Development & Innovation
Roadmap

IBM Quantum
Development roadmap

Back in 2020, IBM released an ambitious roadmap for maturing and scaling quantum technology. This roadmap set us on course to deliver a 1,000+ qubit chip in just three years while developing software and services necessary to run applications on quantum systems.

### 2019
- Run quantum circuits on the IBM cloud

### 2020
- Demonstrated and prototype quantum algorithms and applications
- Run quantum programs 100x faster with Qiskit Runtime

### 2021
- Brought dynamic circuits to Qiskit Runtime to unlock more computations
- Machine learning | Natural science | Optimization

### 2022
- Enhance applications with elastic computing and parallelization of Qiskit Runtime
- QASM 3
- Dynamic circuits
- Threaded primitives

### 2023
- Improve accuracy of Qiskit Runtime with scalable error mitigation
- Error suppression & mitigation

### 2024
- Scale quantum applications with circuit knitting toolbox controlling Qiskit Runtime
- Quantum software functions
- Quantum Serverless
- Intelligent orchestration

### 2025
- Increase accuracy and speed of quantum workflows with integration of error correction into Qiskit Runtime
- Machine learning | Natural science | Optimization

### 2026
- Scaling to 10K-100K qubits with classical and quantum communication

**Completed Milestones**
- Falcon: 27 qubits
- Hummingbird: 65 qubits
- Eagle: 127 qubits
- Osprey: 433 qubits
- Condor: 1,121 qubits
- Flamingo: 1,386+ qubits
- Kookaburra: 4,156+ qubits

**On Target**
- Heron: 333 qubits x p
- Crossbill: 408 qubits
By 2023, our research and development work made it possible to use quantum computers as tools to run circuits beyond the reach of brute-force classical computation. We could also begin thinking about implementing error correction.

We realized: it was time for a bigger roadmap.
Our updated development roadmap charts our course for delivering client-facing systems and services. It now focuses both on qubit count and on the size of the circuits that our systems can run, tracked by the number of gates in those circuits.

You can start exploring quantum utility today, and this roadmap shows how the quantum workload size available for that exploration will increase.

Our challenge is to develop the tools that users need to explore quantum utility and unlock the full power of quantum-centric supercomputing by 2033.

We will also incorporate advances in machine learning and generative AI to turbocharge our software’s performance.

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### Development roadmap: Updated

**2016–2019**
- Released multi-dimensional roadmap publicly with initial aim focused on scaling

**2020**
- Enhanced quantum execution speed by 10x with Qiskit Runtime

**2021**
- Enhanced quantum execution speed by 10x with Qiskit Runtime

**2022**
- Enhanced quantum circuit quality and speed to allow 14 gates with parametric circuits

**2023**
- Enhanced quantum circuit quality and speed to allow 14 gates with quantum modularity

**2024**
- Enhance quantum circuit quality to allow 10x gates

**2025**
- Enhance quantum circuit quality to allow 100x gates

**2026**
- Enhance quantum circuit quality to allow 1000x gates

**2027**
- Enhance quantum circuit quality to allow 10000x gates

**2028**
- Enhance quantum circuit quality to allow 100000x gates

**2029**
- Enhance quantum circuit quality to allow 1000000x gates

**2033+**
- Enhanced 20x, quantum-centric supercomputers will include 1000s of logical qubits, unlocking the full power of quantum computing

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**Data scientists**

**Researchers**

**Quantum physicists**

**IBM Quantum Experience**

**QASM 3**

**Dynamic circuits**

**Execution modes**

**Heron** (5K)
- Error mitigation
- 50 gates
- 138 qubits
- Classical modular
- Up to $112.5$ = 391 qubits

**Flamingo** (5K)
- Error mitigation
- 50 gates
- 138 qubits
- Quantum modular
- Up to $156.7$ = 1012 qubits

**Flamingo** (7.5K)
- Error mitigation
- 75 gates
- 156 qubits
- Quantum modular
- Up to $156.7$ = 1012 qubits

**Flamingo** (10K)
- Error mitigation
- 100 gates
- 156 qubits
- Quantum modular
- Up to $156.7$ = 1012 qubits

**Flamingo** (15K)
- Error mitigation
- 150 gates
- 200 qubits
- Quantum modular
- Error corrected modularity

**Starting** (100M)
- Error correction
- 100M qubits
- 2000 qubits

**Blue Jay** (1B)
- Error correction
- 1B qubits
- 2000 qubits

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- Executed by IBM
- On target
What we have accomplished:

### Hardware

From 2020 to 2023, we focused on solving single-chip scaling with the IBM Quantum Falcon, Hummingbird, Eagle, Osprey, and Condor chips.

In 2023, we debuted the IBM Quantum Heron chip, which uses tunable couplers to achieve our lowest error rates yet. Heron will serve as the basis for modular scaling of quantum processors. In 2024, Heron will be capable of running 5,000 gates.

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**Platform**
- Code assistant
- Functions
- Mapping collections
- Specific libraries
- General purpose Q# libraries

**Middleware**
- Quantum Serverless
- Transpiler service
- Resource management
- Circuit knitting + p
- Intelligent orchestration
- Circuit libraries

**IBM Quantum physicists**

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**Executed by IBM**

**On target**

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Looking forward: Hardware

Now, we use error mitigation and interconnects to run larger circuits so users can look for quantum advantages in their domains. Through classical and quantum modularity, we plan to achieve an IBM Quantum Flamingo system capable of running 15,000 gates with the help of error mitigation by 2028.

We foresee advances in quantum error correction allowing us to debut IBM Quantum Starling, a system capable of running circuits with 100 million gates on 200 logical qubits, by 2029. In 2033, we will debut IBM Quantum Blue Jay, a system capable of running circuits with a billion gates on 2,000 logical qubits.

As we roll out error correction, developers need not change how they write quantum programs. They will simply notice that they can run longer workloads.

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What we have accomplished: Execution and orchestration

Running quantum workloads requires infrastructure that coordinates quantum resources with near-time and real-time classical resources.

Since 2016, we have worked to create Qiskit and a variety of application libraries to show our users what coding a quantum computer looks like.

In 2021, we released Qiskit Runtime, a service allowing users to orchestrate their programs across IBM Quantum processors and the cloud.

In 2023, we introduced middleware for quantum tools to automate and optimize heterogeneous compute tasks. That included quantum serverless to provision users the exact quantum resources they need, when they need them.
Looking forward:
Execution and orchestration

In 2024, our AI-powered transpiler service will optimize circuits with fewer gates.

In 2025, we will introduce resource management tools to facilitate system partitioning and enable parallel execution.

2026 will bring us circuit knitting across parallel quantum processors—the ability to decompose quantum circuits into shorter circuits, run them in parallel, and then stitch them back together with classical hardware. Circuit knitting will bring performance gains and let you run complex algorithms sooner.

From 2027 onward, we will focus on intelligent orchestration: optimizing workflows to combine classical and quantum efficiently, thus improving performance.
What we have accomplished:
Software

Useful quantum computing requires performant software. We’re committed to maturing Qiskit into a software stack capable of running utility-scale circuits on cloud-based quantum resources. As we say, Qiskit + IBM Quantum systems = work.

In 2023, we aggregated Qiskit documentation and learning resources into the IBM Quantum Platform to create a single Qiskit source of truth.
Looking forward:

Software

In 2025, we will introduce quantum functions so users can create and share reusable blocks of Qiskit code.

2026 will bring mapping collections so users can start automating the process of mapping their specific use cases to quantum circuits.

From 2027 onward, we will work alongside clients to build use-case-specific libraries as quantum advantages emerge for a variety of use cases.

By 2033, we expect to see general-purpose quantum computing libraries that users can incorporate into a wide variety of quantum applications.

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<td>Canary 5 qubits</td>
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IBM Quantum Experience / © 2024 IBM Corporation
We remain committed to the transparent development of IBM quantum hardware and software. This includes showing off scientific discoveries required to clear roadblocks in the field.

Therefore, in 2023, we also announced our innovation roadmap. This roadmap features internal releases of hardware and software to enable the subsequent milestones on our development roadmap.

Some technologies on our innovation roadmap will be internal proofs-of-concept to inform future development. Others will be prototypes for eventual release.
Our hardware innovations focus on building interconnects that allow us to scale processors and parallelize quantum workloads while laying a foundation for quantum error correction.

In 2024, we will demonstrate m-couplers to seam chips together and l-couplers to connect chips over longer distances with Crossbill and Flamingo, respectively.

In 2025 and 2026, we will develop c-couplers capable of linking distant qubits on the same chip as required by error correction schemes for a concept called Kookaburra.

2027 and 2028 further pave a path to error correction. Cockatoo will debut logical communication and Starling will be able to run logical gates on error-corrected logical qubits.

### Innovation Roadmap

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<td>2028</td>
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<td>2029</td>
<td>Starling</td>
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**Notes:**
- **Early Canopy** consists of 36 sub-chips, 100 sub-chips, and 50 qubits.
- **Falcon** demonstrates scaling with 15 qubits.
- **Hummingbird** demonstrates scaling with 1.3T.
- **Eagle** demonstrates scaling with 1.5T.
- **Osprey** enables scaling with module-to-module signal delivery.
- **Condor** demonstrates scaling with 15 modules.
- **Flamingo** demonstrates scaling with a non-classical c-coupler.
- **Kookaburra** demonstrates scaling with 32 physical qubits.
- **Cockatoo** demonstrates scaling with module connections.
- **Starling** demonstrates scaling with 33 qubits.

**Executed by IBM:**
- Canary, Canopy, Falcon, Hummingbird, Eagle, Osprey, Condor, Flamingo, Kookaburra, Cockatoo, Starling

**On target:**
- Crossbill, Heron, Heron, Crossbill

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Our software innovations will support the execution of large circuits on modular quantum computers and build the tools for a frictionless developer experience, rising to the Development Roadmap in the following years.

In 2023, we showed our plan to incorporate AI into quantum computing workflows with AI-assisted circuit transpilation. In 2024 and 2025, we will prototype new tools for resource management and scalable circuit knitting for parallel execution and classical reconstruction of circuits at the HPC scale. In 2026, we will prototype a real-time error correction decoder for later error corrected systems.

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<td>AI-enhanced quantum</td>
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<td>System partitioning to enable parallel execution</td>
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<td>Error correction decoder</td>
<td>Cockatoo</td>
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**Innovation roadmap**

- **2016-2019**: Demonstrated circuits on the IBM Quantum Platform
  - 2016: Demonstrated Qiskit's ability to incorporate AI into quantum computing workflows with AI-assisted circuit transpilation.
  - 2018: Demonstrated Quantum Serverless's ability to execute quantum circuits with enhanced performance and scalability.
  - 2019: Demonstrated AI-enhanced quantum's ability to optimize quantum circuits for resource management.

- **2020-2021**: Enhanced quantum execution speed by utilizing Qiskit Runtime
  - 2020: Enhanced circuit execution speed with Qiskit Runtime.
  - 2021: Enhanced circuit execution speed with Quantum Serverless.

- **2022**: Enhanced quantum execution specifications for modular quantum computers and execution indexes
  - 2022: Improved quantum circuit quality and speed to about 24 gates with improved circuits.

- **2023**: Enhanced quantum circuit quality to about 75 gates
  - 2023: Improved quantum circuit quality to about 102 gates.

- **2024**: Enhanced quantum circuit quality to about 154 gates
  - 2024: Improved quantum circuit quality to about 211 gates.

- **2025**: Enhanced quantum circuit quality to about 286 gates
  - 2025: Improved quantum circuit quality to about 343 gates.

- **2026**: Enhanced quantum circuit quality to about 408 gates
  - 2026: Improved quantum circuit quality to about 476 gates.

- **2027**: Enhanced quantum circuit quality to about 545 gates
  - 2027: Improved quantum circuit quality to about 614 gates.

- **2028**: Enhanced quantum circuit quality to about 674 gates
  - 2028: Improved quantum circuit quality to about 743 gates.

- **2029**: Enhanced quantum circuit quality to about 803 gates
  - 2029: Improved quantum circuit quality to about 863 gates.

**Notes:**
- **Executed by IBM**: Indicates tasks completed by IBM.
- **On target**: Indicates tasks on track for completion.

**IBM Quantum**

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