Quantum Mechanical Computers

Reading Report

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Abstract

The article was written by Dr. Richard Feynman [1]. The article explores the mathematical foundations and quantum architecture needed to buld a reversible computer at atomic level. This reversible computer would be able to minimize the energy dissipated by any computation considering the limits imposed by quantum physics.

Hypothesis and evidence

The author states that using a mathematical construction and architecture based on Hermitian (Hamiltonian) operators a reversible quantum computer implementation is possible. The reversible quantum computer will dissipate less energy than the $10^{10}KT$ joules per gate on transistor system and even less energy that the former $kT \ln 2$, the first lower limit calculated by Bennett [2].

Contribution

The first contribution of the article is a set of reversible primitive operators parallel to any logical gate . This demonstrates in theory that reversible primitives can be used to build any general Turing Machine. These operators replicate the input to the output so the operation can be reversed. The most important of those is the *CONTROLLED CONTROLLED NOT* but several other operations such as COPY and CLEAR are also presented. A full adder example is constructed using just those gates.

Second, the author demonstrates the architecture for a complete reversible computer and their input, output and garbage registers.

A third contribution is the mathematical constitution of the primitives into unitary operators of a Hamiltonian system. A set of matrix operations are shown to successfully emulate the *CONTROLLED CONTROLLED NOT* . Those systems can be easily translated in to a series approximation that can emulate a physical system.

Considerations on the substrate needed to move the cursor are also presented. These considerations are bounded in time to allow reversibility with minimal energy loss. The number of steps are shown to be irrelevant.

Finally, simpler *switch-based* primitive elements are proposed by choosing middle point initial states for the cursor in the Hamiltonian. The CONTROLLED NOT and garbage cleaner among others are reformulated. These primitives constitute a real advantage over transistors due to the fact that the previous model is only about four orders of magnitude over present time delays in transistors. Also is demonstrated that these new primitives allow subroutines.

Limitations and weaknesses

The author states regarding the imperfections of the implementation that:

> "... until we find a specific implementation for this computer, I do not know how to proceed to analyze these effects. However, it appears that they would be very important, in practice."

Until we have a real implementation it is not possible to determine how slow should the computer be to avoid unwanted atom scattering in the channel and impedance miss-coupling.

Second, the whole model is dependent of micro operations. Several operations are by themselves constructed by other operations, e.g. increasing the cursor binary counter for managing the cursor position. Then, the produced layout is of a recursive nature that could exponentially grow. The article doesn't tackle this issue explicitly.

Controversial ideas

A controversial idea hinted by Bennett and taken here, is that there is no fundamental quantum mechanical limit for minimize free energy dissipation onto virtually zero. The limit is explained through the proposed mathematical tools and quantum architecture.

Also, the fact that just by using a Hamiltonian system we can model out any sequential operation demonstrate that we can compress any number of operations in a precomputed operator that makes the length of the sequence irrelevant.

Furthermore, the idea that processing time does not depends on the operation sequence but instead it depends on the energy of the interactions in the Hamiltonian brings into consideration many quantum mechanical effects that are still unexplored.

Future work

Feynman points out that his work needs empirical feedback for tuning up the equations. So future work, at the time this writing, includes to build a full fledged quantum reversible computer.

Feynman also suggest to explore the benefits of concurrent operations. They can prove useful for building complex entangled states.

Also he suggest hybrid operating architectures that setup a planned point of no-reversibility to leverage the power of quantum primitive operators into other more classical platforms. Then memories or any other kind of irreversible circuits can be coupled.

References

[1] R. P. Feynman, "Quantum mechanical computers," *Foundations of Physics*, vol. 16, no. 6, pp. 507–531, 1986.

[2] C. H. Bennett, "Logical reversibility of computation," *IBM J. Res. Dev.*, vol. 17, no. 6, pp. 525–532, Nov. 1973.