The Quantum Questions

POSTED ON DECEMBER 3, 2020

Roughly each month I write "from" a different research center about the NQCO's progress coordinating Quantum Information Science (QIS) activities. Learn more about the Q-SEnSE Quantum Leap Challenge Institute by going to https://www.colorado.edu/research/qsense/

This summer, the White House Office of Science and Technology Policy (OSTP) joined the National Science Foundation (NSF) to announce three new Quantum Leap Challenge Institutes (QLCI), representing $75 million more funding in support of the National Quantum Initiative. These centers will explore fundamental questions in quantum sensing, quantum networking, and quantum computing. The NSF *Quantum Systems through Entangled Science and Engineering* (Q-SEnSE) QLCI, with its hub at the University of Colorado Boulder, will push the frontiers of sensing.

Quantum information science unifies concepts from quantum mechanics and information theory, the two foundational theories underpinning modern information technology. Quantum mechanical objects, like an atom, can behave as if they are in two or more places at once, even though they are really in a single quantum "state." This property is called *quantum superposition* and enables highly accurate clocks and precise sensors. The Global Positioning System, which has unquestionably affected our society, relies on atomic clocks.

Quantum mechanics also allows for *quantum entanglement*. Here, two atoms can be correlated no matter their distance apart. We know far less about how entanglement will benefit quantum sensing. This is a scientific and engineering frontier to explore and faces many open and challenging questions. As such, it is a perfect research topic for the National Science Foundation (NSF) to fund. NSF's mission is to broadly promote progress in science [1].

Science policy is the responsibility of many organizations throughout the Federal Government. Executive branch agencies and Congress must work together. Agencies spend funds allocated by Congress and implement science programs according to their own missions (which are all different) and in their own funding models. Bodies within the Executive Office of the President, such as OSTP, where I work, provide advice to the President, set budget priorities, and serve as mechanisms for coordination and policy setting. Congress, primarily through their own committees, provides funding and oversight.

This federal, decentralized approach to science funding has worked extremely well over the last 75 years. There is no one body that controls all the funding for QIS. There is no quantum czar. And coordination is not meant to be easy. The National Quantum Coordination Office (NQCO) is one of only four legislated national coordination offices, which is an indication of the importance of QIS. I want to thank my colleagues here in the coordination office, Alex Cronin, on detail from NSF as our Senior Program Coordinator, and Corey Stambaugh, on detail from the National Institute of Standards and Technology as our Industry Liaison. Our office only works because amazing people like them (and you) are willing to serve. So please consider doing a tour in the coordination office, or at another science agency. You can have tremendous impact!

At the Q-12 kickoff event in October, the NQCO launched Quantum.gov and released the Quantum Frontiers Report, an intelligent compilation of the hundreds of pages of community responses (through two formal Requests For Information) and over three dozen reports and workshops that were held by Agencies in response to the National Strategic Overview for Quantum Information Science and the National Quantum Initiative Act. All this input, in multiple venues, from U.S. and world-wide technical experts, has been collated in this document into eight technical areas which we call the *Quantum Frontiers*. Within each frontier you can find the "quantum questions" that should be answered first: the hard, technical challenges that must be overcome before you can develop applications, and even the need for new applications themselves.

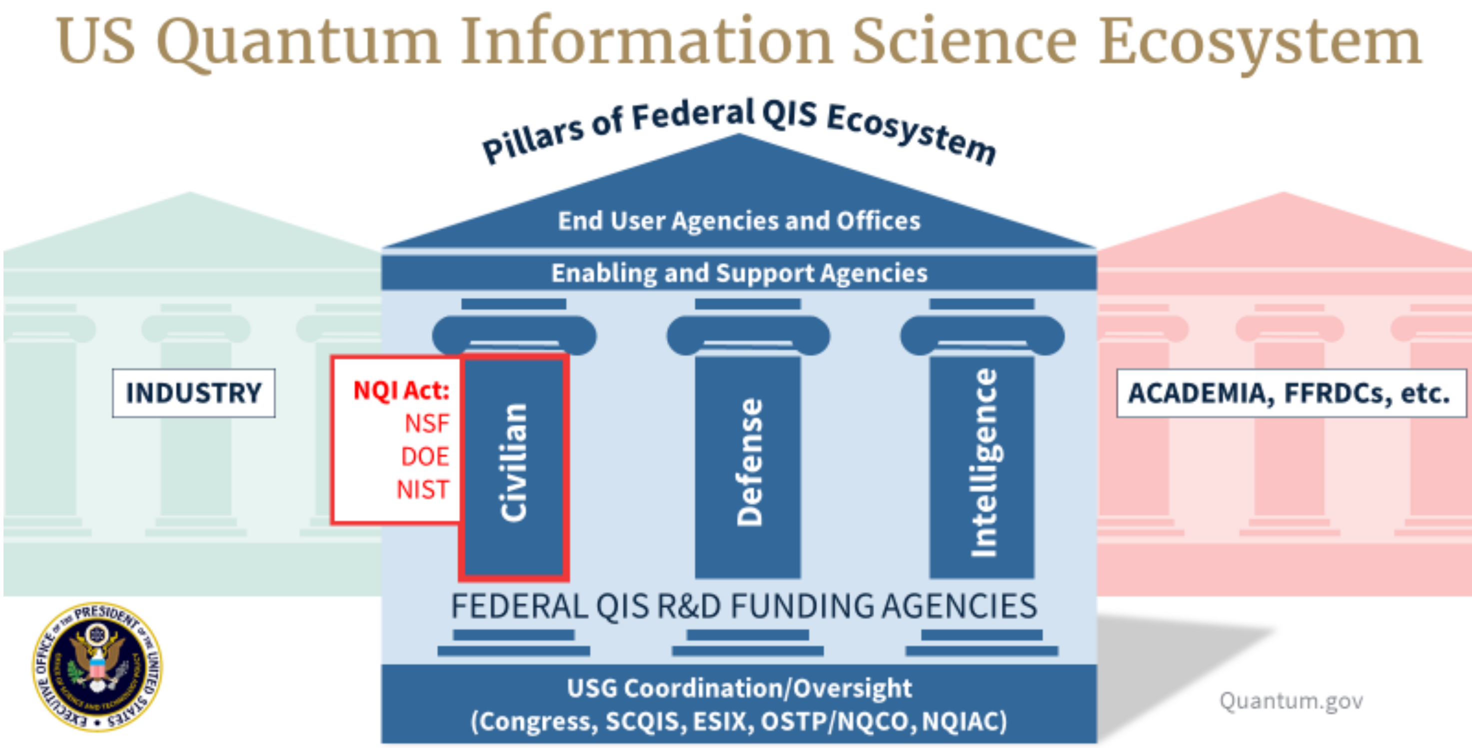
What are these grand challenges facing QIS? The answer to that depends on each agency's mission and objectives. The breadth of responses and detail of R&D pursuits laid out in the RFI and the various QIS workshop reports provide new opportunities for research agencies to fund and pursue. Ensuring sustained American leadership in this field hinges on coordinating core research programs across the U.S. QIS ecosystem. For each mission, the grand challenges may be different, but there are common hurdles across all where coordination can have big benefits.

Can we find a useful application for quantum computers we can build in the next 5-10 years? How good can qubits get? Why should I build a large quantum entanglement distribution network? Are there surprises lurking in the nature of quantum errors that would make building a quantum computer even more difficult than we think? Five years from now, halfway through the NQI Program, we need answers to some of these questions.

Many thanks to the University of Colorado Boulder's Q-SEnSE center for hosting us this month. The Q-SENSE team of 37 researchers, from 11 institutes located in 6 different states and one collaborating from Europe, will tackle a deeply scientific question at the heart of quantum information: does quantum entanglement, not just superposition, provide an advantage for quantum timekeeping, sensing, or measurement? Remember, being a scientist means asking a question that you don't know the answer to (or may not want a negative answer to). Let me give you a sense of how far they will reach to answer these questions. Some of the best clocks, like those made by NIST at their joint lab (JILA) with the University of Colorado Boulder, reach accuracies of a small fraction of 10^{18}. That means that *over the age of the Universe*, they may be wrong by one second. Q-SEnSE may make "10^{-20}" clocks possible. Clocks like that can potentially measure such small changes in fields or laboratory environments so as to predict future earthquakes and enable fundamental discoveries about nature, such as searching for dark matter and detecting gravitational waves. That goal may not be easy either, but it sounds like a great quantum question.

Charles Tahan is the Assistant Director for Quantum Information Science at the White House Office of Science and Technology Policy and Director of the National Quantum Coordination Office.

[1] The NSF Statutory mission: *To promote the* ***progress*** *of science; to advance the national health, prosperity, and welfare; and to secure the national defense; and for other purposes. Vision:* NSF envisions a nation that capitalizes on new concepts in science and engineering and provides global leadership in advancing research and education. https://www.nsf.gov/pubs/2014/nsf14002/pdf/02_mission_vision.pdf



The United States QIS Ecosystem. The three pillars of Federal support for QIS R&D include the civilian science agencies highlighted in the National Quantum Initiative (NQI) Act along with the Department of Defense and the Intelligence Community. Success depends on government, industry, and academia working together. Find out more at https://quantum.gov/

POSTED IN CENTERS, NQCO LETTERS, NQI