Building the Foundations for Quantum Industry

Report prepared by J. Bienfang, Z. Eldredge, A. Peng, J. Porto, K. Srinivasan, J. Taylor, and C. Williams.

Executive Summary

Groundbreaking advances in our ability to control quantum systems have the potential to revolutionize medicine, manufacturing, artificial intelligence, and national defense. In October 2017, "Building the Foundations for Quantum Industry," an event hosted by the National Institute of Standards and Technology (NIST), brought together stakeholders from government, industry, and academia to consider the challenges and opportunities in quantum information science (QIS). This report overviews the identified challenges to scientific and industrial research and development, and compiles those ideas that can facilitate the future development of a robust quantum ecosystem for quantum technologies. One recurrent theme was the potential use of a consortium as a means to address some of the community-wide challenges and facilitate cooperation among the disparate stakeholders. Given the identified changes in the field towards deeper industrial engagement, immediate action can enable a healthy, long-term-focused ecosystem.

Event Overview

Attendees (see appendix) comprised both large cap and small cap quantum companies as well as many suppliers and OEM-oriented members plus government and academic thought leaders. Discussions focused on quantum sensing, quantum networking and communication, and quantum computation. Overview talks in the morning were followed by breakout sessions in each of those three areas, followed by a reconvening to present considerations raised in the breakouts.

Challenges Identified

Participants noted that, as the field grows and industrial involvement expands dramatically, there exist many gaps in the existing organization and coordination efforts in quantum technology. A point raised several times focused on the lack of quantum engineering capabilities that enable U.S. researchers to more rapidly create, test, and validate potential platforms. A second obstacle presented was different approaches taken by different sub-industries with respect to intellectual property and cooperation within and between sectors. Coordination activities, including ad hoc discussion, regular workshops and mailings, and more formal consortia were suggested as a partial means of addressing these challenges by providing a forum for government, industry, and academic partners to come together.

A Quantum Consortium

A more detailed discussion on the solution space considered the benefits that formal coordination can provide. Many indicated that a quantum-focused consortium should be a trusted neutral party that allows industry to broadly interact with academia, national laboratories, government agencies, and business. Its preliminary objectives could include:

- Working with academia, national laboratories, and industry to do technology forecasting and identify gaps within the QIS ecosystem. This could include providing overall market guidance, in addition to roadmapping and planning what capabilities industry can deliver in a reasonable time frame.

- Providing an efficient mechanism for strong public-private sector coordination, as appropriate, via convening meetings and the creation of technical groups and consultative bodies, as well as exploring and establishing novel approaches to cooperative development and technology transfer.
- Identifying Grand Challenges for the QIS field to focus funding towards specific, industry-wide challenges and exploring truly transformative science and engineering relevant to academia, national laboratories, and/or industry.
- Identifying key technologies that if developed will allow stakeholders to make more rapid development, and consider means of encouraging research and development on those areas, including appropriate frameworks for intellectual property in the field.
- Examining the benefits and challenges of standards and benchmarks for different sub-fields and across disciplines.
- Identifying the workforce needs essential to the efficient development of quantum technologies. This includes providing input to academic institutions on the education and training needed to create a capable workforce with skills relevant to that particular sector of employment (i.e., industry, academia, or national laboratories).

A point of concern brought up several times was the timetable of the scientific and technical discourse, and at which point the field needs the aspects of coordination identified above. Opportunities for further discussions and platforms for maintaining open dialogue were highlighted as key areas for immediate consideration.

Other commentary indicated that a coordinating body would provide a valuable central organizational hub for the QIS field at-large. In addition to identifying important open questions and problems to be solved, such a group must be able to identify whether those problems are best addressed in an academic setting, national labs, or by industrial actors. A sector-wide collaborative body would be able to help mediate the government's efforts to fund quantum information research both by helping groups acquire and retain appropriate funding, by providing a resource to program managers for unbiased evaluation of the state of the art, and by identifying critical workforce and/or training shortfalls and means of addressing the same. Finally, a consortium or other collaborative body could also serve as a representative of the field at large, performing advocacy work and educating the public and policymakers on the potential impacts of quantum technology.

Conclusion

QIS technologies have the potential for huge impact, but the field currently lacks sufficient organization and coordination to implement long-term strategies for effective development. NIST can begin creating basic organizational tools that can form the groundwork for further collaborative work, such as establishing a means of coordination with industry. Coordination mechanisms would also provide a forum for government, industry, and academic stakeholders to come together and discuss challenges faced and provide potential solutions. NIST could continue to engage with a variety of stakeholders in other government agencies, industry, and academia, such as in an annual meeting like the one held in October 2017, and consider the formation of an industrial consortium to address these challenges.

Addendum: Concept for a Quantum Consortium[1]

Groundbreaking advances in our ability to control quantum systems have the potential to revolutionize medicine, manufacturing, artificial intelligence, and national defense. Continued U.S. leadership in quantum technology becomes less certain as other nations make significant investments in quantum programs and quickly gain ground. A key obstacle to making swift progress in the application of quantum information science (QIS) to both basic research and technology development is the lack of quantum engineering capabilities that enable U.S. researchers to more rapidly create, test, and validate potential platforms. This brief white paper describes how NIST proposes to address an approach to a *Quantum Information Science Collaborative Consortium* that together with Quantum Technology Centers should allow the U.S. to efficiently create the engineering and technological foundations for this nascent engineering field.

The quantum consortium should be a lean organization that allows industry to broadly interact with academia, national laboratories, government agencies, and business. Its preliminary objectives are:

- Work with academia, national laboratories, and industry to do technology forecasting and identify gaps within the QIS ecosystem. This should include providing overall market guidance
- Provide an efficient mechanism for strong public-private sector coordination as appropriate.
- Work with the QIS community to identify Grand Challenges for the QIS field and explore truly transformative device technology relevant to academia, national laboratories, and/or industry.
- Identify key technologies that if developed will allow academia, national laboratories, and/or industry to make more rapid development.
- Prioritize gaps, grand challenges, and key technology needs to allow improved government investments.
- Provide a forum for joint public-private funding of relevant gaps and key technologies. Such joint calls may support individual and multi-PI research efforts in addition to quantum technology centers focused on a broader technological capability.
- Explore and establish novel approaches to cooperative development and technology transfer between industrial partners, academic partners, and governmental partners, as well as useful and practical structures to facilitate rapid technological development.
- Identify the work force needs essential to efficient development of quantum technologies.
- Develop IP sharing while fostering innovation and early stage R&D.

The initial steps toward establishing a *Quantum Information Science Collaborative Consortium* will be a set of workshops to scope out and establish the membership and governing structure for the consortium and the role of academia, national laboratories, industry, and government agencies. The consortium will probably jointly fund a small number of focused activities, but the information gained from consortium activities should help inform government agencies of needs and opportunities.

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[1] *Note this is a part of a broader NIST initiative to create the foundation for a quantum industry. This addendum is a draft proposal that would establish a Quantum Consortium as a part of a NIST initiative in support of QIS.*

Appendix

Participating included representatives from the following organizations:

Air Force Office of Scientific Research (AFOSR), American Defense International, AOSense, Applied Materials, Army Research Laboratory, AT&T, BAE Systems, Booz Allen Hamilton, Bra-Ket Science, CMC Microsystems, ColdQuanta, Condensed Matter Physics Program, Division of Materials Research, D-Wave Government, DARPA, Department of Energy, Department of Defense, Department of Justice, FBI, Fibertek, Florida Atlantic University, French Embassy, General Dynamics Mission Systems, Georgia Institute of Technology, Globalfoundries, Google, Government Accountability Office (GAO), Harvard University, Hudson Institute, IARPA, IBM, ID Quantique, IDA Science & Technology Policy Institute, imec, Intel, IonQ, Jenner & Block, Joint Quantum Institute (JQI), La Nebbia Winery, Laboratory for Telecommunication Sciences, Leidos, Lewis-Burke Associates LLC, Lockheed Martin, LPS, MaCT USA, MIT, MITRE Corporation, NIST, National Instruments, NSF, New York University, Northrop Grumman, Northwestern University, NSA, NXP Semiconductors, Office of Naval Research, Photon Spot, Inc., Quandela, Quantum Circuits, Inc., Quantum Diamond Technologies Inc., Quantum Valley Ideas Lab, QxBranch, Raytheon BBN Technologies, Sandia National Laboratories, Siemens Corporation, SUNY Polytechnic Institute, The Gordon and Betty Moore Foundation, Thorium Capital Management, Translume, University of Arizona, University of Colorado, University of Maryland, University of Minnesota, University of Pennsylvania, University of Queensland, University of Southern California, University of Vermont, VroomConsults, White House Office of Science and Technology Policy.