The Physical Implementation of Quantum Computation

Reading Report

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Abstract

The chapter was written by Dr. David DiVincenzo [1] while working at IMB research center. It describes several requirements that he and his coworkers were discussing to be properly included in the implementation as part of the definition of a quantum computer.

Hypothesis and evidence

The main hypothesis of the article is that postulates of quantum computation are sufficient to start deriving a set of physical requirements for materializing a quantum computer implementation.

Those requirements are deemed indispensable but not in an axiomatic way. Instead, evidence derived from the mathematical postulates of quantum mechanics and then presented in strict order. Also, some implementations are called into question by discussing pros and cons of each.

Contribution

The article gives a brief and generic introduction to quantum computing. However, its main contribution are the 5+2 physical requirements of quantum computation. Each of those enumerates first a brief introduction to the related mathematical postulates and then gives a complete study of the state of the art around options for the implementation. Since each can be considered different study over disjoint postulates, they are by themselves worth of a section for explanation:

The first requirement maps to the first postulate, i.e. it maps the definition of a qubit. Namely, it requires a *well characterizable* physical translation of the two-level quantum system. The author defines *well characterized* as the ability to accurately know all the parameters of the system namely the internal Hamiltonian and couplings to other states and to external fields. Photons,

The second requirement is the ability to prepare qubits with zeroes. This requirement is important to initialize computation and to allow error correction. The author enumerates two approaches: cooled when reached the desired state or projected.

A third requirement is longer decoherence times than the gate operation time. Understand *decoherence* as the process a qubit suffers when interacting with its environment and losses its meaningful characteristics. Decoherence time must be long enough to allow quantum properties to be used and measured. It also affects error correcting procedures.

The fourth requirement is a set of universal quantum gates (alias unitary operators) and directly relates with the system's evolution postulate. First we need to be able to identify the physical Hamiltonians that produce the unitary operators. However this Hamiltonians must allow interactions to be turned on and off. Also the interactions of the two qubits must avoid overlaps. Interactions between the quantum computer and the control devices should avoid entanglement. Fully parallel unentangled operation is needed for the error correction procedure.

The fifth requirement maps to the quantum measurement postulate, it is the ability to measure the qubits. A probability is needed to measure a 0 state or a 1 state. Even though this probability would be not so high, it can be extended by running the measurements several times.

Those requirements are for computation. For taking advantage of *entanglement* the author add two more requirements: (1) the ability to translate flying qubits to stationary and vice versa and (2) the ability of transmitting flying qubits between specified locations.

Limitations and weaknesses

Even though there is an explicit link to the postulates of quantum mechanics, the criteria for selecting the set of requirements is not well defined under mathematical terms. It is apparently based on the opinions of a subset of scientist on the peer network of Dr. David P. DiVincenzo. The two last requirements aim at taking advantage of the *entanglement* effect, but many other quantum effects that are obviated from their discussion.

Also, there are too few quantum system implementations to bullet-proof all the requirements. The most cited work is the NMR by Cory whose work was the most advanced at the time of that writing.

Controversial ideas

Decoherence time is very much remarked as a potential problem in most of the requirements. One of the most controversial ideas is that this decoherence time requirement will lead to different error correction code circuits that will be harder to build because internally they also depend on decoherence times.

Future work

Extend the requirements to specific applications that take advantage of distinct quantum mechanical properties, apart from *entanglement* e.g. bound the decoherence time requirement to the *Hall effect*.

Also, there is another computational paradigm available for exploitation, one that subjects each bit to the same evolution rule. Future work over this paradigm could lead to novel architecture models and new polymers.

References

[1] D. P. DiVincenzo and IBM, “The Physical Implementation of Quantum Computation,” Feb. 2000.