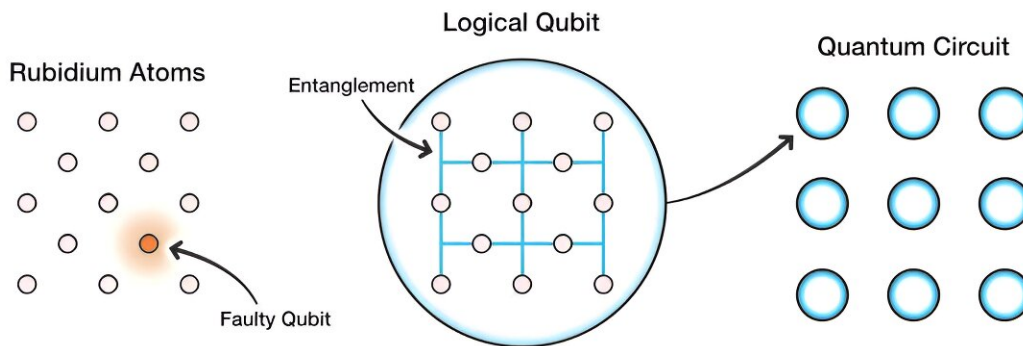


Researchers create first programmable, logical quantum processor

December 21 2023, by Anne J. Manning



Individual physical qubits, like rubidium atoms, are notoriously fragile and easily disturbed by interactions with their environment. To minimize errors, researchers entangle the atoms together to form a single "logical qubit," which can be combined with other logical qubits into a fault-tolerant quantum circuit. Credit: S. Kelley/NIST

Harvard researchers have realized a key milestone in the quest for stable, scalable quantum computing, an ultra-high-speed technology that will enable game-changing advances in a variety of fields, including medicine, science, and finance.

The team, led by Mikhail Lukin, the Joshua and Beth Friedman University Professor in physics and co-director of the Harvard Quantum

Initiative, has created the first programmable, logical quantum processor, capable of encoding up to 48 logical qubits, and executing hundreds of logical gate operations, a vast improvement over prior efforts.

Published in *Nature*, the [work](#) was performed in collaboration with Markus Greiner, the George Vasmer Leverett Professor of Physics; colleagues from MIT; and QuEra Computing, a Boston company founded on technology from Harvard labs.

The system is the first demonstration of large-scale algorithm execution on an error-corrected quantum computer, heralding the advent of early fault-tolerant, or reliably uninterrupted, quantum computation.

Lukin described the achievement as a possible inflection point akin to the early days in the field of artificial intelligence: the ideas of quantum error correction and fault tolerance, long theorized, are starting to bear fruit.

"I think this is one of the moments in which it is clear that something very special is coming," Lukin said. "Although there are still challenges ahead, we expect that this new advance will greatly accelerate the progress toward large-scale, useful quantum computers."

Denise Caldwell of the National Science Foundation agrees.

"This breakthrough is a tour de force of quantum engineering and design," said Caldwell, acting assistant director of the Mathematical and Physical Sciences Directorate, which supported the research through NSF's Physics Frontiers Centers and Quantum Leap Challenge Institutes programs. "The team has not only accelerated the development of quantum information processing by using [neutral atoms](#), but opened a new door to explorations of large-scale logical qubit devices, which

could enable transformative benefits for science and society as a whole."

It's been a long, complex path.

In quantum computing, a quantum bit or "[qubit](#)" is one unit of information, just like a binary bit in classical computing. For more than two decades, physicists and engineers have shown the world that quantum computing is, in principle, possible by manipulating quantum particles—be they atoms, ions, or photons—to create physical qubits.

But successfully exploiting the weirdness of quantum mechanics for computation is more complicated than simply amassing a large-enough number of qubits, which are inherently unstable and prone to collapse out of their quantum states.

The real coins of the realm are so-called logical qubits: bundles of redundant, error-corrected physical qubits, which can store information for use in a quantum algorithm. Creating logical qubits as controllable units—like classical bits—has been a fundamental obstacle for the field, and it's generally accepted that until quantum computers can run reliably on logical qubits, the technology can't really take off.

To date, the best computing systems have demonstrated one or two logical qubits, and one quantum gate operation—akin to just one unit of code—between them.

The Harvard team's breakthrough builds on several years of work on a [quantum computing](#) architecture known as a neutral atom array, pioneered in Lukin's lab. It is now being commercialized by QuEra, which recently entered into a [licensing agreement](#) with Harvard's Office of Technology Development for a patent portfolio based on innovations developed by Lukin's group.

The key component of the system is a block of ultra-cold, suspended rubidium atoms, in which the atoms—the system's physical qubits—can move about and be connected into pairs—or "entangled"—mid-computation.

Entangled pairs of atoms form gates, which are units of computing power. Previously, the team had demonstrated low error rates in their entangling operations, proving the reliability of their neutral atom array system.

With their logical quantum processor, the researchers now demonstrate parallel, multiplexed control of an entire patch of logical qubits, using lasers. This result is more efficient and scalable than having to control individual physical qubits.

"We are trying to mark a transition in the field, toward starting to test algorithms with error-corrected qubits instead of physical ones, and enabling a path toward larger devices," said paper first author Dolev Bluvstein, a Griffin School of Arts and Sciences Ph.D. student in Lukin's lab.

The team will continue to work toward demonstrating more types of operations on their 48 logical qubits and to configure their system to run continuously, as opposed to manual cycling as it does now.

More information: Dolev Bluvstein et al, Logical quantum processor based on reconfigurable atom arrays, *Nature* (2023). [DOI: 10.1038/s41586-023-06927-3](https://doi.org/10.1038/s41586-023-06927-3)

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