evaluation procedure sets the connectivity of the objective function in the target system state on a fixed hardware architecture of the quantum computer. The proposed solution evolves the target system state without requiring the preparation of intermediate states between the initial and target states of the quantum computer. Our method avoids high-cost system state preparations and expensive running procedures and measurement apparatuses in gate-model quantum computers. The results are convenient for gate-model quantum computations and the near-term quantum devices of the quantum Internet.

**Introduction**

Quantum computers utilize the fundamentals of quantum mechanics to perform computations. For experimental gate-model quantum computer architectures and the near-term quantum devices of the quantum Internet, gate-based architectures provide an implementable solution to realize quantum computations. In a gate-model quantum computer the operations are realized via a sequence of quantum gates, and each quantum gate represents a unitary transformation. The input of a quantum computer is a quantum system realized via several quantum states, and the unitaries of the quantum computer change the initial system state into a specific state. The output quantum system is then measured by a measurement array.

A computational problem fed into a quantum computer defines an objective function with a particular connectivity (computational pathway). The solution of this computational problem in the quantum computer involves identifying an objective function with a target value that is subject to be reached. To achieve the target objective function value, the quantum computer must reach a particular system state such that the gate parameters of the unitary operations satisfy the target value. These optimal gate parameter values of the unitary operations of the quantum computer identify the optimal state of the quantum computer. This optimal system state is referred to as the target system state of the quantum computer. Finding the target system state involves multiple measurement rounds and iterations, with high-cost system state preparations (Note, the term "quantum state preparation" in the current context refers to a quantum state determination method. It is because the aim of the proposed procedure is the determination of an optimal state of the quantum computer, i.e., the optimal values of the gate-parameters of the unitaries of the quantum computer), quantum computations, and measurement procedures. Therefore, optimizing the determination procedure of the target system state is essential for gate-model quantum computers.

Here, we define a method for state determination and computational path evaluation for gate-model quantum computers. The aim of state determination is to find a target system state for a quantum computer such that the pre-determined target objective function value is reached. The aim of the computational path evaluation is to find the connectivity of the objective function in the target system state on the fixed hardware architecture of the quantum computer. To resolve these issues, we define a framework that utilizes the theory of kernel methods and high-dimensional Hilbert spaces. In traditional theoretical computer science, kernel methods represent a useful and low computational-cost tool in statistical learning, signal processing theory and machine learning. We prove that these methods can also be utilized in gate-model quantum computations for particular problems.

**Gate-model quantum computers**

The model of gate-model quantum computer architectures and the construction of algorithms for qubit architectures are studied in10. The proposed system model of the work also serves as a reference for our system model. Some related preliminaries can also be found in “Farhi, E., Goldstone, J. & Gutmann, S. Quantum Approximate Optimization Algorithm” and “Farhi, E., Goldstone, J. & Gutmann, S. A Quantum Approximate Optimization Algorithm Applied to a Bounded Occurrence Constraint Problem.”

In “Farhi, E. & Neven, H. Classification with Quantum Neural Networks on Near Term Processors”, the authors defined a gate-model quantum neural network. The proposed system model is a quantum neural network realized via a gate-model quantum computer.

In “Farhi, E., Goldstone, J., Gutmann, S. & Zhou, L. The Quantum Approximate Optimization Algorithm and the Sherrington-Kirkpatrick Model at Infinite Size”, the authors studied a gate-model quantum algorithm called the “Quantum Approximate Optimization Algorithm” (QAOA) and its connection with the Sherrington-Kirkpatrick (SK) model. The results serve as a framework for analyzing the QAOA, and can be used for evaluating the performance of QAOA on more general problems.

The behavior of the objective function value of the QAOA algorithm for some specific cases has been studied in “Brandao, F. G. S. L., Broughton, M., Farhi, E., Gutmann, S. & Neven, H. For Fixed Control Parameters the Quantum Approximate Optimization Algorithm’s Objective Function Value Concentrates for Typical Instances”. As the authors concluded, for some fixed parameters and instances drawn from a particular distribution, the objective function value is concentrated such that typical instances have almost the same value of the objective function.

A recent experimental quantum computer implementation has been demonstrated in “Arute, F. et al. Quantum supremacy using a programmable superconducting processor”. The results of the work confirmed the quantum supremacy of quantum computers over traditional computers in particular problems.

The work of “Preskill, J. Quantum Computing in the NISQ era and beyond. Quantum” gives a summary on quantum computing technologies in the NISQ (Noisy Intermediate-Scale Quantum) era and beyond.

**Conclusions**

Gate-model quantum computers represent an implementable way for near-term experimental quantum computations. The resolution of a computational problem fed into a quantum computer can be modeled via reaching the target value of an objective function. The objective function is determined by the actual computational problem. To satisfy the target objective function value, a quantum computer must reach a target system state. In the target system state, the gate parameters of the unitaries pick up values that set the objective function into the target value. Finding the target system state is a challenge that requires several rounds of measurement and system state preparations via the quantum computer.

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