NEW CLASS OF QUANTUM ERROR-CORRECTING CODES FOR A BOSONIC MODE

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Error correction will be an indispensable ingredient of fault-tolerant quantum information processing. Typically protection against local errors is achieved by non-locally embedding a single 'logical' qubit in a set of many physical qubits via clever circuit design (e.g., the surface code) or by using topological approaches where the hardware itself is error-resistant. These techniques provide powerful protection in theory, but their realization is a daunting engineering challenge.

Here we study theoretically a complementary approach, embedding a logical qubit in the state space of a single bosonic mode [1], such as an electromagnetic cavity mode. We are motivated by the conceptual and physical simplicity of our proposal and, more importantly, by the recent remarkable progress in realizing universally controllable superconducting cavities with lifetimes longer than the best possible corresponding qubits [2, 3]. Such cavities are very appealing as long-lived quantum memories. The limiting factors are the loss of energy via emitted radiation and errors introduced by imperfect quantum control. We address these issues by developing a new class of quantum error-correcting codes for a bosonic mode [4] which are advantageous for applications in quantum memories, communication, and scalable computation.

These developed *binomial quantum codes* are formed from a finite superposition of Fock states weighted with binomial coefficients. They work for generic systems and can systematically protect against any errors, both discrete and continuous, up to an arbitrary order in the timestep between error detection measurements. These new codes have smaller rates for uncorrectable errors than earlier codes. By imposing a specific parity structure in our codes, we make error detection experimentally straightforward. Interestingly, however, we show that even better intrinsic code performance can be achieved without a definite parity structure. The binomial quantum codes are realizable with current superconducting circuit technology and they should prove useful in other quantum technologies, including bosonic quantum memories, photonic quantum communication, and optical-to-microwave up- and down-conversion.

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