Scaling Quantum Computing Technologies – Opportunities, Challenges and Policy Interventions

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Abstract

In November 2022, IBM unveiled a quantum computer with the largest number of qubits ever reported. IBM Osprey has 433 qubits or more than three times more than the previous record-breaking IBM Eagle processor with 127 qubits revealed a year earlier in November 2021. IBM's next breakthrough is announced for 2023, dubbed IBM Condor processor is going to have 1,121 qubits and getting closer to so-called quantum advantage. While still far away from practical quantum computing, these extraordinary developments require appropriate policy interventions, financial incentives, and educational developments to enable and fully benefit from the opportunities brought by quantum computers.

Quantum computing is a rapidly emerging breakthrough technology that can disrupt numerous industries. Initially proposed by Yuri Manin in 1980 and in 1982 by Richard Feynman, (Feynman, 1982) Universal Quantum Simulators have taken over four decades to become a reality. Feynman proved that a classical Turing computer would not be able to simulate a quantum effect, while back then a hypothetical universal quantum computer would be able to mimic the quantum effect offering unprecedented performance and modeling capabilities (Feynman, 1982)

While practical or universal quantum computers are still far from commercial use cases and broad deployment, technological progress, amount of investment, and industrial and societal hype around quantum computing technologies has never been stronger. (National Academies of Sciences, Engineering, and Medicine, 2019) (Brooks, 2023) Quantum computers have been heralded as tools to quickly and effectively simulate, pre-screen, and develop new functional materials and drugs to address numerous conditions, as well as to solve complex multivariate problems including those in logistics and transportation, decision making and optimization, energy, and financial sectors. (National Academies of Sciences, Engineering, and Medicine, 2019) (Brooks, 2023) Quantum computers have even been proposed as a powerful tool to answering some climate change issues. (O'Brien, 2019) (Bobier, Gerbert, Burchardt, & Gourévitch, 2020) Quantum annealers, a type of quantum computer that deploys quantum annealing effect, have already shown "quantum advantage" over classical machines allowing them to quickly solve complex optimization problems (Daley, et al., 2022) (Centrone, Kumar, Diamanti, & Kerenidis, 2021).

The scale and momentum that quantum computers have achieved in the last five years is astonishing, and hard to compare with any other emerging technology. Despite all its advantages, this new quantum computing industry will face its unique challenges. Three most commonly mentioned challenges of quantum computing are skill and labor shortages, losing the momentum due to initial technology hype and subsequent technological disappointment caused by current readiness or maturity of quantum computing technologies, also colloquially known as "quantum winter", and finally, malicious use of quantum technologies.

The Quantum Threat Timeline Report 2022 published by the Global Risk Institute (Mosca & Piani, 2022) based on cumulative expert responses indicates that even in a pessimistic interpretation of responses the probability associated with quantum computing cybersecurity threat is roughly 10%in the next decade and up to 27% for the optimistic interpretation for the same timeframe. Based on expert opinions this threat is likely to increase to 59% likelihood in the next 20 years for pessimistic interpretation and roughly 83% likelihood in case of optimistic interpretation.

This policy brief intends to raise awareness about opportunities and challenges of rapidly evolving quantum computing ecosystem and its multitude of use cases and applications including those related to addressing the SDGs and propose policy interventions in order to maintain the current momentum and allow for a smooth transition to benefit from this new and exciting opportunity. Proposed interventions include financial incentives and benefits necessary to mature quantum computing technologies, investing in education, skills, and capabilities – quantum literacy, developing safeguarding mechanisms to limit wrongdoing or malicious uses of quantum computers, and finally developing fist movers' coalition to mature, showcase and promote use of quantum technologies as well as to enable knowledge sharing within and across industries.

Policy recommendations / conclusions

Financial Incentives to Mature Quantum Computing Technologies – today's early quantum computers and quantum circuits are not powerful enough to enable quantum advantage. The current state of quantum computing technologies is referred to as the noisy intermediate-scale quantum (NISQ) era, characterized by quantum processors containing limited numbers of qubits which are not yet advanced enough for fault-tolerance or large enough to achieve quantum supremacy. First quantum computers are also impractically expensive to be deployed in commercial applications.

To overcome these complex challenges significant financial investments are required. Maturing quantum computing technologies to make them more practical but also cost-competitive with classical computers will require dedicated funds and incentive programs. The multitude of advantages that quantum computers bring are possibly far greater than investment required to overcome today's technology challenges. As such, first movers and states that incentivize and support the work in quantum computing technologies will likely establish a strong position and be first benefactors of this new industry. Some of the mechanisms that worked well in other similar industries include grants, dilutive and non-dilutive funding, and R&D tax incentives.

Quantum Literacy – quantum physics and classical computer science are complex enough to require detailed knowledge to be proficient in both fields. Quantum computing goes beyond concepts of quantum physics and computer science and involves photonics, electronics, advanced mathematics and more. The multidisciplinary quantum computing field makes it extremely challenging for students to acquire and deploy this complex multidisciplinary knowledge in practice. Yet, this multidisciplinary knowledge is necessary to embrace the full potential of quantum computing technologies. Even when the technology matures and new tools and frameworks will make quantum computers more practical and more user friendly, there will still be a need for quantum computing theorists to develop new concepts and ensure that technology evolves and becomes more practical over time.

Achieving quantum literacy to the extent it was done in classical computers is going to be intrinsically more difficult given greater complexity of underlying concepts.

Investment in education, skills, and quantum capabilities must happen early to ensure that a critical workforce exists to drive quantum computing uptake across multiple fields. On the other hand, lack of qualified workforce will likely result in a bottleneck in quantum computing implementation and significant slowdown for this new industry.

Education is a time-consuming process as such to be able to gain access to quantum computing experts in four to five years we need to start training them today.

The role of educator can be fulfilled by universities, however, there is also a need for future employers to indicate current and future demand for these new skill sets. In addition, the industry should work closely with educational providers to ensure that course curricula align with their needs. Partnership between Accenture and Universidad Politécnica de Madrid is one of the examples of such partnership in developing a Master in Quantum Computing Technologies where a limited number of lecturers are employees of Accenture.

Enabling Access to Quantum Computers – Quantum computers are highly specialized machines which today are expensive and hence with limited access. Quantum computers are not suited for use outside of specialized laboratories and under specific conditions. As such, access to quantum computers is very limited. While quantum computers can be accessed via cloud services, their accessibility is still limited and expensive today. Quantum simulators that can run on classical computers partially address this accessibility issue. However, simulators are limited in their capabilities and performance. Ensuring easy and affordable access to early quantum computers will be a major enabling factor for this promising technology. Enabling access to quantum computers is also one of the enabling factors to achieve quantum literacy.

Quantum Governance – Developing safeguarding mechanisms to limit wrongdoing or malicious uses of quantum computers and associated technologies should start early and evolve together with technological progress. Quantum computers have a chance to become significantly faster and more sophisticated than classical computing within this decade. Some early use cases exploit quantum computers for applications in cryptography, with quantum advantage today's cryptography may become obsolete. Policymakers, data management companies and end users should be at least aware if not proactively engaged in these future privacy and data security implications. Cryptography is only one example of potential malicious use of quantum technology, defence industry is already exploring the use of quantum computing in defence applications, while the concept of quantum internet is gaining more proponents. Ethical considerations and adequate governance interventions for quantum computing technologies should be developed to understand the full spectrum of implications and their extent on our lives. These future developments must be balanced so that they prevent or limit malicious uses of quantum computers, while promoting and enabling the use of quantum for broadly understood societal and economic progress.

Standardization and Performance Measurements – Various pathways have been proposed to create stable qubits. Each of these pathways relies on different physical phenomena and offers different advantages. In order to be able to understand advantages and compare various technologies, performance measures must be developed. In addition, uniform standardization measures must be in place to enable transferability and applicability of various competing technologies.

First Movers Coalition – When quantum governance focuses on ethical considerations and safeguarding mechanisms to limit wrongdoing or malicious uses of quantum computers, first movers' coalition focuses on promotion of quantum computing technologies for advancement across industries and everyday life.

The aim behind fist movers' coalition is to mature, showcase and promote use of quantum technologies as well as to enable knowledge sharing within and across industries.

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