

Quantum Computing – An Overview

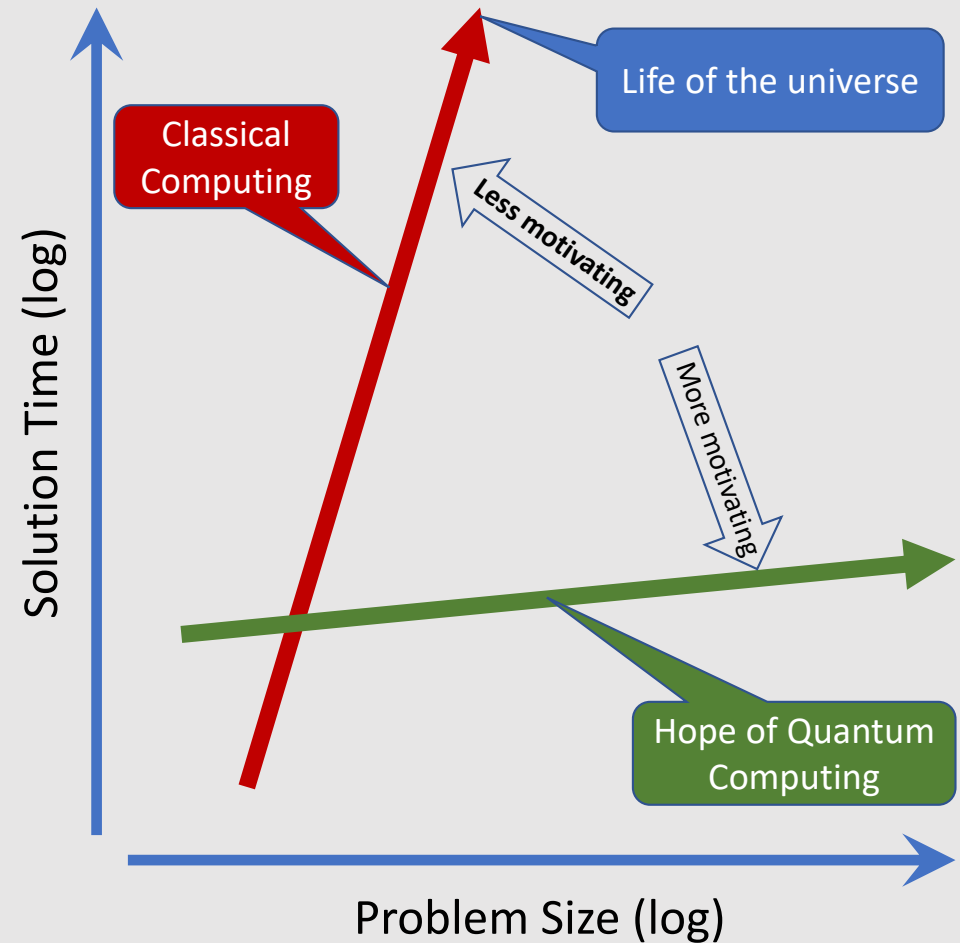
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Motivation

- Fundamentally different model of computation from classical computation
- Model changes classical computational complexity



Challenges

- Qubits with long coherence times
 - Materials, fabrication
 - Control of the qubit
 - Control of the environment in which the qubits operate
- High-fidelity (precision) operations on the qubit
 - One and two-qubit (multi-qubit) gates
 - High-fidelity state preparation (initialization)
 - High-fidelity readout (measurement)
- Fault-tolerant error correction
- Validation and verification of multi-qubit systems
- Algorithms

Focus of the last twenty years of research. which continues

Recent focus

Always searching

Essentials of the QC model

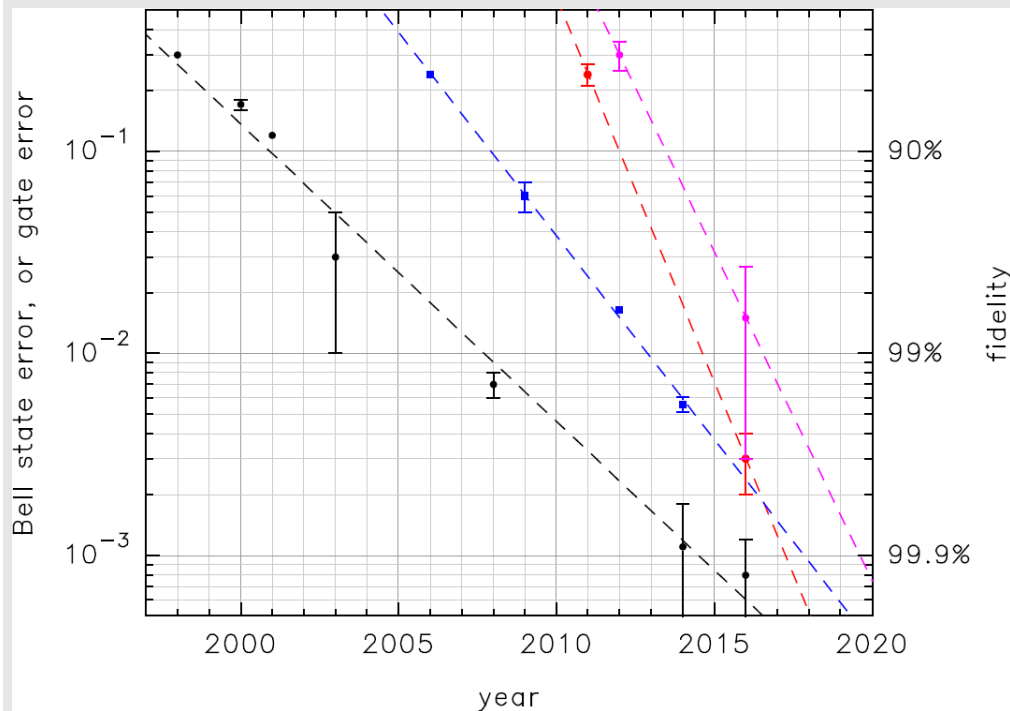
- Computations are probabilistic
- Computations can be arranged (algorithms) so that certain probabilities are enhanced and others are depressed (zeroed)
- Information is exponential in the number of qubits (superposition)
- Entanglement provides access to the exponential information space
- Universal computation from a small gate set (one and two-qubit gates)

Physical qubit types

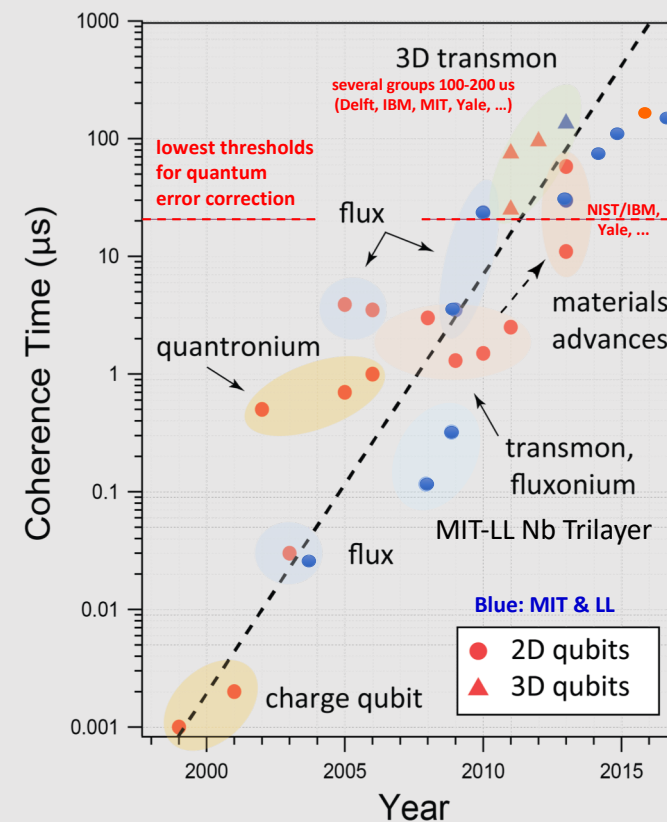
- Trapped ions
 - Currently most “quantum” of qubit types
 - Very little leverage for technology scaling
- Superconductors
 - Recent rapid progress in coherence and gate fidelity
 - Leverage semiconductor technology for scaling, but materials are different
- Semiconductors (silicon)
 - Only recent demonstrations of one and two-qubit gates
 - Matched to leverage silicon technology
- Topologically protected qubits
 - No qubit demonstrations but very promising theory
 - Circuit based or materials based
 - Anticipate rapid scaling leveraging very low error rates

Progress

Partial history of two-qubit gate fidelity progress
(From: David Lucas, Oxford)



Partial history of coherence improvements in superconducting qubits
(From: Will Oliver, MIT)



Summary

- Much progress has been made in demonstrating basic steps in quantum information processing from nearly two-decades of research
- Much research still to be done and understanding gained to overcome remaining challenges
- Expect many demonstrations of multi-qubit systems with “noisy” qubits (see John Preskill’s arxiv paper, Noisy Intermediate Scale Quantum technology)
- In the next few years, we will learn about the capabilities and usefulness of these systems and point the way to applications