Quantum Computation and Combinatorial Spacetime

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Abstract

While quantum computation depends on the validity of the quantum mechanical model of nature, it is known that quantum mechanics is not a complete description of "small things." Indeed, since there is no conclusive evidence that the universe is continuous at its lowest levels, it is natural to wonder just how much information it takes to describe a slice of spacetime. By considering finite portions of the spacetime of various proposed theories of quantum gravity as combinatorial objects with strictly classical descriptions, we can determine, for each such theory, the amount of information it supports (e.g. per unit volume).

Since we can also establish a relation between this information density and the maximum size of a quantum computer that can be expected to operate correctly in a given spacetime, a simple information-theoretic argument leads us to conclude that the laboratory demonstration of freely-scalable quantum computation (i.e. the use of a fault tolerant quantum system to create sufficiently noiseless Hilbert spaces in which desired computations may take place) could potentially serve as a sensitive test with which to place limits on quantum gravitational corrections to quantum mechanics.

Perhaps of more immediate concern, however, is the converse: if quantum gravity is substantially incompatible with conventional quantum mechanics, new limits to the scalability of quantum computers may need to be addressed. As an example, we note that the most precise tests of the isotropy of space, searches for quadrupolar shifts of nuclear energy levels, reject the hypothesis that there is a classical "substrate" underlying our universe only to the point where a $10^2 \sim 10^3$ qubit quantum computer may be expected to operate.