Quantum Information Science and the Technology Frontier

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February 5th, 2020

Office of Science and Technology Policy

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Photo credit: Lloyd Whitman

The National Quantum Initiative

Signed Dec 21, 2018

11 years of sustained effort

DOE: new centers working with the labs, new programs

NSF: new academic centers

NIST: industrial consortium, expand core programs

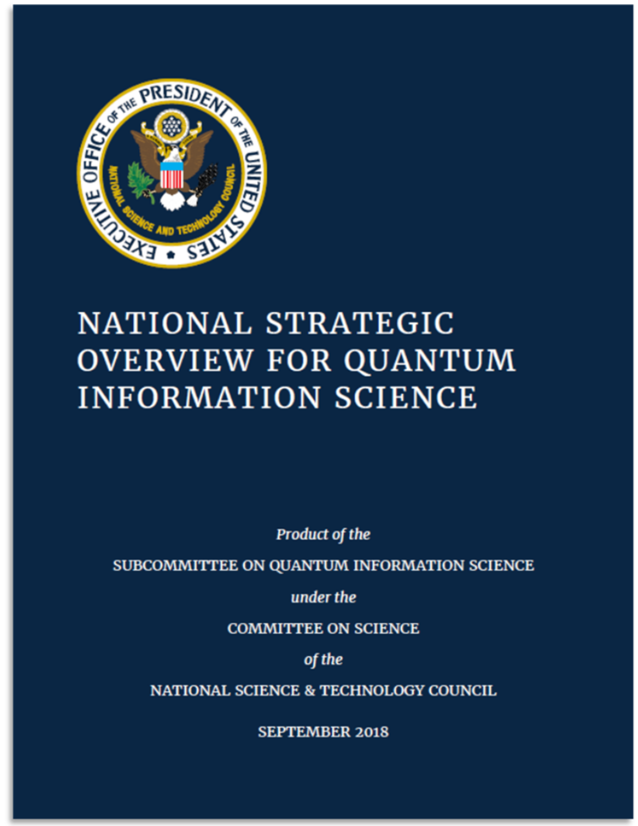
Coordination: NSTC combined with a National Coordination Office and an external Advisory committee

National Science and Technology Council

- Subcommittee on Quantum Information Science (SCQIS)
  - DoE, NSF, NIST co-chairs
  - Coordinates NQI, other research activities
- Subcommittee on Economic and Security Implication of Quantum Science (ESIX)
  - DoD, DoE, NSA co-chairs
  - Civilian, IC, Defense conversation space

Policy Recommendations

- Focus on a science-first approach that aims to identify and solve Grand Challenges: problems whose solutions enable transformative scientific and industrial progress;
- Build a quantum-smart and diverse workforce to meet the needs of a growing field;
- Encourage industry engagement, providing appropriate mechanisms for public-private partnerships;
- Provide the key infrastructure and support needed to realize the scientific and technological opportunities;
- Drive economic growth;
- Maintain national security; and
- Continue to develop international collaboration and cooperation.

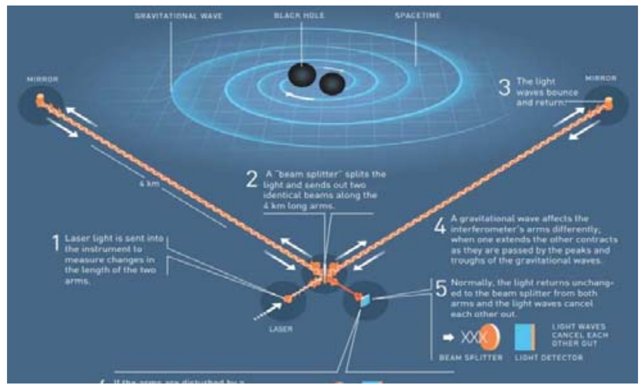


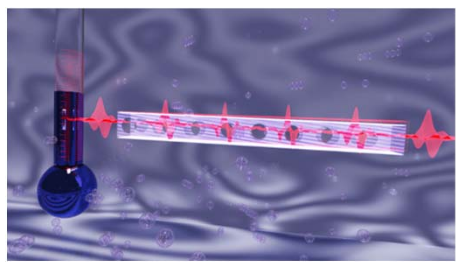
Quantum Sensing

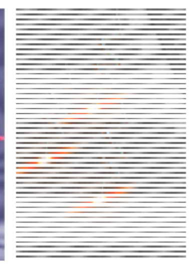
Accuracy via physical law
Concept: atoms are indistinguishable. Use this to create time standards, enables global navigation.

Concept: speed of light is constant. Use this to measure distance using a time standard.

Concept: electrons are quantized, have the same charge. Use this to calibrate electrical currents and voltages.







New modalities of measurement
Challenge: measuring inside the body. Use quantum behavior of individual nuclei to image magnetic resonances (MRI)

Challenge: estimating length limited by 'shot noise' (individual photons!). Use quantum correlations between photons to reduce this noise (LIGO v3)

Challenge: measuring brain activity must be fast, sensitive. Use entanglement between magnetic sensors to increase bandwidth

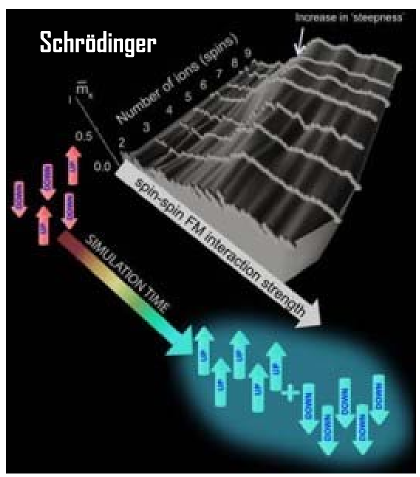
New worldwide approach: the Quantum SI, started May 2019

Quantum Computing

Quantum simulation
Chemistry, biology, materials science all depend on
solving quantum mechanics problems

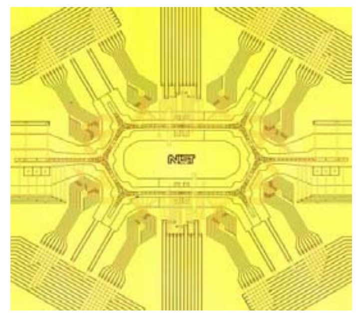
Recall: Simulating quantum mechanics is hard...

Solution: Use one system to simulate another

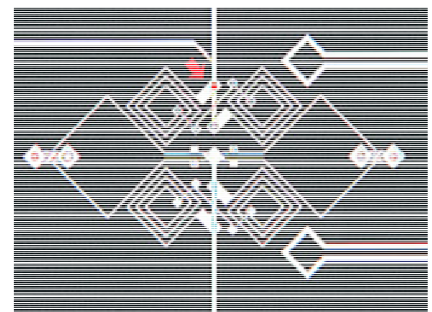


Quantum computation
Ideal case: programmable quantum computer, which is now moving from the lab to systems and engineering.

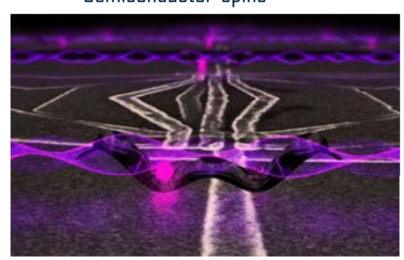
Atomic qubits

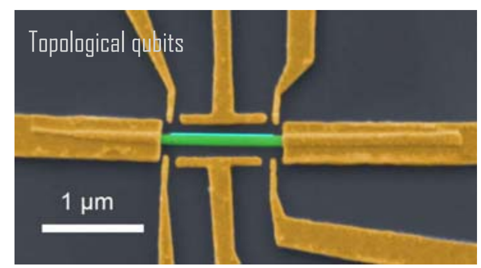


Superconducting qubits



Semiconductor spins





Quantum Networking

Quantum communication
Quantum key distribution,
and tons of enabling technology:
Sources, detectors, fibers, transducers, low-loss elements, improved engineering, new networking protocols and procedures

Quantum repeaters drive small-scale (5 qubit-ish) device growth, enable modular architectures.

Quantum internet of things
Internetworked sensors enable new measurement modalities and capabilities.

Many technological steps such as optical phase synchronization between distant clocks are goals in their own right.

Space-based systems can play critical roles in both comms and sensing.

Quantum^2 cloud computing
Distributed quantum computing:
* quantum error correction (inside data center)

* interactive proofs (MIP*=RE ☺)

* homomorphic computing

And more???

NSF 2019 workshop on quantum interconnects,
Loncar, Marko, Michael G. Raymer, et al "Development of Quantum InterConnects for Next- Generation Information Technologies." arXiv preprint arXiv:1912.06642 (2019).

Department of Energy ASCR Workshop Report,
Thomas Ndousse-Fetter, Warren Grice (ORNL), Prem Kumar (Northwestern), et al. "Quantum Networks for Open Science," 2019, https://info.ornl.gov/sites/publications/Files/Pub124247.pdf

Key Steps Today?

- Technology development (classical): sources, detectors, interconnects, space-to-ground, classical networking, cybersecurity
- Quantum signal routing: transduction, processor-photon interconnection, teleportation-based gates
- Entanglement generation: rate, frequency, distance, measurement, characterization, application
- Quantum memories and quantum repeaters: system integration of small scale computers, memories, and optical or microwave qubits that travel.
- Algorithms and applications, from QEC to Q^2C

National Opportunities?

- Five year horizon:
  - demonstrate foundational science and technology for entanglement distribution, quantum repeaters, and entangled sensor systems
  - Get to intercontinental distances (space-based) and multi-hop (ground-based)
  - Develop new applications and protocols, and classical technology, to show viability for economic and security benefits of a quantum internet
- Twenty year horizon:
  - Quantum internet links enable mission critical function at companies and in the Government.
  - Advanced understanding of protocols changes mathematical and information theoretic understandings of physical theory.

Quantum Industry and the Frontier

- Current quantum technology: atomic clocks, nuclear magnetic resonance, modern telecom, LIGO
- Next generation quantum?
  - Improved computational approach to materials, chemistry
  - Novel networking applications and security approaches
  - New understanding of optimization, machine learning
  - Spin-offs: Quantum random number generators, QKD, sensing modalities, PNT, qubit technologies, analog microwave and optical technologies
- The 10 year outlook?
  - The beginnings of a sea change for corporations and government – the need to incorporate quantum computing and technologies into their business model
  - Unimagined applications are around the corner, but only if we explore!

FORTUNE

U.S. CTO: How America Achieved 'Quantum Supremacy'

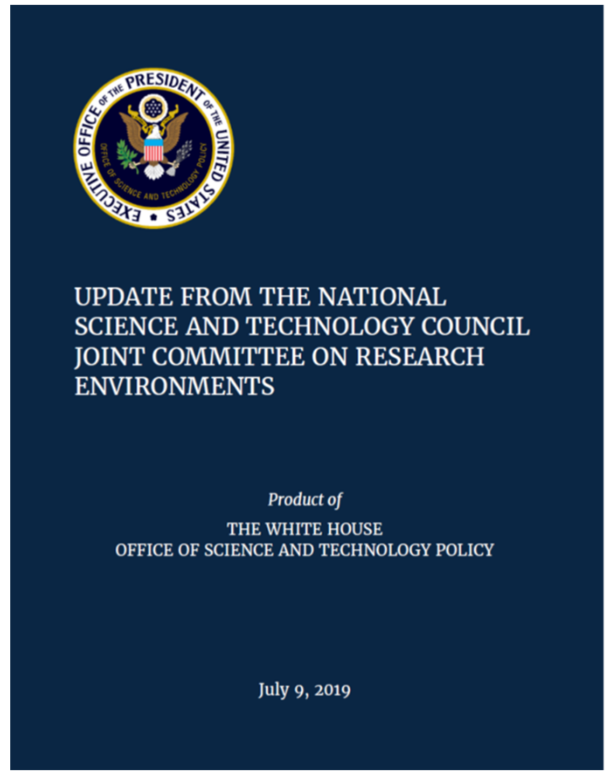
COMMENTARY • QUANTUM COMPUTING

U.S. CTO: How America Achieved 'Quantum Supremacy'

By Michael Kratsios October 23, 2019

Building the Research Environment for Transformative Quantum Science

- **The quantum workforce?** Need more people, from a broader set of backgrounds; requires a safe and inclusive work environment.
- **Science-first approach?** Need to maintain an open, rigorous approach to the research.
- **Connecting science to society?** Must continue to balance innovation and disruption, from industry to security to citizens.
- **Efficient and effective?** Leverage existing approaches, minimize administrative burden, nurture a culture of discovery, and enable responsible risk-taking.


UPDATE FROM THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL JOINT COMMITTEE ON RESEARCH ENVIRONMENTS

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THE WHITE HOUSE
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

July 9, 2019

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