Quantum circuits get a dynamic upgrade with the help of concurrent classical computation

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By allowing quantum and classical resources to do what they do best, our team has demonstrated the potential power of dynamic circuits—those where we perform a measurement in a quantum circuit and then feed the resulting classical information to a later quantum calculation—a demonstration that provides an advantage over static circuits run on quantum computers alone.

Today's announcement of the IBM Quantum development roadmap charts a course towards a comprehensive software ecosystem, and crucially, ushers in a new era for dynamic circuits to help users squeeze more out of their quantum programs with fewer quantum computing resources. This fits into our core aim to increase the capacity of our hardware to run programs, while also making quantum programs more accessible than ever before. Central to these dynamic circuits is our expansion to real-time compute capabilities, where devices now permit interactions with classical computing instructions within the runtime of a quantum program.

Our newly released access to real-time compute will include capabilities such as mid-circuit measurement, mid-circuit reset of qubit values, and simple demonstrations of quantum teleportation. However, in our paper,[1] we further hoped to take on a more demanding class of dynamic circuit, one that requires accurate quantum operations, measurements, and resets, while efficiently handling larger volumes of classical information—all within the coherence time of the system. So, we decided to tackle what could be the most important quantum algorithm: quantum phase estimation.

Quantum phase estimation (QPE) serves as a core building block of many other quantum algorithms due to its potential to provide exponential speedups, for example, as in Shor's famous factoring algorithm. Today, quantum phase estimation requires many repetitions of a quantum circuit; in the current quantum ecosystem, users might lack the resources to run enough shots on quantum hardware to return estimation," a version of the quantum phase estimation algorithm reliant on dynamic circuits, that could provide an accurate answer with fewer quantum resources than other methods.

Through QPE, we estimate the eigenvalue—a single number that results from an operator acting on a given quantum state. The quantum phase estimation algorithm relies on the concept of "phase kickback" in order to find this value; we prepare the quantum state on a set of qubits, then entangle them with an auxiliary qubit, using it as a switch which decides whether to apply the quantum operation in question to the quantum state. This act of entanglement "kicks" otherwise unknowable information about the quantum operator acting on the quantum state back onto the auxiliary qubit.

The traditional Kitaev QPE protocol for estimating the eigenvalues relies on a number of repetitions of a quantum circuit, where more repetitions results in additional accuracy (and fewer repetitions means less accuracy). However, iterative QPE offers a baseline level of accuracy after just a single repetition. Its power comes from classical processing mixed in with the quantum processing; between each repetition, the system stores the results of the previous iteration, then feeds it forward into the next iteration of the quantum circuit to dynamically alter its subsequent operations.

While iterative phase estimation isn't asymptotically better or worse than the Kitaev protocol, it can provide a baseline level of accuracy in fewer shots on a quantum computer. This algorithm is a fundamental demonstration of the potential tradeoffs between running quantum-only static circuits and running dynamic circuits augmented by classical processing. We expect to continue finding advantages from dynamic circuits, where we allow quantum and classical computation to do what they do best in a given algorithm in order to maximize the program's overall efficiency.

Iterative phase estimation is just one of the many critical points along quantum programs for our developers to explore. And soon, dynamic circuits will one day play an important role in the story of frictionless quantum computing, where quantum computing resources fit so seamlessly into the overall computing workflow that quantum calculations go unnoticed by the end user.

A big part of our software strategy is to continue to use and create open source tools, eventually converting some into first-class cloud native components. This will allow us to continue scaling and extending our quantum software so that users can take advantage of our architecture while running quantum programs in a secure and reliable way. On the other side, users will be able to install and use some components from our software stack directly in their preferred cloud architectures.

And as we roll out this roadmap, we want to hear from you; If you're a developer who wants to be able to take advantage of quantum, and are interested in being part of our feedback program to help shape the future of quantum, please sign up here.

References

1. Antonio D. Corcoles, Maika Takita, Ken Inoue, Scott Lekuch, Zlatko K. Minev, Jerry M. Chow, Jay M. Gambetta (2021). *Exploiting dynamic quantum circuits in a quantum algorithm with superconducting qubits*. arXiv. https://arxiv.org/abs/2102.01682 | ↩

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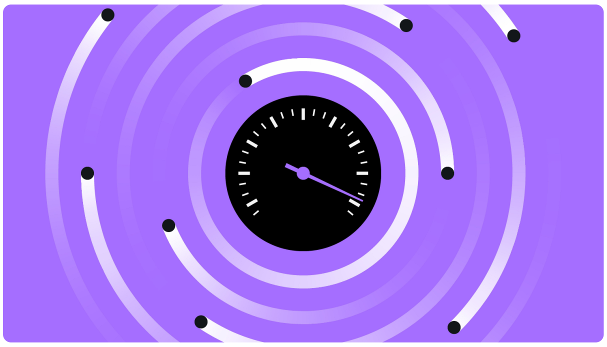

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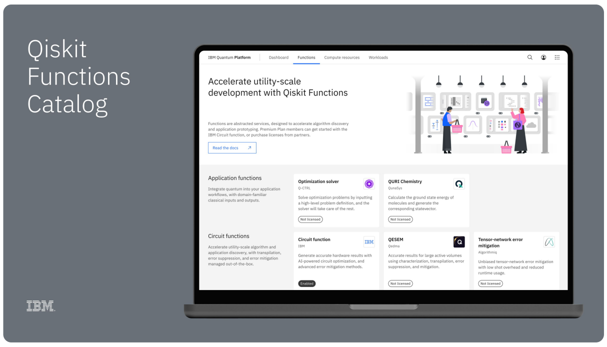

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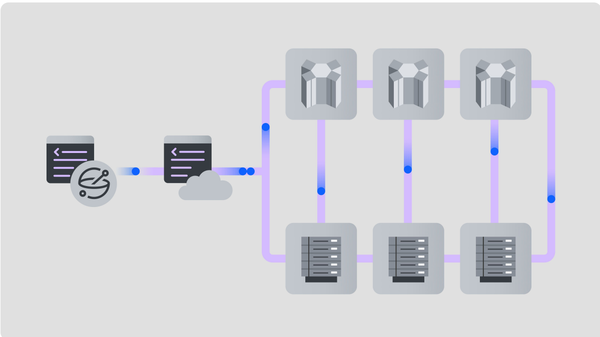

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