Reversibility for Efficient Computing

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Michael P. Frank

CISE Department
University of Florida
http://www.cise.ufl.edu/~mpf

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Abstract

Today's computers are based on *irreversible* logic devices, which have been known to be fundamentally energy-inefficient for several decades. Recently, alternative *reversible* logic technologies have improved rapidly, and are now becoming practical.

In traditional models of computation, pure reversibility seems to decrease overall computational efficiency; I provide a proof to this effect. However, traditional models ignore important physical constraints on information processing.

This thesis gives the first analysis demonstrating that in a realistic model of computation that accounts for thermodynamic issues, as well as other physical constraints, the judicious use of reversible computing can strictly *increase* asymptotic computational efficiency, as machine sizes increase. I project real benefits for supercomputing at a large (but achievable) scale in the fairly near term. And with proposed future computing technologies, I show that reversibility will benefit computing at all scales.

Next, the thesis demonstrates that reversible computing techniques do not make computer design much more difficult. I describe how to design asymptotically efficient processors using an "adiabatic" reversible electronic logic technology that can be built with today's microprocessor fabrication processes. I describe a simple universal reversible parallel processor chip that our group recently fabricated, and a reversible instruction set for a more traditional RISC-style uniprocessor.

Finally, I describe techniques for programming reversible computers. I present a high-level language and a compiler suitable for coding efficient reversible algorithms, and I describe a variety of example algorithms, including efficient reversible sorting, searching, arithmetic, matrix, and graph algorithms. As an example application, I present a linear-time, constant-space reversible program for simulating the Schrödinger wave equation of quantum mechanics.

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to my father, Patrick Gene Frank

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