The U.S. National Quantum Initiative

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Recognizing the potential impact of quantum technology, the U.S. government has enacted legislation to coordinate and accelerate U.S. quantum research and development. This article provides an inside look at the National Quantum Initiative Act and current U.S. quantum policy.

Over the past few years, the quantum fields have begun to move from theory toward practice. We have seen substantial progress in quantum computing, cryptography, communication, clocks, and sensors. An ecosystem of quantum companies is developing, building on research from universities and national labs and working in partnership with some of the world's largest IT companies to advance and commercialize quantum research and development.

As quantum technologies advance, they offer some interesting opportunities to support national security, but they potentially threaten it as well. In the relatively near term, quantum clocks and sensors will be able help the U.S. military navigate in the event that an adversary disrupts or destroys the GPS system. In the medium term, quantum cryptography and quantum communication will be able to help both the United States and its adversaries protect sensitive messages. In the long term, a universal quantum computer has the potential to break most forms of encryption currently in use, putting at risk all sorts of sensitive military and civilian information.

Similarly, quantum technologies may potentially have profound economic impacts. As part of a cloud-based computing toolkit, quantum computers may be able to help companies, researchers, and governments answer questions that traditional computers cannot. Among the most promising applications are drug development, logistics, and traffic optimization. Quantum communication and postquantum cryptography could form the next defensive weapons in the never-ending battle for cybersecurity.

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FROM THE EDITOR

As the readers of this periodical know, quantum computing has made substantial strides during the past decade. A recent special issue of *Computer* (June 2019) discussed the practical accomplishments of the field and its prospects for the future. To put some of those actions in a bigger context, we thought it would be useful for our readers to understand some of the work that is being done in Washington, D.C., to support and develop quantum technology. As a result, we asked one of the industry leaders, K&L Gates partner Paul Stimers, executive director of the Quantum Industry Coalition, to describe the current state of quantum policy. The Quantum Industry Coalition is a trade association, a group that represents the new quantum industry to the U.S. Congress and the U.S. administration. Hence, this article gives an insider's view of the new government programs to support quantum research and development. As with all things that touch government and politics, this kind of support has the potential for stirring up diverse and conflicting opinions. Our intent here is not to debate the effectiveness or ineffectiveness of such government sponsorship of research but to give a description of the new quantum information programs to our readers, who may easily be involved in these programs, as quickly as possible. Any opinions in this article are held by the author and are not necessarily those of the IEEE, the Quantum Industry Coalition, or his law firm. —*David Alan Grier*

Amazon founder Jeff Bezos argues that it is still "day one" of the Internet. The Quantum Industry Coalition believes that it is still "hour one," and maybe only "minute one," of quantum computing and other quantum technologies. The June 2019 issue of *Computer* devoted to quantum realism addressed, in several respects, both the promise and the challenge posed by quantum technology. At this point, we cannot accurately predict which quantum technologies will be successful, what benefits they will bring, and how they will support a national security agenda. However, the potential impact of these technologies on both economic and national security activities is simply too great to ignore.

The rest of the world is not blind to the potential military and economic benefits of quantum leadership: the European Union, Canada, Australia, Israel, Japan, and other countries have made significant investments in quantum research and development during the past 20 years. No country is investing as heavily as China, however. China's public accomplishments—likely augmented by substantial secret efforts—are impressive. It has developed and demonstrated quantum key distribution via satellite (*Micius*, launched in August 2016) and ground-based quantum communications (the Quantum Beijing–Shanghai Trunk, in use since September 2017) and has announced that it will spend US$10 billion to build a National Laboratory for Quantum Information Sciences in Hefei.[1]

NATIONAL QUANTUM INITIATIVE ACT

Against this background, Congress acted quickly last year to codify a multiagency approach to accelerating and coordinating quantum research and development. The National Quantum Initiative Act (NQIA) was introduced in both the House and the Senate in June 2018 and passed by both bodies overwhelmingly in December 2018, at which point it was quickly signed into law by the president.[2] The speed with which it moved stemmed from a bipartisan, collegial drafting process, substantial stakeholder outreach, and a sense of urgency created by news of foreign achievements in the field.

The NQIA creates a central structure for the National Quantum Initiative (NQI) and authorizes three agencies—the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the Department of Energy (DOE)—to implement the bulk of the program. It authorizes up to US$1.275 billion for the NQI through five years.

Central structure

The act requires the president to implement a program to develop and advance quantum technologies. The outline for this program follows a model that was devised, in 2003, for the National Nanotechnology Initiative, a piece of legislation that was very effective at developing its technology. The quantum program will be based on a 10-year plan to accelerate the development of quantum information science and technology applications in the United States. It will expand quantum research through new investment; increase efforts to provide the training and education needed to build a workforce skilled in quantum; create an interagency process to coordinate the activities of the different federal agencies, liaise with industry, and leverage existing federal investments such as the national laboratories; and create a network of quantum centers throughout the country.

National Quantum Coordination Office

At the center of the NQI is the National Quantum Coordination Office that will be housed in the White House Office of Science and Technology Policy. This coordinating office will act as a hub for all civilian federal quantum activities and a point of connection between federal and nonfederal quantum activities. It will coordinate the NQI's efforts; conduct public outreach; and promote access to and the application of quantum research, technologies, innovations, and resources. Although the 2018–2019 government shutdown slowed its initial formation, the office is staffing up and getting underway.

Subcommittee on Quantum Information Science

The NQIA requires the administration to form the Subcommittee on Quantum Information Science (SCQIS) within the National Science and Technology Council, a cabinet-level group that coordinates scientific research within the federal government. In anticipation of this legislation, the Trump administration moved to create such a subcommittee early last year, putting it under the council's Committee on Science. That step elevates quantum research to the highest levels of national interest.

The SCQIS has members drawn from across the government, including the U.S. Department of Defense (DOD) and the Office of the Director of National Intelligence. Its cochairs are delegates from the DOE, NIST, NSF, and the White House Office of Science and Technology Policy. In autumn 2018, the SCQIS produced its first report, which argued for a "science-first approach" that would start by supporting research, building a workforce, and working with industry. It proposed a grand-challenges approach to research, focusing on "fundamental scientific or technology problems with answers that will be transformative" for the nation and have "broad economic and scientific impact."[3]

The National Quantum Initiative Advisory Committee

The NQIA requires the president to create the NQI Advisory Committee. This group has a somewhat different mission from the SCQIS, as it is intended to include representatives from industry, universities, and federal laboratories who are qualified to provide advice and information on quantum information science and technology research and development, demonstrations, standards, education, technology transfer, commercial application, and national security and economic concerns. It reviews the trends in research and industry and identifies opportunities to improve the NQI. It is required to report to the president and Congress every six months. Although the White House announced, in spring 2019, that the committee would be formed, convening the body required further executive action. The president signed an executive order on 30 August establishing the advisory committee, with membership including the director of the Office of Science and Technology Policy and up to 22 experts appointed by the Secretary of Energy.[7]

FEDERAL AGENCIES

The NQIA requires three agencies to take specific roles in developing policy and promoting research: NIST, the NSF, and the DOE. It creates two new kinds of institutions: multidisciplinary centers for quantum research and education (under NIST) and quantum information science research centers (under the DOE).

NIST

Giving a central role to NIST is not a surprising decision as the agency has been engaged in quantum research and development for more than a decade, and it produced a report, in 2009, that has guided government policies to this point. The NQIA gives NIST three roles that are traditionally within its mandate. First, it requires NIST to deal with measurement issues by supporting and expanding the "research and development of measurement and standards infrastructure necessary to advance commercial development of quantum applications."[2] [See Sec. 201(a)(1).] Second, it requires NIST to use its existing programs to help train quantum scientists and expand the quantum workforce. Third, it requires NIST to establish or expand collaborative ventures with industry and other government agencies. This approach proved effective for nanotechnology and is expected to have similar results for quantum information technology.

The NQIA also requires NIST to convene a quantum consortium of stakeholders to identify the future measurement, standards, cybersecurity, and other appropriate needs for supporting the development of the U.S. quantum information science and technology industry. The act authorizes up to US$80 million per year through fiscal year 2023 for NIST's activities, including the consortium. NIST began this work by partnering with SRI International, Menlo Park, California, to create the Quantum Economic Development

Consortium (QEDC). The QEDC met for the first time in October 2018 and has been holding regular stakeholder meetings and workshops. It started with approximately 25 members, including several of the large computing firms, and has been growing since then.[4]

The NSF

The NQIA gives the NSF the natural role of developing research programs and supporting graduate education in the quantum information sciences. The NQIA requires the NSF to carry out a basic research and education program on quantum information science and engineering, which includes awarding competitive grants to universities, nonprofits, and consortia to support basic interdisciplinary quantum research and promote human resources development in all aspects of quantum information science and engineering. In particular, the act requires the NSF use its existing programs to

- use its existing programs to improve quantum education at the undergraduate, graduate, and postgraduate levels and increase participation in the quantum fields
- formulate goals for quantum science, research, and education activities to be supported by the NSF
- coordinate NSF research efforts
- engage with the rest of the government, research communities, and potential users of the information that the NSF produces.

In its 2020 budget request, the NSF asked for US$105 million for quantum information research programs.

Multidisciplinary centers for quantum research and education

Under the NQIA, the NSF is responsible for creating multidisciplinary centers for quantum research and education. The act requires the NSF to open between two and five such facilities. The NQIA authorizes up to US$10 million, out of existing NSF funding, per center per year through fiscal year 2023. The centers will be created through the common competitive process and likely be university based, although the legislation anticipates that there may be consortia of universities that include collaborators from the private sector. The centers are to conduct basic research and education activities to advance quantum science and engineering; support curriculum and workforce development; and leverage industry perspectives, knowledge, and resources. The centers will be authorized for a five-year term with five-year renewals and may be terminated for cause if they underperform.

The DOE

The DOE is also a natural contributor to the NQI. It has a long history of supporting high-performance computing, and its laboratories, such as Sandia National Laboratories, have conducted some of the fundamental research on quantum information. The NQIA requires the DOE to carry out a quantum information science research program. This basic research program will formulate DOE quantum information science research goals, provide research experiences and training for undergraduate and graduate students, coordinate research across existing DOE programs, and engage with the rest of the government, research communities, and potential users of the information the DOE produces.

National quantum information science research centers

To support its basic research, the DOE will create the second form of new research entity, the national quantum information science research centers. In parallel with its requirements for the NSF, the NQIA requires the DOE, through its Office of Science, to establish and operate at least two and as many as five of these centers to conduct basic research to accelerate scientific breakthroughs in quantum information science and technology and support research conducted by the DOE. Some of the existing projects at DOE labs may form the core of the new centers. The NQIA states that the centers are to coordinate with other DOE initiatives, including the nanoscale science research centers, energy frontier research centers, energy innovation hubs, and national laboratories as well as with higher education and industry. As with the NSF centers, DOE centers will be authorized for a five-year term with five-year renewals and may be terminated for cause if they underperform. The NQIA authorizes up to US$25 million per center per year through fiscal year 2023, taken out of DOE funding.

OTHER U.S. QUANTUM WORK

Of course, the United States is not new to the field of quantum technology. Richard Feynman discussed the possibility of quantum computing in his famous 1959 lecture "There's Plenty of Room at the Bottom."[5] Throughout the 1980s, Feynman and others advanced the science and promoted the idea of building quantum computers. In 1994, Peter Shor described an algorithm for factoring large numbers—thereby breaking many of the cryptography systems currently in use—using a quantum computer.

NIST and the DOD held their first quantum information workshops in the mid-1990s. Two NIST partnerships, the Joint Institute for Laboratory Astrophysics and the Joint Quantum Institute, have been doing quantum research since the 1990s and 2000s, respectively. Several of the national laboratories have ongoing quantum research programs. The first mention of quantum information science in the U.S. budget was in 2008 when it was included in the Networking and Information Technology Research and Development Program, under the National Science and Technology Council.

It is widely understood that the DOD and the intelligence community have conducted quantum research for years and that some portion of the research is classified. The 2019 National Defense Authorization Act established a defense quantum information science and technology research and development program to coordinate and accelerate the DOD's quantum research and development efforts.[6] The program was designed to develop and manage a balanced portfolio of fundamental and applied quantum research and transition that research into deployable technology. This year's National Defense Authorization Act is expected to expand the DOD's quantum capabilities further as both the House and Senate have passed versions of the bill that include quantum language supported by the Quantum Industry Coalition. If enacted, the language will enable the DOD to coordinate closely with the civilian elements of the NQI as well as with industry, academic institutions, and national laboratories.

PRINCIPLES FOR FEDERAL ACTION

Our organization, the Quantum Industry Coalition, is designed to represent the American quantum information industry to Congress and the administration and present the industry's point of view to both of those bodies. The coalition strongly supports the NQIA because its members believe that quantum information technology is an important field of research that has the potential to expand the U.S. economy and promote national security and that U.S. leadership in the field is vitally important.

> THE NQIA IS A STRONG PIECE OF LEGISLATION THAT IS LIKELY TO SUCCEED.

We believe that the NQIA is a strong piece of legislation that is likely to succeed. First, it follows the examples of other successful programs, such as the National Nanotechnology Initiative. Second, it follows a set of key principles in American science policy that have been tested and proven to be effective. The members of the coalition believe—as do many across industry, academia, and professional societies—that federal action to promote U.S. quantum leadership should have the following characteristics:

- *Set broad goals for quantum research and development*: These should not be imposed top-down by the government but should develop out of an ongoing discussion among industry, academic, civilian government, and military stakeholders. The goals should focus on results that help strengthen the U.S. economy and national security.
- *Exchange information*: Compiling and sharing nonsensitive information about public- and private-sector research and development will enable the government to assess progress toward goals and minimize gaps and overlaps. Participation should be voluntary. Steps should be taken to avoid collecting sensitive information and protect any such information that is collected.
- *Accelerate research and development toward usable results*: Clear objectives and information about current efforts should enable the federal government to direct increased funding toward a balanced mix of fundamental and translational research efforts that will yield usable technology in the medium term as well as advancing quantum science in the long term.
- *Advance U.S. national security*: Only by harnessing the capabilities of a strong and diverse quantum economy will the United States be able to win the national security quantum race. Excessive or unwieldy secrecy and export control requirements will stifle U.S. quantum research

and development while spurring innovation overseas.

- *Promote workforce development*: American quantum companies need to have access to a pool of qualified American workers. Educational institutions should be incentivized to respond to projected industry demand.
- *Work with U.S. allies as appropriate*: American leadership does not need to exclude other countries. Many of our closest allies are home to leading companies and research institutions in the field that can help advance U.S. priorities in partnership with industry.
- *Avoid common pitfalls*.
    - *Mandating specific technologies*: It is too early to know which technologies will pan out, and the federal government should not play that role at any point.
    - *Picking winners and losers in the marketplace*: The government should maintain a level playing field and let competition determine who wins and loses.
    - *Crowding out private-sector investment*: The government should leverage private-sector investment, not compete against it.
    - *Excessively controlling technology*: Over-classification and stringent export controls will merely push development overseas while slowing it in the United States.

Some of the United States' strongest international competitors have shown a willingness to commit large amounts of money and large numbers of people to this race and back those commitments with a cohesive strategy, an aggressive industrial policy, and a convenient disrespect for intellectual property law. The United States cannot take that approach, and even if it could, it would not do so as well as its competitors. Instead, it must focus on executing the approach that has worked so well before: free inquiry, free enterprise, cooperation, coordination, and investment. If the United States is able to lead the way in quantum technology, the value to the country and the world could be tremendous. ◼

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