Fault-Tolerant Quantum Computers

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Quantum computation is a recently-introduced and novel computing technique which is based on quantum mechanics rather than classical physics. Its starting point is the notion of a quantum bit or “qubit”. Because of the superposition property of quantum states, n qubits can store 2^n numbers simultaneously, implying a type of massive parallelism. Furthermore, quantum states allow powerful forms of interaction such as entanglement that have no classical counterparts. As a result, quantum computers can solve some important and hitherto intractable problems such as prime factorization of large numbers. However, practical quantum computing circuits are very difficult to construct and they contain far more sources of error than classical circuits. For example, signal states are inherently unstable and tend to decay rapidly due to interaction with the environment, a phenomenon called decoherence. Quantum gates are defined by continuous parameters that allow small errors to arise and propagate to other gates. Furthermore, state measurement is probabilistic and destructive in that the measurement process affects the state being measured. While it is too soon to predict the physical form that quantum computers will eventually take, it is likely that they will incorporate various forms of fault tolerance. This talk will review the basics of quantum computation and the design of fault-tolerant circuits to implement quantum algorithms. In particular, methods for error correction and recovery that have been developed specifically for quantum circuits will be discussed. Finally, the physical implementation of these circuits will be considered, along with the prospects for fault-tolerant quantum computers.

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