IMPLEMENTING QUANTUM CONTROL FOR UNKNOWN SUBROUTINES

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INTRODUCTION & MOTIVATION

Recently, there has been renewed interest in the problem of controlling unknown operations [1, 2], previously addressed in an experiment [3], and the related problem of controlling their order [4], within the circuit model of quantum computation. From a computational point of view, it is desirable to equip quantum computers with generic circuits realizing "black box" classes that take as their input a number of unknown gates and implement these conditionally on the state of a control qubit. Given an unknown unitary U, one naively expects that it can be inserted into a prefabricated circuit that is independent of U, which performs the operation ctrl-U. However, various no-go theorems [1, 2] show that such constructions are not allowed by the mathematical structure of quantum mechanics. Here [5], we discuss the implications of these theorems, and introduce a novel scheme that allows to add quantum control to unknown units for trapped ions, as well as setups for ions and photons that can realize the quantum-controlled switch of operations.

NO-GO THEOREM (SEE Refs. [1, 2])

How is this possible? Theorem cannot be broken!
• Inspection of Dashed box: visual similarity to circuit, but circuit guarantees single qubit input in each "wire"
• Schematic diagrams, on the other hand, do not generally obey rules of circuit diagram.
• Alternative view: control not "added" to U at all, action of device spatially localized, hence conditioned on position.

ADDITIONAL CONTROL POSSIBLE IN OPTICAL SETTINGS (SEE Ref. [1, 3]) — PARADOX?

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ION TRAPS

Paul trap: individually addressable ions confined in harmonic potential; Common vibrational mode cooled to ground state; Metastable electronic transition encodes qubit; Picture courtesy of B. Lanyon

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THE CONTROLLED SWITCH (SEE Ref. [4, 5])

Similar no-go theorem for ordering of unknown operations [4]:
• Steps (i),(ii) as before; then (iii) with pulse U₁; reflect pulse by mirror
• σ₅ for like pulses S₅ = [ϕ₁(ϕ₁) + ϕ₂(ϕ₂)] and S₆ = [σ₅] = [ϕ₁(ϕ₁) + ϕ₂(ϕ₂)]: (see above)
• Pulse U₁; reflected pulse U₁; repeat S₅, S₆; reflected pulse U₁; (iv) as before
As far as adversary is concerned: pulses used only once, one photon used per pulse

CONCLUSIONS

• Have shown: can add control also in ion-trap setup; method easily generalizes to control of qubits
• Can implement ctrl-Switch in ionic & photonic setups
• No paradoxes, make use of additionally available degrees of freedom or dimensions of physical system
• Other setups: possibility to add control whenever only restricted part of the Hilbert space is used for qubits
• Significance for adversarial settings: provider vs. user

REFERENCES


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