SAND2021-10009PE

Quantum computing

Where we are now, & where we're headed

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August 17th, 2021

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Quantum computing: where we are now

TECH & SCIENCE

Will quantum computing become the next space race?

By Dr. Tim Sandle Published July 1, 2021

Vinod Vaikuntanathan, Chief Cryptographer, Duality Technologies
August 23, 2019

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Quantum computing: The new moonshot in the cyber space race

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China Is Pulling Ahead in Global Quantum Race, New Studies Suggest

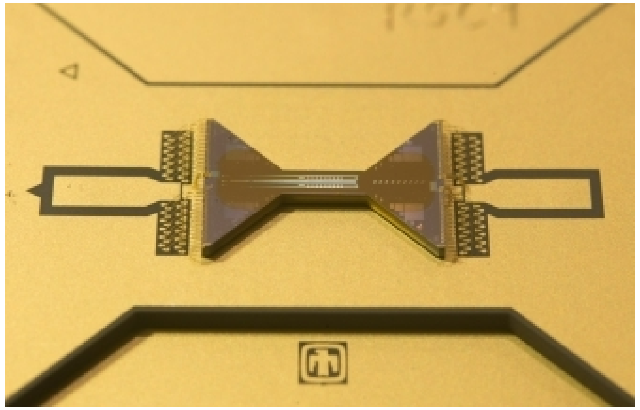
Quantum computing: where we are now

Devices are available, spanning different institutions & hardware platforms

- Trapped ions
- Superconducting circuits

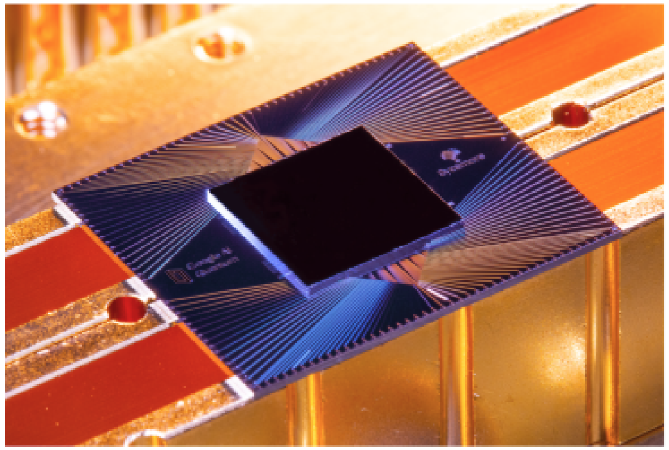
Noisy, intermediate-scale quantum or "NISQ"

Preskill, *Quantum*, **2**, 29 (2018)



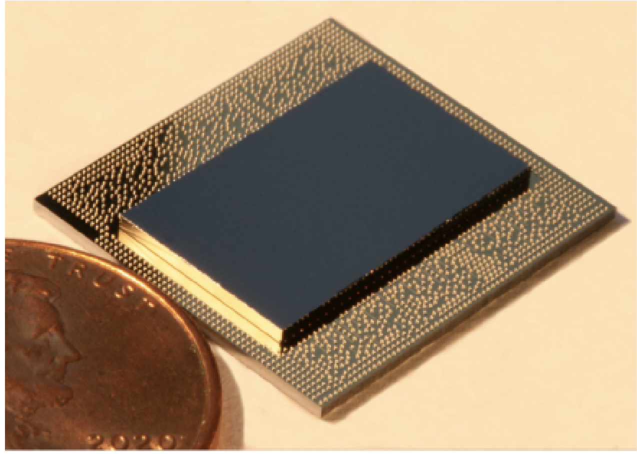
Sandia's Quantum Scientific Computing Open User Testbed (QSCOUT)

https://www.sandia.gov/quantum/Projects/QSCOUT.html



Google Sycamore processor

Arute et. al., *Nature*, **574** (2019)



IBM Quantum Falcon processor

Jurcevic et. al., *Quantum Sci. Technol.*, **6** (2021)

What can we do with them?

Quantum computing: where we are now

Article | Published: 23 October 2019

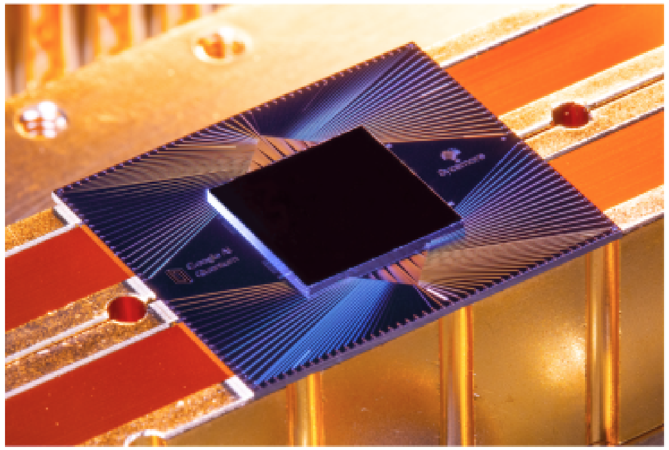
Quantum supremacy using a programmable superconducting processor

Frank Arute, Kunal Arya, […]John M. Martinis

Nature **574**, 505–510 (2019) | Cite this article

844k Accesses | **1025** Citations | **6066** Altmetric | Metrics

"Our largest random quantum circuits have 53 qubits, 1,113 single-qubit gates, 430 two-qubit gates, and a measurement on each qubit, for which we predict a total fidelity of 0.2%."



Arute et. al., *Nature*, **574** (2019)

Google Sycamore processor

54 qubits

(53 used)

Sampled from a probability distribution a million times in 200 seconds

The same calculation on a classical computer would take orders-of-magnitude longer

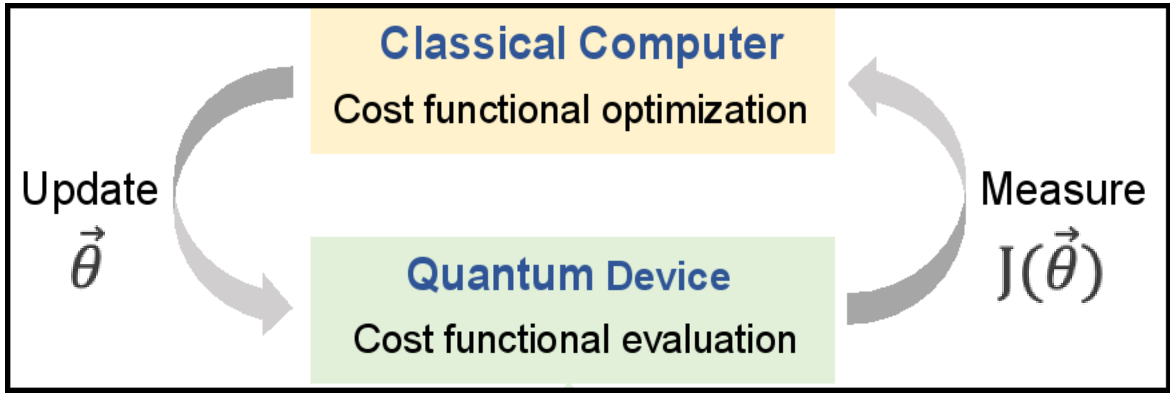
- Google estimated it at 10,000 years
- The problem was contrived for the demonstration

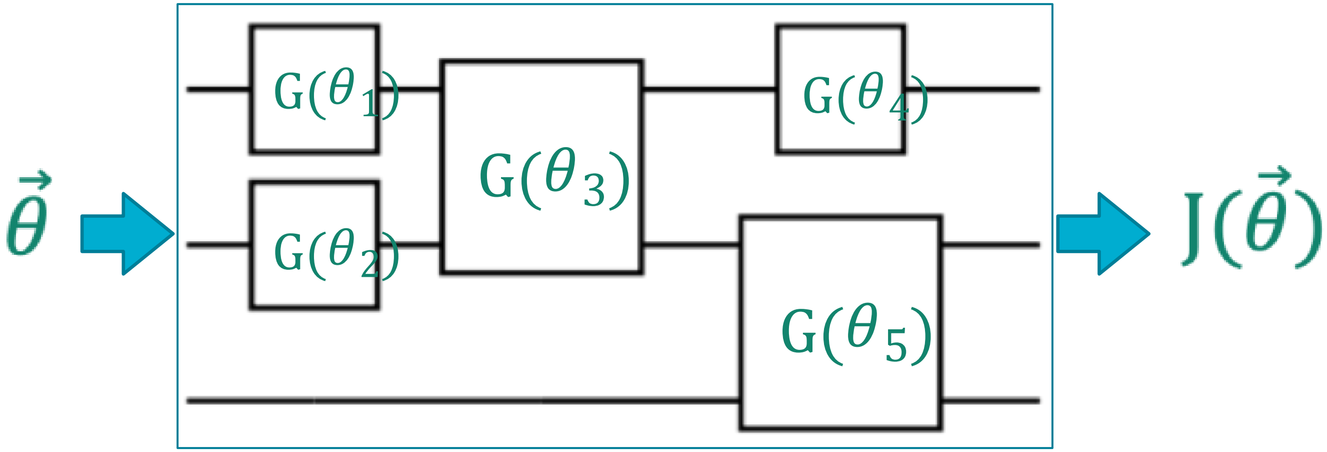
What can we do with them that is practically useful?

Quantum computing: where we're headed

What can we do with them that is practically useful?

Hybrid quantum-classical algorithms



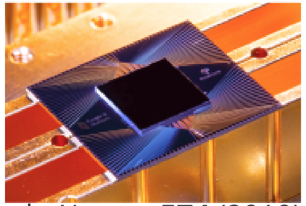


- Define objective function $J(\vec{\theta})$
- Hope is that we can calculate/minimize $J(\vec{\theta})$ easier with a quantum device
- Classical computer iteratively searches for $\vec{\theta}$ to minimize $J(\vec{\theta})$
  - Evaluation of $J(\vec{\theta})$ is done by calling quantum device

Quantum computing: where we're headed

What can we do with them that is practically useful?

Hybrid quantum-classical algorithms



Arute et. al., *Nature*, **574** (2019)

Variational Quantum Eigensolver (VQE)

Peruzzo et. al., *Nat. Comm.*, **5** (2014)

- Find ground states of chemical systems
  - Quantum chemistry

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Hartree-Fock on a superconducting qubit quantum computer

Google AI Quantum and Collaborators*,†, Frank Arute, Kunal Arya, Ryan Babbush, Dave Bacon, Joseph C. Bardin, R

Quantum Approximate Optimization Algorithm (QAOA)

Farhi, Goldstone, Gutmann, arXiv:1411.4028 (2014)

- Find approximate solutions of combinatorial optimization problems
  - Routing and timing problems

Article | Published: 04 February 2021

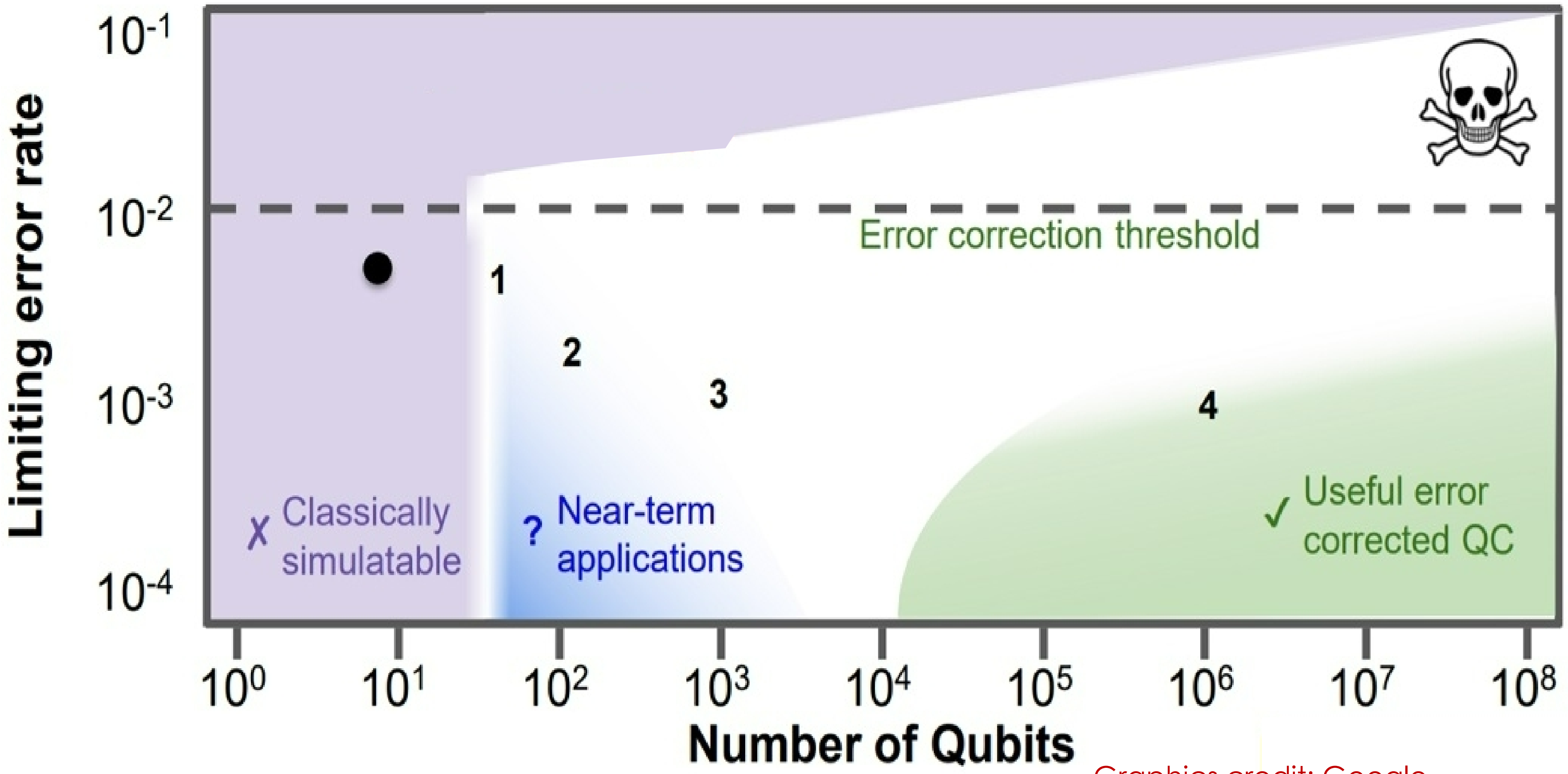
Quantum approximate optimization of non-planar graph problems on a planar superconducting processor

Matthew P. Harrigan, Kevin J. Sung, […]Ryan Babbush

Nature Physics **17**, 332–336 (2021) | Cite this article

Quantum computing: where we're headed

Fault-tolerant quantum computing

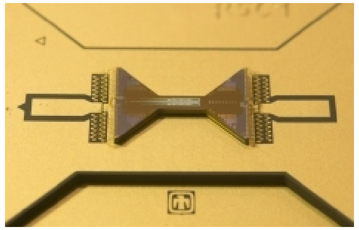


Graphics credit: Google

Quantum computing: Sandia

Some examples of quantum computing research at Sandia:

- Quantum transduction and networking
- DOE quantum testbed based on trapped ions



QSCOUT

- Quantum programming languages

JAQAL

- Quantum device characterization methods

pyGSTi

QPL

- Quantum algorithm design and analysis

OVER-QC

FAR-QC

Thank you