RESEARCH NOTE

INSIDE IBM'S ADVANCES IN QUANTUM PROCESSORS & PLATFORMS

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CONTEXT

IBM's Quantum Summit 2023 highlighted several significant advancements in quantum computing, showcasing the company's commitment to pushing the boundaries of this revolutionary technology.

The key takeaways from the event include:

- **Introduction of 'IBM Quantum Heron':** This new quantum processor represents a significant leap in performance, offering a five-fold improvement in error reduction compared to its predecessor, 'IBM Quantum Eagle.' This advancement underscores IBM's leadership in developing high-performance quantum processors.
- **Launch of IBM Quantum System Two:** This system marks IBM's foray into modular quantum computing and is central to their vision of quantum-centric supercomputing. The system, which has begun operations with three IBM Heron processors, integrates scalable cryogenic infrastructure with classical runtime servers and modular qubit control electronics.
- **Extended IBM Quantum Development Roadmap:** IBM extended its roadmap to 2033, focusing on enhancing the quality of gate operations to scale up the complexity and size of quantum workloads. This long-term vision emphasizes the company's commitment to advancing quantum computing technology and its utility.
- **Collaborative Research and Demonstrations:** Notable institutions, including the University of Tokyo, Argonne National Laboratory, and Harvard University, have joined IBM in demonstrating the utility-scale capabilities of quantum computing. These collaborations aim to explore complex problems in chemistry, physics, and materials science.
- **Release of Qiskit 1.0:** As the world's most widely used open-source quantum programming software, the new version of Qiskit is designed to facilitate easier and faster execution of quantum circuits, enhancing the accessibility of quantum computing for computational scientists.

- **Advancements in AI for Quantum Computing:** IBM showcased generative AI models engineered to automate quantum code development through watsonx and optimize quantum circuits. This innovation aims to democratize quantum computing development and make it more accessible.

NEW: IBM QUANTUM HERON PROCESSOR

. The IBM Quantum Heron is a significant advancement in IBM's quantum computing technology, characterized by the following key features:

- **133-Qubit Processor**: The IBM Quantum Heron is equipped with 133 fixed-frequency qubits. This substantial number of qubits represents a significant increase in computational capacity compared to previous quantum processors.
- **Advanced Error Reduction**: One of the most notable advancements of the IBM Quantum Heron is its improved error rates. It is designed to offer a 3-5x improvement in device performance over the previous flagship, the 127-qubit IBM Quantum Eagle processor. This enhancement in error reduction is crucial for performing more complex and reliable quantum computations.
- **Tunable Couplers**: The Heron processor features tunable couplers. This technology allows for enhanced control over the qubits, enabling more precise quantum operations and interactions between qubits. Tunable couplers are vital in reducing cross-talk, which is the unwanted interference between qubits, thereby increasing the overall fidelity of quantum operations.
- **Scalable Design**: The architecture of the IBM Quantum Heron is built with scalability in mind. This design is pivotal for IBM's vision of quantum-centric supercomputing, as it allows for integrating more qubits and complex quantum circuits in future developments.
- **Utility in Quantum Computing**: The IBM Quantum Heron represents a leap forward in making quantum computing a practical tool for scientific exploration and problem-solving in various fields beyond quantum computing.
- **Integration in IBM Quantum System Two**: The Heron processor is a central component of the IBM Quantum System Two, IBM's modular quantum computer. This system is a cornerstone in IBM's scalable and parallel quantum computation strategy, supported by advanced classical computing resources.

The IBM Quantum Heron processor marks a pivotal development in quantum computing with its increased number of qubits, significant improvements in error rates, and advanced features like tunable couplers. It is crucial in IBM's broader strategy for advancing quantum computing technology and its practical applications.

NEW: IBM QUANTUM SYSTEM TWO

IBM introduced its new Quantum System Two quantum computing platform, representing a significant step forward in the field of quantum computing.

The following key features characterize the new platform:

- **Modular Architecture:**
  - The Quantum System Two is IBM's first modular quantum computer.
  - This design approach allows scalability and flexibility, essential for future expansion and upgrades as quantum technology evolves.
- **Integration of Advanced Technologies:**
  - The system combines cryogenic infrastructure with third-generation control electronics and classical runtime servers.
  - This integration is crucial for efficient quantum computation and handling complex quantum-classical workflows.
- **Support for Multiple Quantum Processors:**
  - Currently operational with three IBM Quantum Heron processors, the system is designed to house future generations of quantum processors.
  - This capability underscores IBM's commitment to continuous innovation in quantum processor technology.
- **Scalable Quantum Computation:**
  - Quantum System Two is envisioned as the bedrock for scalable quantum computation.
  - Its design and infrastructure are tailored to support the execution of large-scale quantum algorithms and experiments.
- **22 Feet Wide and 12 Feet High Structure:**
  - The system's physical dimensions reflect its complexity and the advanced technology it encapsulates.
  - Its size reflects the extensive hardware and sophisticated engineering required for cutting-edge quantum computing.
- **Focus on Quantum-Centric Supercomputing:**
  - The system represents a shift towards quantum-centric supercomputing, seamlessly integrating quantum and classical computing elements.
  - It aims to realize parallel circuit executions for enhanced computational capabilities.
- **Designed for Heterogeneous Computing:**
  - Quantum System Two is part of a broader strategy to develop a heterogeneous computing architecture.
  - This approach involves the use of scalable and parallel circuit execution, along with advanced classical computation.
- **Extended IBM Quantum Development Roadmap:**
  - The system is a key component in IBM's extended roadmap towards quantum-centric supercomputing over the next decade.
  - It signifies IBM's long-term vision and commitment to advancing utility-scale quantum computing.

In summary, IBM Quantum System Two is a groundbreaking development in quantum computing, embodying a modular design and integrating advanced quantum and classical technologies. It is a foundation for scalable and future-proof quantum computation, aligning with IBM's vision for quantum-centric supercomputing and ongoing innovation in the field.

ADVANCEMENTS IN QUANTUM PROCESSORS

Beyond the Heron processor, IBM detailed several significant and multi-faceted processor innovations, marking critical steps forward in the field of quantum computing:

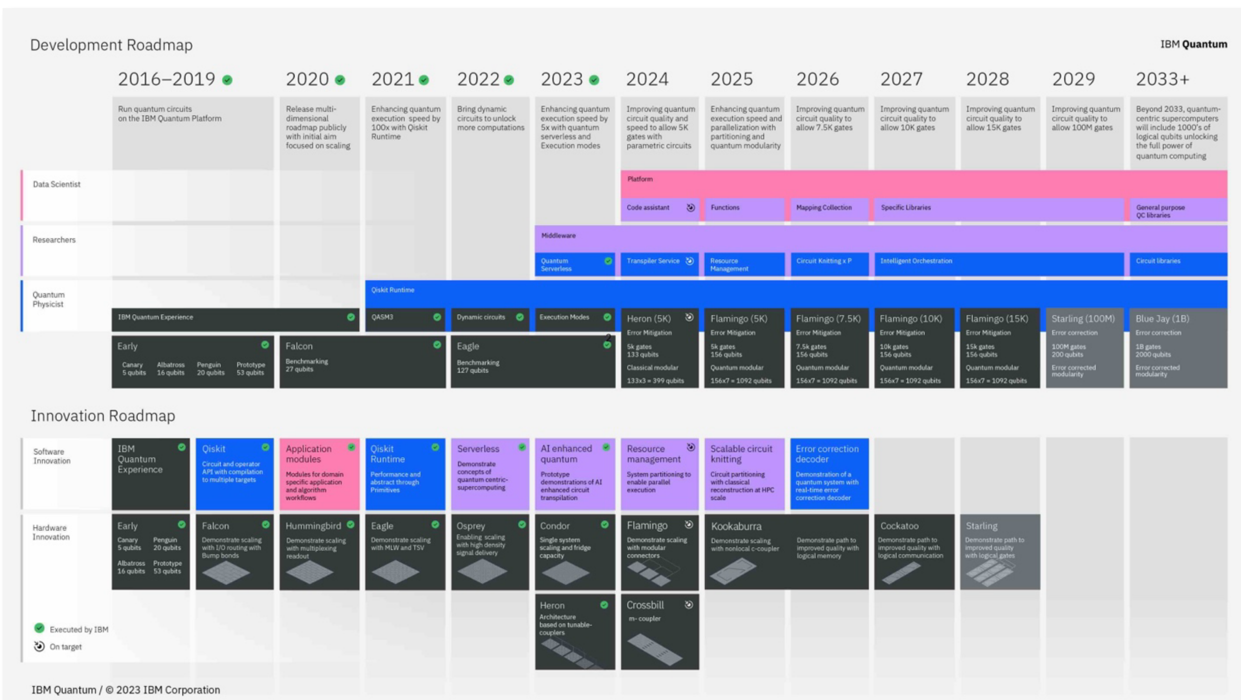
- **IBM Condor Processor:**
  - The IBM Condor represents a significant leap in qubit count, housing 1,121 superconducting qubits.
  - It demonstrates a 50% increase in qubit density, advances in qubit fabrication, and large-scale integration of high-density cryogenic wiring.
  - The Condor processor is a milestone in quantum processor scalability and informs future hardware design.
- **Error Correction and Gate Fidelity:**
  - IBM's advancements are in qubit count, error correction, and gate fidelity, which are crucial for practical quantum computing applications.
  - These improvements are essential for reliably executing more complex quantum algorithms.
- **Modular Processor Design:**
  - As seen in Quantum System Two, IBM's focus on modular processor design enables scalability and flexibility in quantum computing infrastructure.
- **Roadmap to Scalability:**
  - IBM delivered a roadmap for continuous improvement in its quantum processors, aiming to achieve larger qubit counts and more complex gate operations.
  - Targets include reaching 5,000 gates by 2024 with the Heron processor and progressing to 1 billion gates across 2,000 qubits by 2033 with future processors.
- **Parallel Circuit Execution:**
  - The advancement in quantum processors is also geared towards enabling parallel circuit execution, a critical factor for quantum-centric supercomputing.
- **Integration with Classical Computing:**
  - IBM’s quantum processors are designed to work in tandem with classical computing resources, facilitating the execution of hybrid quantum-classical workflows.
- **Focus on Quantum Utility:**

- o The advancements in IBM's quantum processors are aimed at transitioning from mere experimental use to practical, utility-scale applications in various scientific and commercial fields.

IBM significantly improved qubit count, error reduction, and overall performance. These developments, underpinned by a strong focus on modular design and scalability, highlight IBM's commitment to pushing the boundaries of quantum computing towards practical, real-world applications.

UPDATED: IBM'S QUANTUM ROADMAP

IBM's extended quantum roadmap is a strategic plan that outlines the company's vision and milestones for advancing quantum computing technology over the next decade. This roadmap is pivotal in guiding IBM's efforts to realize quantum-centric supercomputing and enhance the utility of quantum computing.



Key aspects of the updated roadmap include:

- **Long-Term Vision:**
  - o The roadmap extends to 2033, demonstrating IBM's long-term commitment to quantum computing innovation.
  - o It includes goals for developing quantum hardware, software, and applications, aiming to make quantum computing more practical and accessible for a wide range of uses.
- **Processor and System Improvements:**

- The roadmap envisions multiple generations of quantum processors, each designed to leverage improvements in quality to handle increasingly complex workloads.
- IBM plans to continually enhance the performance of its quantum processors, targeting a significant increase in the number of gates and qubits.

- **Milestone Targets:**
  - Specific milestones include achieving 5,000 gates with the Heron processor by 2024.
  - By 2029, IBM aims to execute 100 million gates over 200 qubits with the Starling processor, employing advanced error correction techniques.
  - The ultimate goal is to develop Blue Jay, a system capable of executing 1 billion gates across 2,000 qubits by 2033.
- **Focus on Error Correction and Scalability:**
  - The roadmap's significant focus is improving error correction capabilities, a crucial factor in scaling quantum computing to practical applications.
  - The roadmap outlines the development of novel error-correcting codes and methods to enhance the reliability of quantum computations.
- **Quantum-Centric Supercomputing Architecture:**
  - IBM's vision includes the integration of quantum and classical computing resources to create a quantum-centric supercomputing architecture.
  - This approach aims to leverage the strengths of both quantum and classical computing for solving complex problems.
- **Software and Middleware Development:**
  - The roadmap also emphasizes the development of quantum software and middleware.
  - IBM plans to enhance its software stack, including improvements to Qiskit, to enable more efficient and user-friendly programming of quantum circuits.
- **Enabling Utility-Scale Quantum Computing:**
  - IBM seeks to transition quantum computing from experimental research to utility-scale applications.
  - The roadmap guides the development of quantum systems capable of tackling real-world problems in various fields.

IBM's extended quantum roadmap is a comprehensive plan encompassing advancements in quantum hardware, software, and applications. It sets ambitious goals for scaling quantum computing capabilities and emphasizes the need for robust error correction. This roadmap is instrumental in guiding IBM's efforts to make quantum computing a practical tool for scientific exploration and practical applications across various industries.

ANALYSIS

IBM's recent advancements in quantum computing, as showcased at their Quantum Summit 2023, underscore the company's pioneering role in this rapidly evolving field. The introduction of the 'IBM Quantum Heron' processor, featuring 133 fixed-frequency qubits, marks a significant leap in quantum computing performance and error reduction, demonstrating IBM's commitment to overcoming some of the most challenging barriers in the field.

Similarly, unveiling the IBM Quantum System Two, a modular quantum computer, reflects a strategic shift towards scalable and flexible quantum computing architectures. This system, operational with three IBM Heron processors, signifies IBM's foresight in building a foundation for quantum-centric supercomputing.

Furthermore, IBM's extended quantum development roadmap to 2033 reveals a long-term vision that is not only ambitious but also pragmatic, focusing on improving gate operations and error correction - critical factors for practical quantum computing applications. The introduction of IBM Condor, a 1,121 superconducting qubit processor, further highlights IBM's strides in enhancing the scale and yield of quantum chip design.

On the software front, the announcement of Qiskit 1.0 and the integration of generative AI into quantum programming through the Watsonx platform are indicative of IBM's efforts to democratize and streamline quantum computing.

These advancements collectively suggest that IBM is not just pushing the boundaries of quantum computing technology but is also keenly focused on making it accessible and practical for a wide range of real-world applications.

This dual approach of advancing the technological frontier while expanding the user base and practical utility cements IBM's position as a leader in the quantum computing landscape.

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