Another Counterexample to Landauer's Principle

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Jan. 2017

Abstract: There has been disagreement about the validity of Landauer's Principle, which places a limitation on computational energy efficiency. The Principle is predicated on a finite entropy increase associated with every erasure of a memory register. Existence of a reversible memory register reduces Landauer' Principle to a disproven conjecture.

The modern understanding of Landauer's Principle is that explained by Bennett.[1] The Principle can be understood as a statement that all computing necessarily results in an increase in entropy, due to the erasure of register bits to place the computing device back to its original state.

Due to Landauer's Principle, computing is seen to fundamentally dissipate energy unless conducted at absolute zero. Most all processes involved in computing, including copying an input and manipulating the input data though Boolean logic, have been shown to be theoretically able to be accomplished reversibly. Indeed, the prototypical Turing Machine can be constructed to run in a reversible manner. The only step that has not been explained to be reversible is the erasure of memory registers. This erasure is a necessary step since a process - be it classically thermodynamic or computational - and the surroundings of the process must be able to start and end at the same state in order to be considered reversible.

The erasure of a register can be pictured as taking a register that is in a given state, say 0 or 1, and forcing it back into its initial state, say 0. If the register is a small mass of silicon with a voltage, then potential electrical energy would be irreversibly dissipated during erasure, with an associated increase in entropy. If the register is a microscopic box with a particle confined to one half of the box volume, it would be erased by first allowing the particle to irreversibly occupy the entire volume, with an associated increase in entropy, and then reversibly and isothermally compressing the particle to confined it to its initial half of the box. The work required to do this is equal to the temperature times the entropy increase realized when the particle was released from its previous half of the microscopic box. It is the entropy associated with erasure that is prescribed by Landauer's Principle.[2]

It is, however, possible to construct a register that is reversibly erased. Computer memories can be composed of flip-flops which, in turn can be made from two OR gates and two NOT gates. The flip-flop has two stable states corresponding to 0 or 1, respectively. These states can be reversibly read from the register and used for computation.

To construct a reversible flip-flop memory register one would only require reversible OR gates and NOT gates. A Taffoli gate is an example of a reversible logic gate.[3] Any Boolean logic gate, including OR and

NOT gates, can be constructed with Taffoli gates. A flip-flop register constructed from Taffoli gates is therefore a reversible register. To erase such a register, all one must do is run its Taffoli gates in reverse. No entropy need be produced during erasure.

Every step of computation can therefore be performed in a reversible manner, including any register erasure required to bring the computer back to its original state. Landauer's Principle therefore does not place any fundamental limit on energy dissipation associated with computation.

Computation does not require any increase in entropy.

References:

[1] C. H. Bennett, "Logical reversibility of computation", IBM Journal of Res. and Dev., 17:6 525 (1973)

[2] C. H. Bennett, "Notes on Landauer's principle, Reversible Computation and Maxwell's Demon", Studies in History and Philosophy of Modern Physics vol. 34 pp. 501-510 (2003)

[3] Toffoli, T. (1980). "Reversible computing," *Technical Memo* MIT/LCS/TM-151, MIT Laboratory for Computer Science (February)