Next steps in Quantum Computing: CS's Role

Challenges and Opportunities in Technologies

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Current Approaches to Qubits

A bit of the action

In the race to build a quantum computer, companies are pursuing many types of quantum bits, or qubits, each with its own strengths and weaknesses.

	Superconducting loops	Trapped ions	Silicon quantum dots	Topological qubits	Diamond vacancies
	A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into superposition states.	Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in superposition states.	These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.	Quasiparticles can be seen in the behavior of electrons channeled through semiconductor structures. Their braided paths can encode quantum information.	A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light.
Longevity (seconds)	0.00005	>1000	0.03	N/A	10
Logic success rate	99.4%	99.9%	~99%	N/A	99.2%
Number entangled	9	14	2	N/A	6
Company support	Google, IBM, Quantum Circuits	ionQ	Intel	Microsoft, Bell Labs	Quantum Diamond Technologies
Pros	Fast working. Build on existing semiconductor industry.	Very stable. Highest achieved gate fidelities.	Stable. Build on existing semiconductor industry.	Greatly reduce errors.	Can operate at room temperature.
Cons	Collapse easily and must be kept cold.	Slow operation. Many lasers are needed.	Only a few entangled. Must be kept cold.	Existence not yet confirmed.	Difficult to entangle.

Note: Longevity is the record coherence time for a single qubit superposition state, logic success rate is the highest reported gate fidelity for logic operations on two qubits, and number entangled is the maximum number of qubits entangled and capable of performing two-qubit operations.

Photons | Neutral Atoms

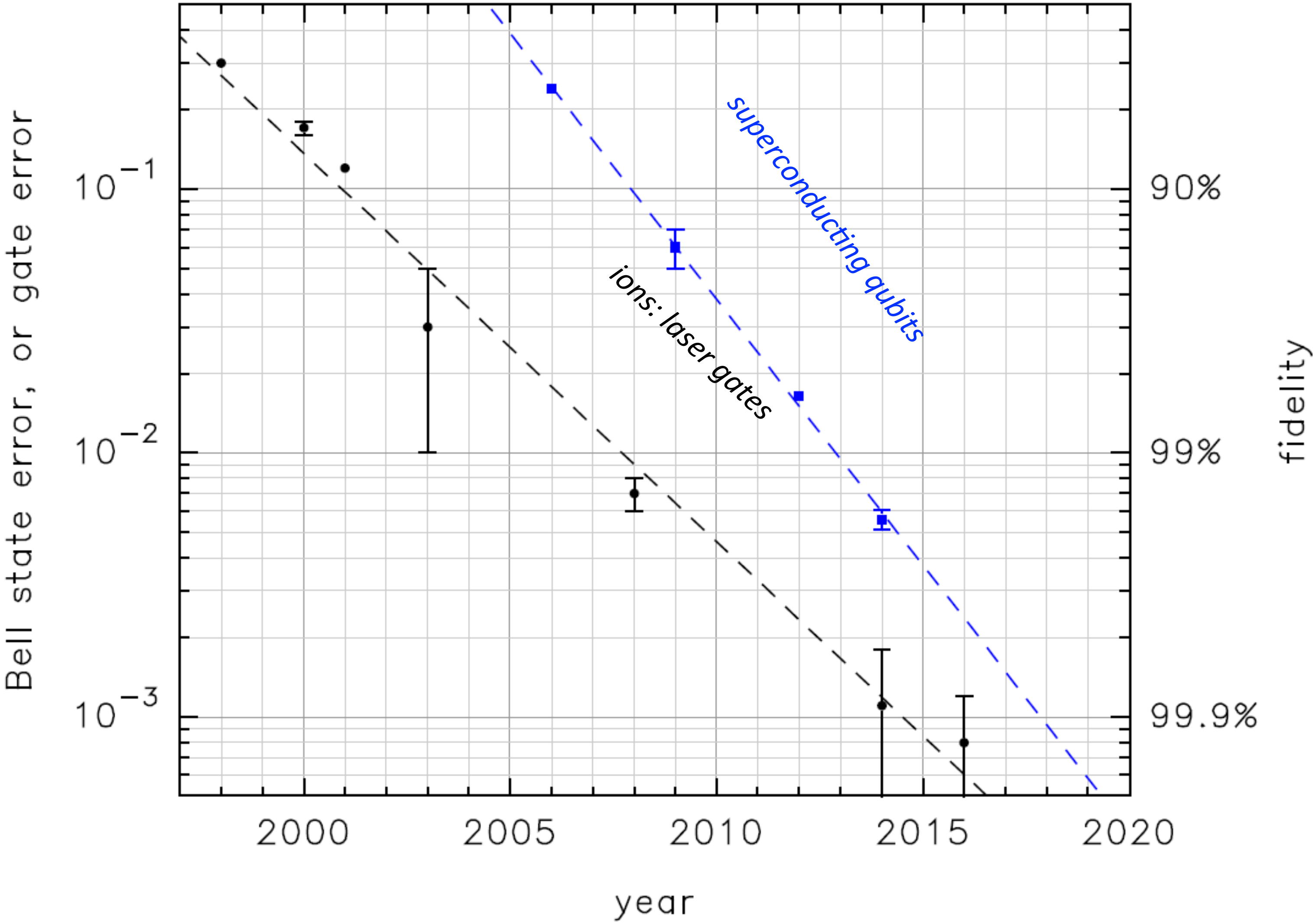
→ ??

→ 30-100

(2018-2020)

Science 354, 1090 (2016)

Historic Trend of Gate Operations



Turchette *et al.*
Sackett *et al.*
Rowe *et al.*
Leibfried *et al.*
Benhelm *et al.*
*Ballance *et al.*
*Gaebler *et al.*

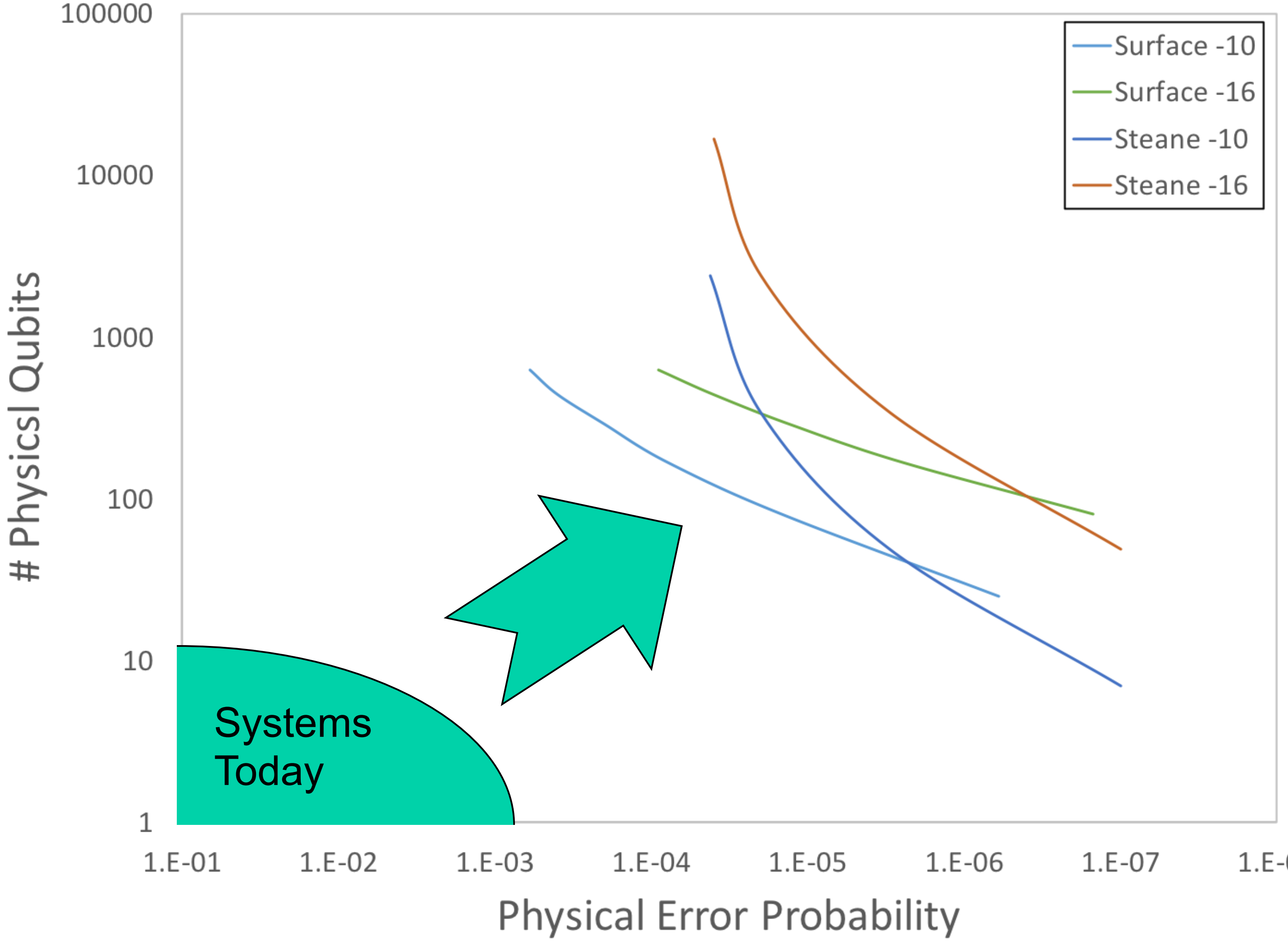
*Steffen *et al.*
*DiCarlo *et al.*
*Chow *et al.*
*Barends *et al.*

* Corrected for SPAM errors

D.Lucas, Oxford

* exclude SPAM errors

Where Do We Go from Here?



Reaching FT

Javadi-Abhari thesis, Princeton Univ. (2017)

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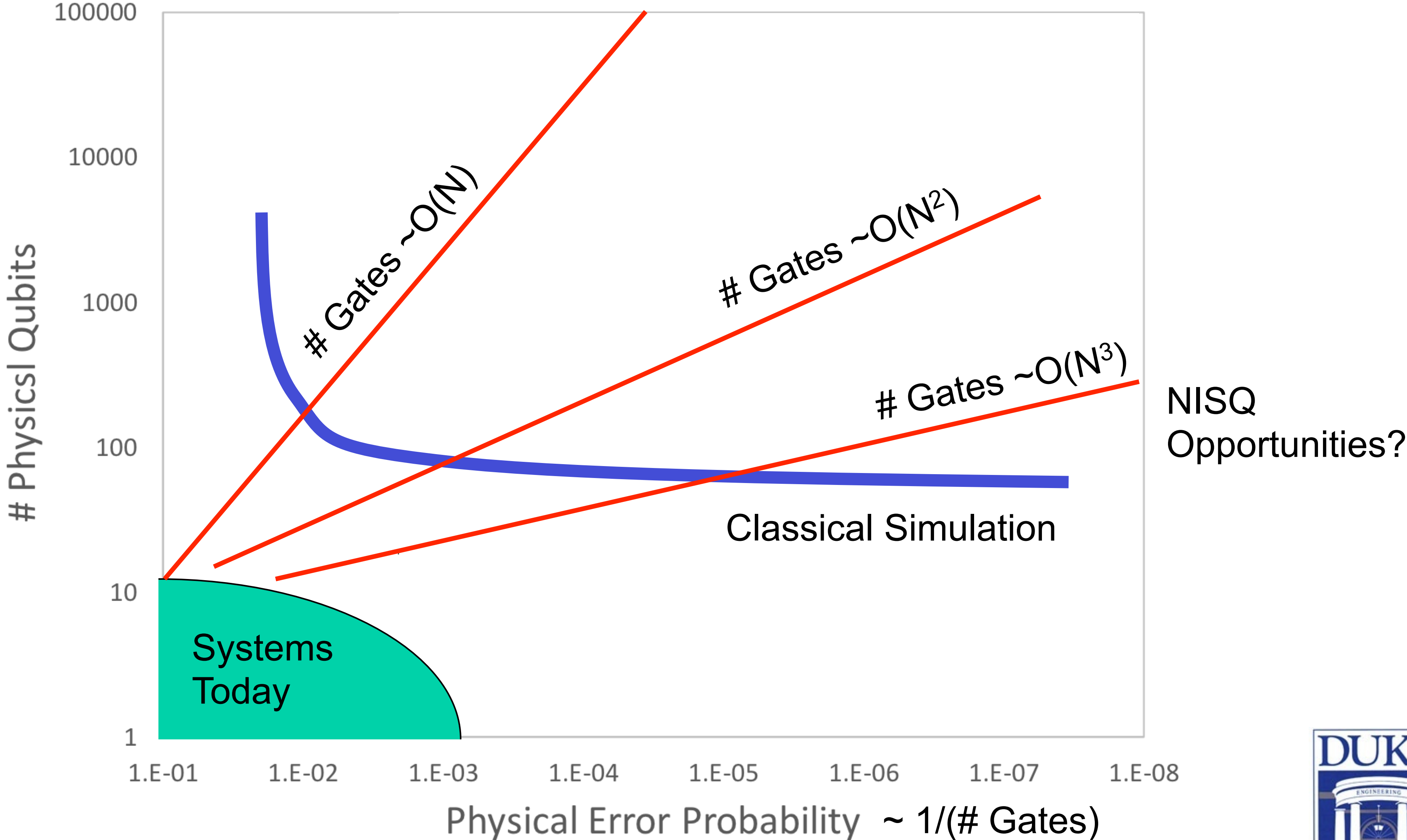
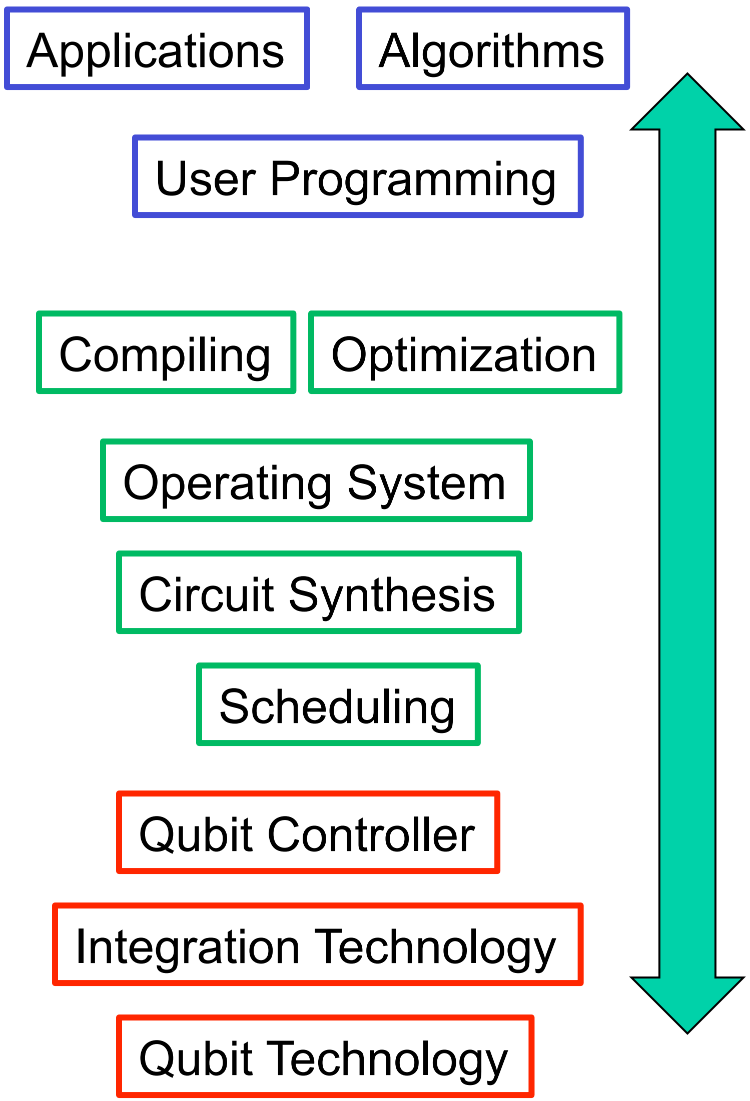


Javadi-Abhari thesis, Princeton Univ. (2017)

Opportunities for New Research



- How do we make this all work?
- What hardware is needed to make it happen?
  - Cross-cutting topics
  - Co-design opportunities
  - Abstraction layers?
  - Circuit optimization
  - Architecture optimization
  - System design
  - Connectivity of qubits
  - Quantum control