IBM Quantum delivers on performance challenge made two years ago

At the first-ever IBM Quantum Developer Conference, IBM is enabling algorithm discovery with high-performance quantum computers and easy-to-use quantum software.

13 Nov 2024

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Topics

Community · Error Correction & Mitigation · Network · Software · Systems · Qiskit

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Two years ago, IBM® set an ambitious challenge for the quantum computing community: Develop quantum algorithms incorporating circuits with 100 qubits and gate depths of 100, while IBM would build a quantum computer capable of returning accurate values for those circuits in less than a day's runtime.

Today at the first-ever IBM Quantum™ Developer Conference (QDC), IBM researchers announced that they'd successfully delivered on that promise: a quantum computer capable of running quantum circuits with up to 5,000 two-qubit gate operations — powered by the second revision of the IBM Quantum Heron. Thanks to groundbreaking advances in hardware, middleware, and software, Heron is now capable of running accurate calculations employing circuits with 5,000 two-qubit gates. For comparison, the utility experiment, which heralded in the era of quantum utility and was powered by the IBM Quantum Eagle processor, only went out to a total of 2,880 two-qubit gates.

Users of IBM Quantum computers and services now have access to this performance thanks to the Qiskit software stack, and the Qiskit Functions offered by third-party partners. The broader quantum community has published dozens of papers at the utility scale, while Functions providers have delivered their own capabilities that push the accuracy and scale of quantum circuits to drive algorithm discovery further.

along our development and innovation roadmaps. Here’s what this all means for you.

IBM Quantum Heron R2

Developing hardware capable of running 5,000 gates

the 100×100 challenge we announced at IBM Quantum Summit 2022. We selected this number because it is well into the regime of circuits beyond exact classical simulation. Developing quantum routines with 5,000+ gates gives users the opportunity to perform real scientific discovery with quantum computers, and to push forward in the search for quantum advantage.

Achieving this goal first and foremost required significant breakthroughs across our hardware and software. At QDC 2024, we showed off the latest version R2 of our modular Heron chip first introduced in 2023. This new chip features 156 qubits in a heavy-hex layout, and preserves the tunable coupler architecture we introduced last year to suppress crosstalk. We also added new two-level system mitigation to help reduce the impact of an important source of noise. Two-level systems are essentially disturbances to the qubits interacting with the material surrounding them.

Running long circuits also requires speed; we must be able to run circuit layers quickly. Over the course of the last year, we made updates to the quantum system software stack, further optimized data movement, and introduced our latest generation runtime. We also introduced parametric compiling, so you only have to compile iterative circuits once if parameters are the only things changing between iterations. Thanks to these updates, we’ve achieved speeds of over 150,000 circuit layer operations per second (CLOPS).

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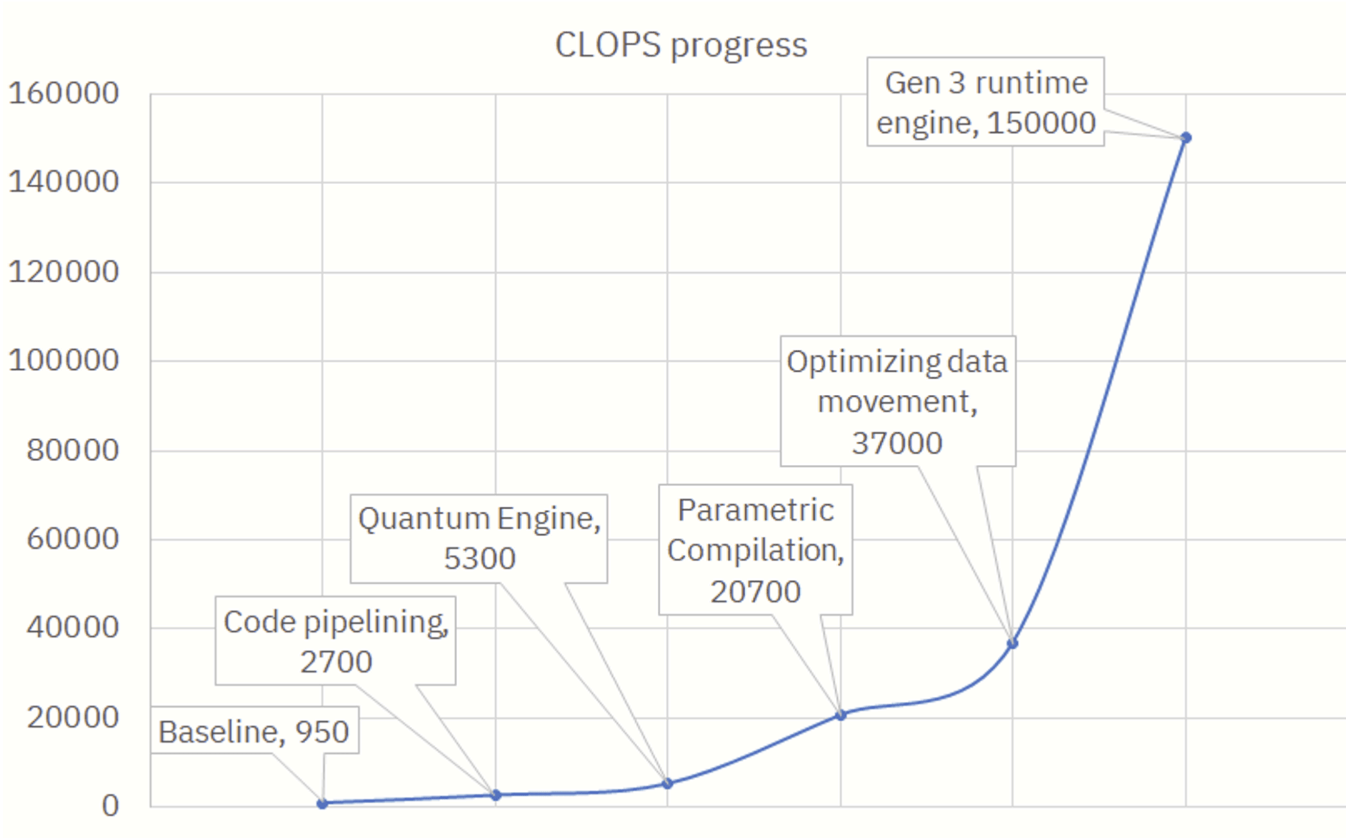

Increase in circuit layer operations per second (CLOPS), 2022-2024

Perhaps most importantly, we've improved the reliability of our computers and services. When we ran the utility experiment last year, we had to do it with custom circuits and software. Now, clients are able to replicate these demonstrations on their own using Qiskit tools, and they can run the corresponding circuits 50x faster than the experiment in the original quantum utility paper.

But the 100×100 challenge was about more than just improving IBM Quantum hardware and software. It was a call to action for the global quantum community to develop algorithms that would take full advantage of such a system. Alongside today's announcements, we're thrilled to say capabilities of their own, which they are making available as part of the Qiskit Functions Catalog. Each of these demonstrations are approaching the 5,000 gate threshold as well.

Performant quantum computing accelerates scientific discovery

Now that quantum devices can run circuits beyond the ability of brute-force classical methods, we must begin to identify the algorithms that will use these circuits to achieve computational advantage. IBM Quantum offers powerful tools that can help researchers in their discovery.

These tools center around an important thesis—that, as computing matures, algorithms increasingly reliant on linear algebra will need to employ quantum computers in places where classical computers can't keep up. The accuracy of these algorithms depends on the accuracy of their quantum subroutines, which, in turn, depends on the length of the quantum circuits that we can run.

In this paradigm, where quantum is a subroutine of a larger algorithm, we need to ensure that our quantum computers can run long circuits, and that quantum hardware is enabled by fast and performant software. Quantum cannot be a bottleneck.

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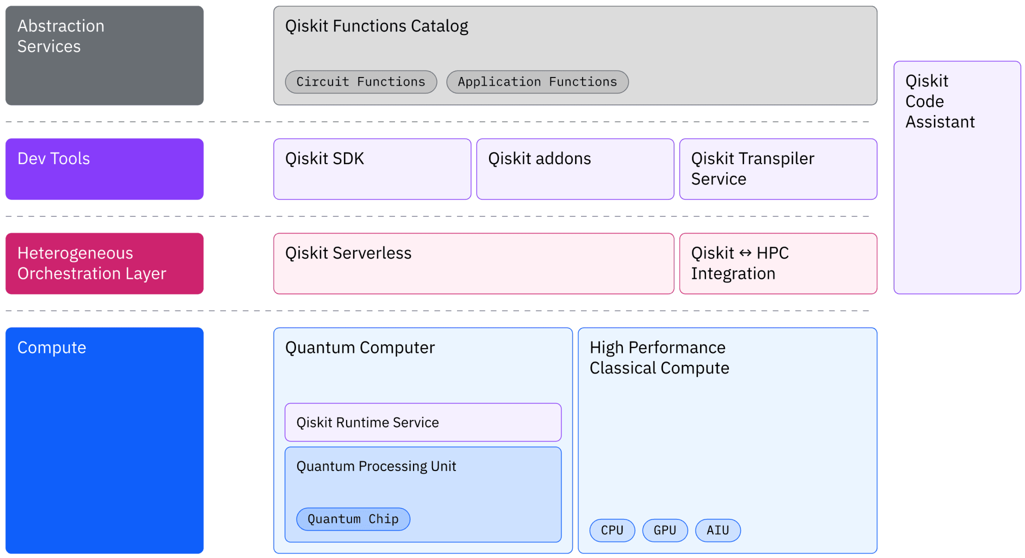


IBM Quantum technology stack

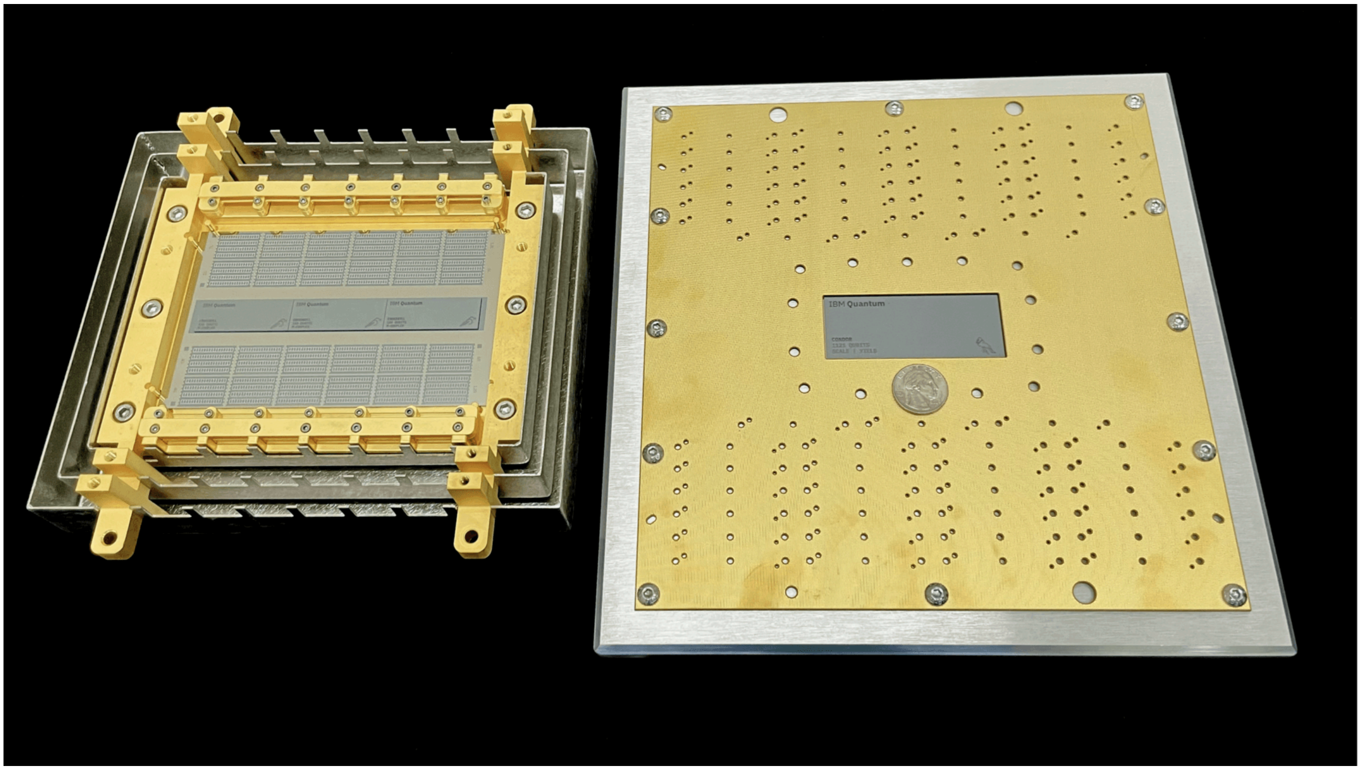
This year, we announced several new tools for improving the performance of our quantum software. We've previously discussed how recent updates to the Qiskit SDK—including its first stable release, Qiskit SDK v1.0—have shown it to be the most performant quantum software for building and transpiling circuits. However, Qiskit is more than just an SDK. It's a full software stack of tools for running quantum circuits and abstracting parts of the development workflow, and our efforts to improve Qiskit have extended far beyond the core SDK.

For example, earlier this year, we introduced the Qiskit Transpiler Service as a preview for our Premium Plan users. The Qiskit Transpiler Service allows you to transpile circuits in the cloud, leveraging the power of AI-powered transpiler passes to run circuits more efficiently. Thanks to these circuits we previously benchmarked while testing Qiskit's performance.

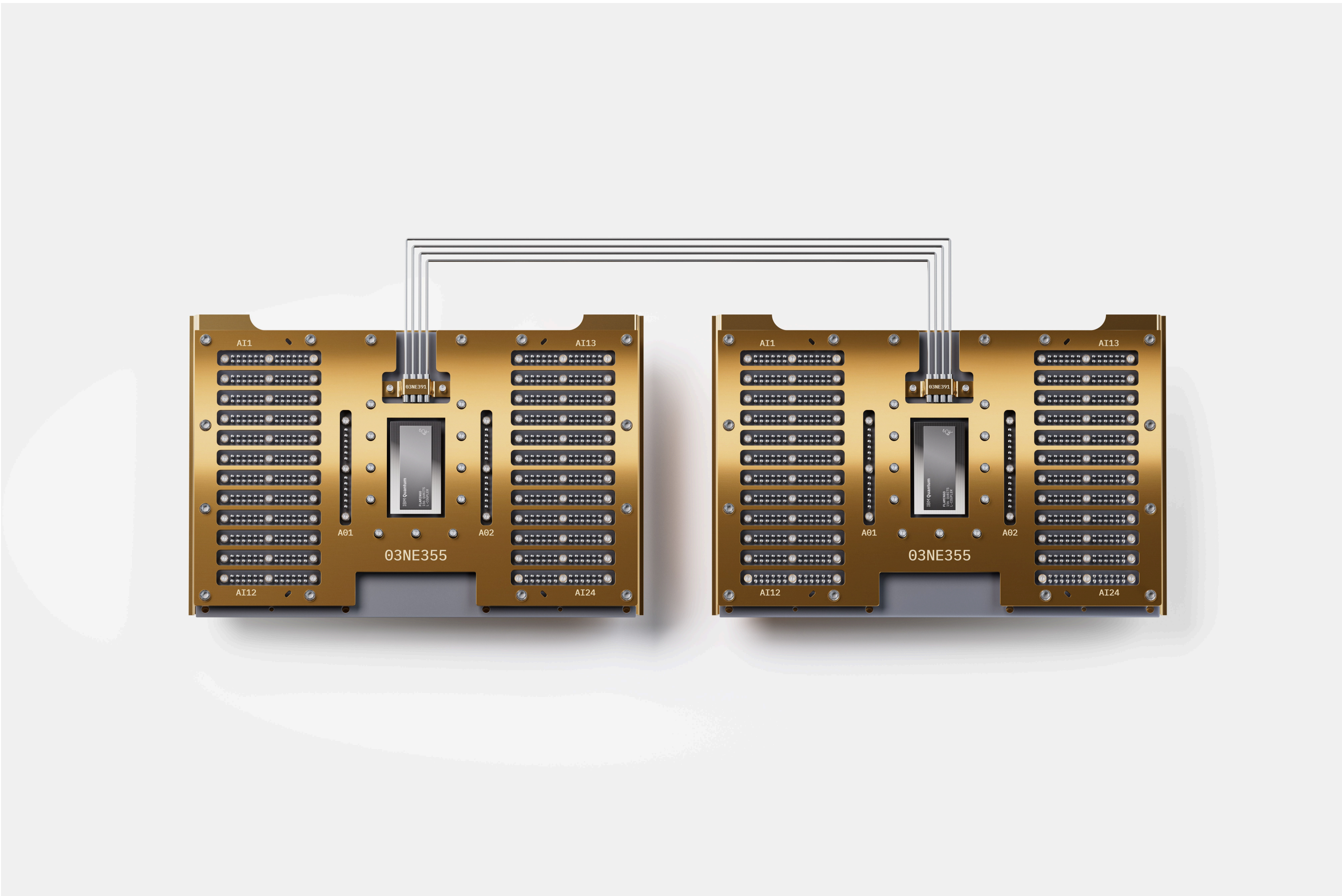
At the same time, it isn't enough for our software to just be fast. It must also be easy to use. This year, we introduced Qiskit addons, research capabilities developed as modular tools that can plug into a workflow to help design new algorithms at the utility scale. Their impact on the R+D process is clear. Last year, RIKEN and IBM used quantum-centric supercomputing environments to model chemistry problems beyond brute force solutions. This work took approximately a year from initial arxiv to publication and now we've transformed that research into the SQD addon. Since then, Cleveland Clinic Foundation has used the SQD addon to publish chemistry simulations of their own—both in just a few months' time.

We've also released a variety of additional tools that are further simplifying the R+D process for our users so they can begin exploring domain-specific applications with quantum computation. We offer new Qiskit Functions that abstract away many of the complexities of quantum software development as part of the Qiskit Functions Catalog. We've also released the Qiskit Code Assistant in preview for our Premium Plan users. Qiskit Code Assistant lets you write quantum computing code faster with GenAI, powered by our `granite-8b-qiskit model` and IBM watsonx™.

New innovations driving performance in the future



IBM Quantum Crossbill (L) and IBM Quantum Condor (R)



IBM Quantum Flamingo

Last year, we updated our development roadmap to track more than just systems slated for release to clients—but also the innovations we must make to realize error-corrected quantum computing at scale. We showed off several of those innovations at this year's QDC.

Central to our innovation roadmap is our plan to develop new couplers to run gates across multiple quantum chips. This year, we reported the results of two kinds of couplers: l-couplers, which connect chips with cables, and m-couplers, which seam together adjacent chips.

Quantum Flamingo, which connects two Heron R2 chips with four connectors measuring up to a meter long. L-couplers allow us to implement CNOT gates across distant chips. At the moment, the best CNOTs we've benchmarked have been on test devices, with errors per gate of 3.5% for a 235 nanosecond operation. We expect these metrics to improve, and will debut a production-ready Flamingo-based system for use by our clients by the end of 2025.

We also prototyped the technologies for m-couplers integrated into a scaled-up device called IBM Quantum Crossbill. This chip comprises three connected Herons with 548 couplers and 8 interchip m-coupler connections. Last year, we showed IBM Quantum Condor—a 1,121-qubit chip that tested the limits of yield and monolithic scaling. This year, we showed that with m-couplers, we can perform high quality two-qubit gates and also showed integrated connectors with large-scale silicon packaging. Fully assembled in Crossbill, together these produce a device with over 1000 quantum elements with just 1/5 the area of a fully packaged Condor in circuit board. The m-coupler technology provides additional scaling options for the next parts of our roadmap.

Now, we must continue developing the advances that will allow us to implement the error correcting code we published earlier this year. This code has the potential to store quantum information with a fraction of the overhead associated with other leading QEC codes. However, it also requires higher qubit connectivity—i.e., qubits connected to more of their neighbors. Additionally, we'll need to develop c-couplers, or couplers that link distant qubits on the same chip. We're well on our way toward realizing these technologies, with the hope of demonstrating c-couplers with Kookaburra, slated for 2026.

Finally, we're beginning to realize our ultimate vision of quantum-centric supercomputing. Today, classical computing facilities are capable of running tremendously complex workflows thanks to systems called workload management systems. They oversee available computational

Rensselaer Polytechnic Institute to bring quantum into the picture of workload management. With the help of our partners at RPI, we were able to demonstrate the first heterogenous workflow in a fully realized quantum-centric supercomputing environment by connecting the AiMOS supercomputer and IBM Quantum System One into a singular computational environment managed by the Slurm resource manager.

Innovating as a community

We've always thought of our quantum mission as a working agreement between IBM and the global quantum research community. We push the performance of our hardware and software, but it's up to the community to discover the algorithms that will use these tools to achieve quantum advantage.

We are committed to offering the tools that our users need to make real scientific discoveries in this new era, where quantum computers are finally demonstrating utility beyond brute force classical methods. Furthermore, we continue investing in the development of world-class learning resources so users can extend these tools, and we continue to collaborate with our clients and partners to help bring their ideas to life. Now, with the first-ever QDC, we are offering developers the resources they need to extend quantum computers to their respective domains.

Now, let's work together to unlock quantum advantage as a community and bring useful quantum computing to the world.

Recordings of all presentations delivered at IBM Quantum Developer Conference 2024 are now available on IBM Quantum Learning.

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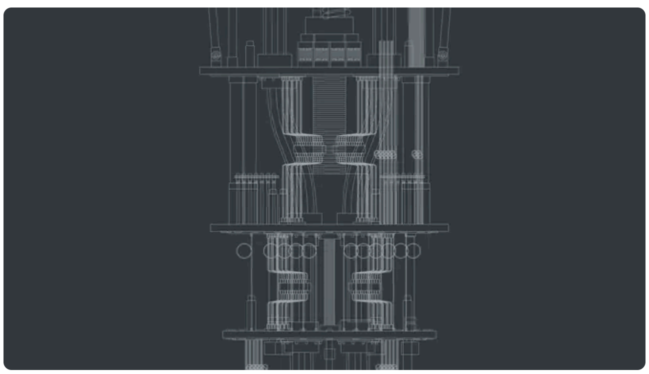

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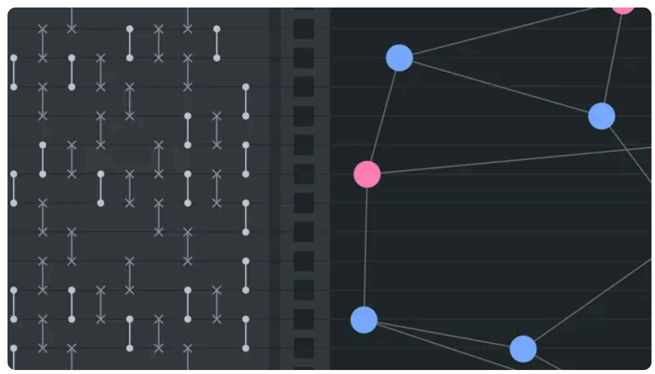

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