Toward Fault-Tolerant Quantum Computing: Ecosystem-Driven Progress and Near-Term Quantum Advantage

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Abstract: This talk explores progress toward fault-tolerant quantum computing, highlighting near-term quantum advantage and the role of ecosystems in accelerating innovation, enabling practical applications, and supporting national strategies for quantum research and industrial development.

Over the past decade, quantum computing has reached a level of technological maturity that enables meaningful experimentation and early demonstrations of utility in selected research domains. Current hardware platforms, while still operating in the noisy intermediate-scale quantum (NISQ) regime, have already supported exploratory applications in areas such as quantum chemistry, optimization, and materials science [1], entering the quantum utility era.

According to IBM's published technology roadmap, the realization of large-scale fault-tolerant quantum systems — capable of executing large-scale, error-corrected algorithms — is targeted for the end of this decade, with first systems expected around 2029 [2]. However, well before the advent of fully fault-tolerant architectures, it is anticipated that quantum advantage, defined as the ability of quantum processors to perform computational tasks infeasible for classical systems, can be demonstrated in specific, carefully selected problem classes [3].

A key enabler of this progress has been the adoption of an open and collaborative development model. Over the last ten years, IBM has fostered a global quantum ecosystem involving academic institutions, research centers, enterprises, and startups [4]. This approach has accelerated innovation not only in hardware and software [4], but also in workforce development, infrastructure, and national quantum strategies through strategic partnerships across multiple countries.

This talk will discuss how an ecosystem-driven approach is shaping the path toward practical quantum computing, highlighting both near-term opportunities for quantum advantage and the long-term vision of fault-tolerant systems [5-6]. It will also explore the implications of this paradigm for scientific discovery and industrial innovation, emphasizing the role of collaboration in unlocking the full potential of quantum technologies [7].

References

[1] R. Mandelbaum, J. Gambetta, B. Peropadre and O. Lanes, "The dawn of quantum advantage", IBM Quantum blog, https://www.ibm.com/quantum/blog/quantum-advantage-era
[2] "IBM Quantum Roadmap", IBM Quantum, https://www.ibm.com/roadmaps/quantum/2029/
[3] "Hardware for useful quantum computing", IBM Quantum, https://www.ibm.com/quantum/hardware
[4] "IBM Quantum Network", https://www.ibm.com/quantum/ibm-quantum-network
[5] S. Bravyi, A. Cross, J. Gambetta, D. Maslov, P. Rall and T. Yoder, "High-threshold and low-overhead fault-tolerant quantum memory", Nature **627**, pages 778–782 (2024)
[6] H. Riel, "Quantum Computing – Toward Large-Scale Fault-Tolerant Quantum Computing", IBM Research, https://research.ibm.com/publications/quantum-computing-toward-large-scale-920-am-fault-tolerant-quantum-computing
[7] R. Mandelbaum, "Scaling for quantum advantage and beyond", IBM Quantum blog, https://www.ibm.com/quantum/blog/qdc-2025