

# Reversible Computing: Quantum Computing's Practical Cousin

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## Abstract

Barring major algorithmic advances, coherent quantum computing using superposition states is known to offer polynomial to exponential speedups for only a few *specialized* classes of problems. Despite this limited usefulness, fault-tolerant quantum computing is very difficult to achieve. Another approach is both easier, and more useful. Suppose we *don't* use superpositions explicitly in our algorithms, but instead restrict the quantum state trajectory to paths that consist (as in classical computing) of only direct transitions between computational basis states. These basis states can then be chosen to be any convenient set of pointer states within whatever decoherence-free subspace happens to be naturally super-selected by the measurement observable induced by the system's built-in parasitic interactions with its environment, and so, as a result, these states are naturally very stable, and require only classical forms of error correction.

However, even in this highly restricted (and much more easily implemented) special case of quantum computing, we can *still* show that a *ballistic* (self-contained, and still mostly coherent) variation of the scheme still in fact provides *polynomial* cost-efficiency advantages for *most* general-purpose computations, excluding only the small minority of tasks that are either totally serial, or totally parallelizable and very loosely-coupled. This general advantage is due simply to the near-reversibility (low rate of entropy generation) in the ballistic evolution of a well-isolated quantum system. Given the existence of both fundamental and practical bounds on attainable entropy flux densities, the improved entropic efficiency can be demonstrated to boost theoretical performance on, in fact, the *majority* of computational applications that require tightly-coupled parallelism. Because of the generality of this advantage, we can even argue that this approach, called *reversible computing*, can reasonably be anticipated to have a *greater* overall practical economic impact than the more difficult, full-quantum approach, which presently appears somewhat more limited in its potential applications.

In this talk, I will outline the basic technological and architectural requirements for reversible computing, and show how to analyze and optimize the system-level cost-efficiency gains that can be attained using this approach. Given the raw decoherence rate of a particular device mechanism, I show how to optimize other design parameters including the redundancy factor (physical qubits per logical bit) of the logic encoding, the speed of the logic transitions, and the degree of logical reversibility of an arbitrary target computation emulated using Bennett's spacetime-efficient algorithm. With these parameters simultaneously optimized, I show that improvements in cost-efficiency on the order of 1,000× that of contemporaneous irreversible computing can be projected for general-purpose desktop-scale applications by the middle of the century.

I also discuss particular technological strategies for implementing the requirement of ballistic, self-contained evolution, which is *not* a requirement for traditional quantum algorithms, which place no limits on dissipation in the control system. I will also demonstrate a simple new mechanical model of self-timed, 3D, ballistic computation that avoids a variety of defects that were present in earlier models of reversible computing.