Quantum Computing – An Overview

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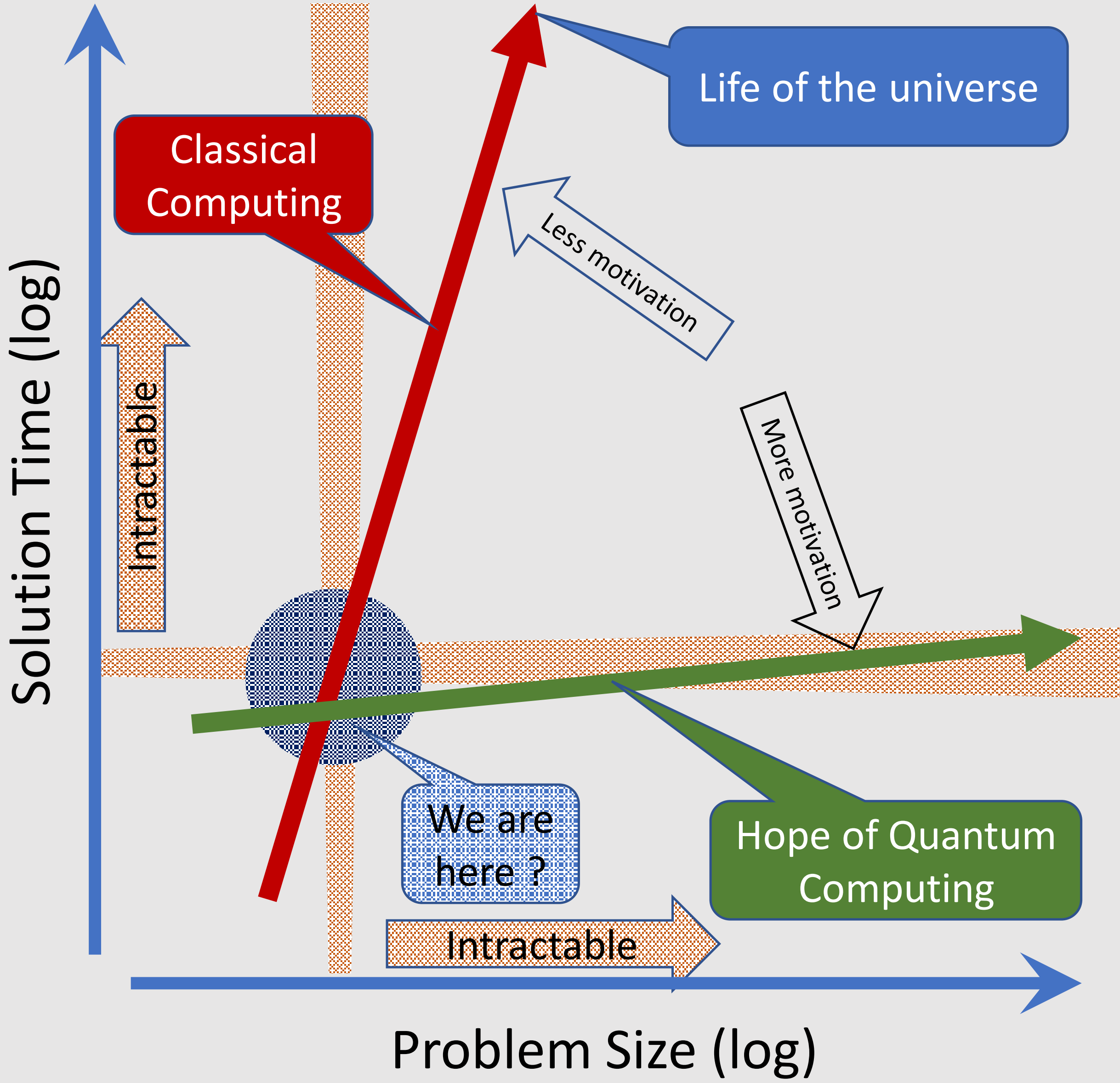
Outline

- Motivation
- Essentials of the Quantum Computing (QC) model
- Challenges for QC science & technology
- Physical qubit types
- Progress
- Summary

- Talk connects with the gate-model of quantum computing

Motivation

- Fundamentally different model of computation from classical computation
- Model changes classical computational complexity of hard problems
  - Makes tractable computational problems that are outside P
  - Unlikely to make NP-Complete problems tractable



Essentials of the QC model

- Computations are probabilistic
  - Quantum mechanics is inherently probabilistic
- Computations can be arranged (algorithms) so that certain probabilities are enhanced and others are depressed (zeroed)
  - Picture interference fringes from a double slit light (photon) experiment
- Information is exponential in the number of qubits (superposition)
- Entanglement provides access to the exponential information space
  - Superposition and entanglement are core resources in the QC model
- Universal computation from a small gate set (one and two-qubit gates)
  - Learn to do a small set of quantum logic gates very well

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

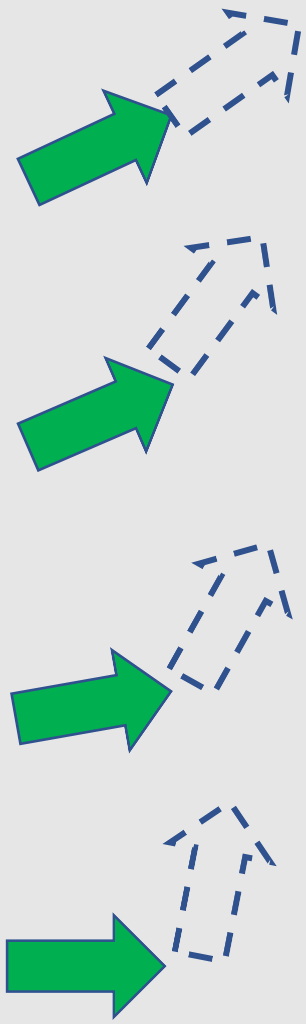
Focus of the last twenty years of research. which continues

Recent focus

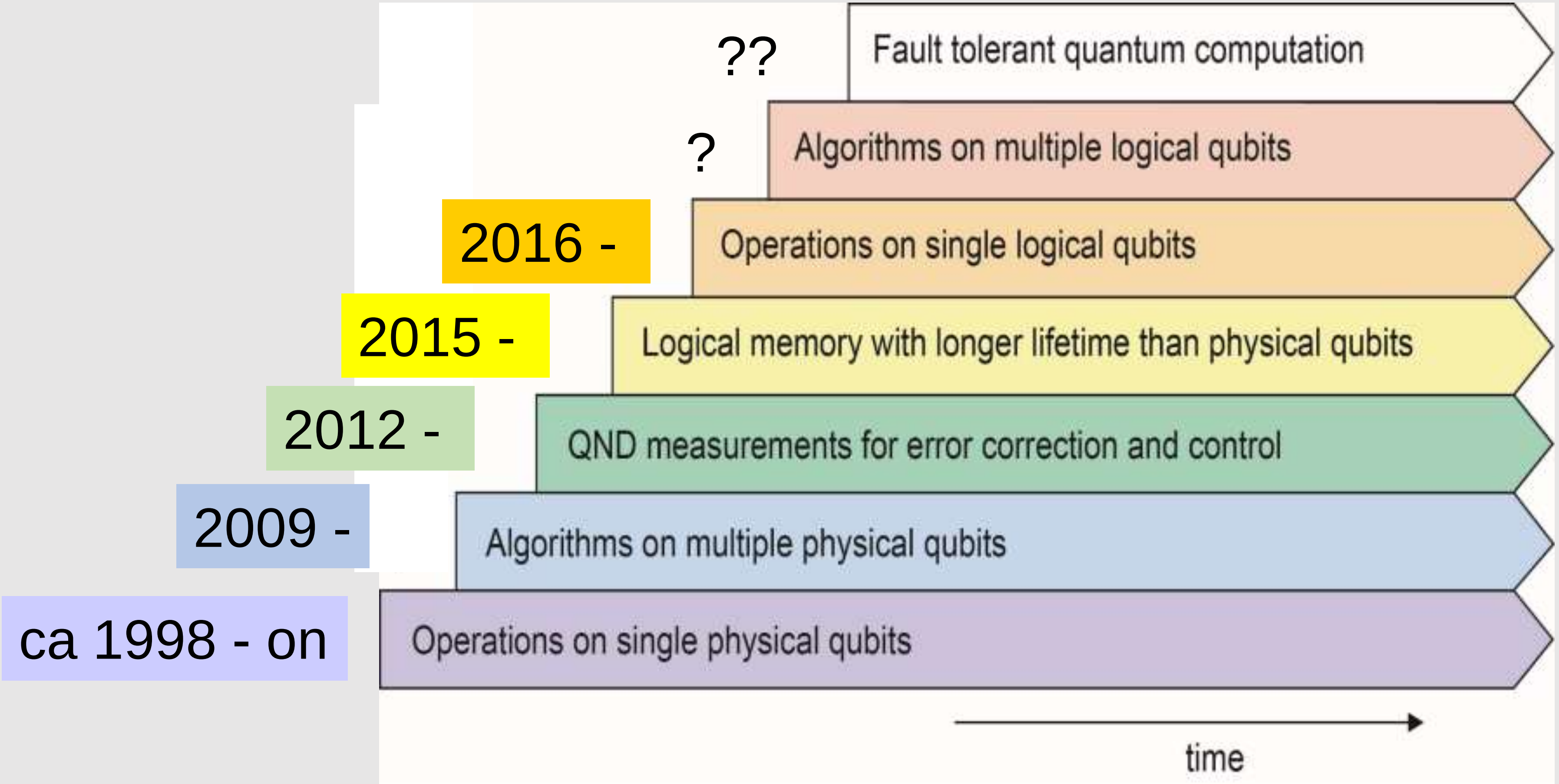
Always searching

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



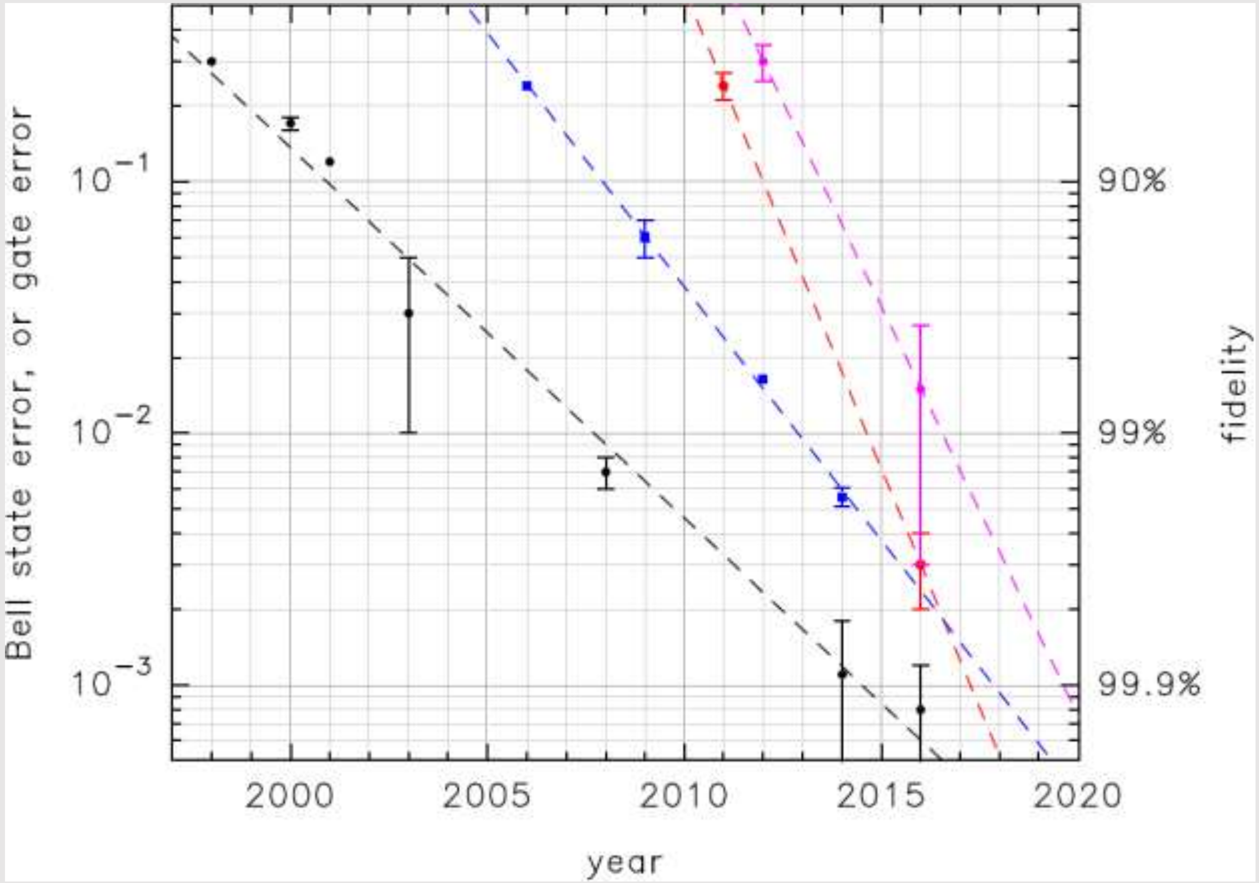
Where are we?



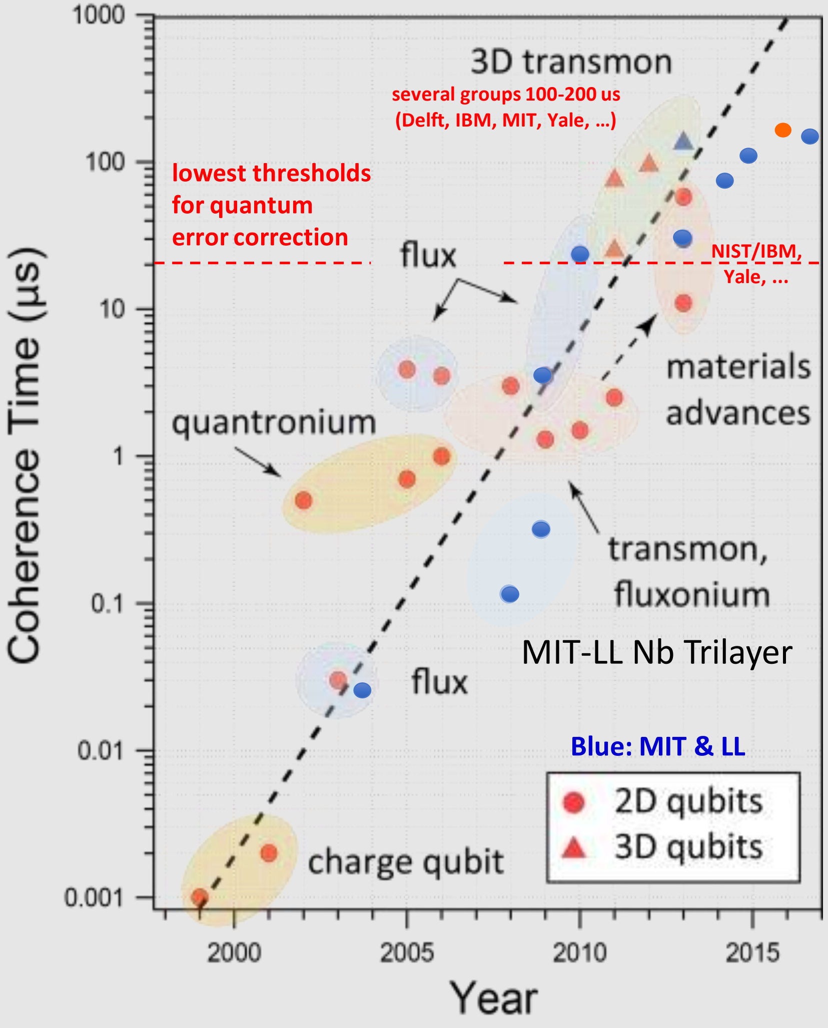
from M. Devoret and R. Schoelkopf, Science (2013)

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 (Feasibility)
- 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
- Testbeds and heuristics likely to greatly expand the application space

Thank you!