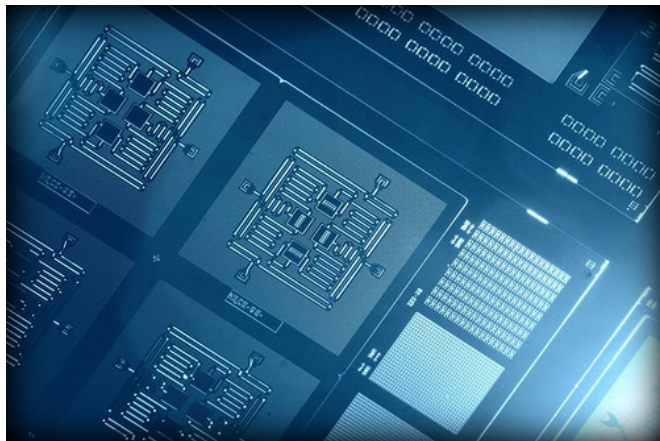


Scientists achieve critical steps to building first practical quantum computer

29 April 2015



Layout of IBM's four superconducting quantum bit device. Using a square lattice, IBM is able to detect both types of quantum errors for the first time. This is the best configuration to add more qubits to scale to larger systems. Credit: IBM Research

IBM scientists today unveiled two critical advances towards the realization of a practical quantum computer. For the first time, they showed the ability to detect and measure both kinds of quantum errors simultaneously, as well as demonstrated a new, square quantum bit circuit design that is the only physical architecture that could successfully scale to larger dimensions.

With Moore's Law expected to run out of steam, quantum computing will be among the inventions that could usher in a new era of innovation across industries. Quantum computers promise to open up new capabilities in the fields of optimization and simulation simply not possible using today's computers. If a quantum computer could be built with just 50 quantum bits (qubits), no combination of today's TOP500 supercomputers could successfully outperform it.

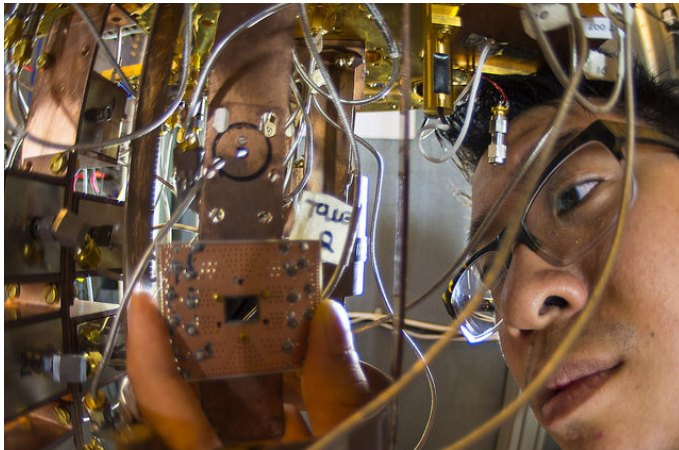
The IBM breakthroughs, described in the April 29

issue of the journal *Nature Communications*, show for the first time the ability to detect and measure the two types of quantum errors (bit-flip and phase-flip) that will occur in any real quantum computer. Until now, it was only possible to address one type of quantum error or the other, but never both at the same time. This is a necessary step toward quantum error correction, which is a critical requirement for building a practical and reliable large-scale quantum computer.

IBM's novel and complex quantum bit circuit, based on a square lattice of four superconducting qubits on a chip roughly one-quarter-inch square, enables both types of quantum errors to be detected at the same time. By opting for a square-shaped design versus a linear array – which prevents the detection of both kinds of quantum errors simultaneously – IBM's design shows the best potential to scale by adding more qubits to arrive at a working quantum system.

"Quantum computing could be potentially transformative, enabling us to solve problems that are impossible or impractical to solve today," said Arvind Krishna, senior vice president and director of IBM Research. "While quantum computers have traditionally been explored for cryptography, one area we find very compelling is the potential for practical quantum systems to solve problems in physics and quantum chemistry that are unsolvable today. This could have enormous potential in materials or drug design, opening up a new realm of applications."

For instance, in physics and chemistry, quantum computing could allow scientists to design new materials and drug compounds without expensive trial and error experiments in the lab, potentially speeding up the rate and pace of innovation across many industries.



IBM Research scientist Jerry Chow conducts a quantum computing experiment at IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y. IBM has been focusing on quantum computing research for more than 30 years. Credit: Jon Simon/Feature Photo Service for IBM

For a world consumed by Big Data, quantum computers could quickly sort and curate ever larger databases as well as massive stores of diverse, unstructured data. This could transform how people make decisions and how researchers across industries make critical discoveries.

One of the great challenges for scientists seeking to harness the power of quantum computing is controlling or removing quantum decoherence – the creation of errors in calculations caused by interference from factors such as heat, electromagnetic radiation, and material defects. The errors are especially acute in quantum machines, since quantum information is so fragile.

"Up until now, researchers have been able to detect bit-flip or phase-flip quantum errors, but never the two together. Previous work in this area, using linear arrangements, only looked at bit-flip errors offering incomplete information on the quantum state of a system and making them inadequate for a quantum computer," said Jay Gambetta, a manager in the IBM Quantum Computing Group. "Our four qubit results take us past this hurdle by detecting both types of quantum errors and can be scalable to larger systems, as the qubits are

arranged in a square lattice as opposed to a linear array."

The work at IBM was funded in part by the IARPA (Intelligence Advanced Research Projects Activity) multi-qubit-coherent-operations program.

Detecting quantum errors

The most basic piece of information that a typical computer understands is a bit. Much like a beam of light that can be switched on or off, a bit can have only one of two values: "1" or "0". However, a quantum bit (qubit) can hold a value of 1 or 0 as well as both values at the same time, described as superposition and simply denoted as "0+1". The sign of this superposition is important because both states 0 and 1 have a phase relationship to each other. This superposition property is what allows quantum computers to choose the correct solution amongst millions of possibilities in a time much faster than a conventional computer.

A Quantum Leap in Computing

With exponentially more power than today's fastest supercomputers, quantum computers could herald a new era of innovation across industries. The first working quantum computer is closer to reality, with IBM overcoming two critical obstacles.

The Building Blocks

In 1981 at a conference co-sponsored by IBM, Nobel Prize winner Richard Feynman challenged scientists to develop a new breed of computers based on quantum physics.

01



Detecting Quantum Errors

Exposure to heat and radiation makes qubits prone to errors.

For the first time, IBM showed how to detect and measure both types of qubit errors simultaneously.



Building Larger Quantum Systems: Linear vs Square Array

02

Others have arranged qubits in a line to measure only one type of quantum error at a time. This is not enough.

VS

IBM figured out a square design for a quantum circuit that, with more qubits, can scale to a working quantum system.

What Can A Quantum Computer Do Better?

Quantum computing will solve a class of problems that are unsolvable today, opening up a new realm of applications.

03



present, which flip the sign of the phase relationship between 0 and 1 in a superposition state. Both types of errors must be detected in order for quantum error correction to function properly.

Quantum information is very fragile because all existing qubit technologies lose their information when interacting with matter and electromagnetic radiation. Theorists have found ways to preserve the information much longer by spreading information across many physical qubits. "Surface code" is the technical name for a specific error correction scheme which spreads quantum information across many qubits. It allows for only nearest neighbor interactions to encode one logical qubit, making it sufficiently stable to perform error-free operations.

The IBM Research team used a variety of techniques to measure the states of two independent syndrome (measurement) qubits. Each reveals one aspect of the quantum information stored on two other qubits (called code, or data qubits). Specifically, one syndrome qubit revealed whether a bit-flip error occurred to either of the code qubits, while the other syndrome qubit revealed whether a phase-flip error occurred. Determining the joint quantum information in the code qubits is an essential step for quantum error correction because directly measuring the code qubits destroys the information contained within them.

Because these qubits can be designed and manufactured using standard silicon fabrication techniques, IBM anticipates that once a handful of superconducting qubits can be manufactured reliably and repeatedly, and controlled with low error rates, there will be no fundamental obstacle to demonstrating error correction in larger lattices of qubits.

More information: *Nature Communications* [DOI: 10.1038/ncomms7979](https://doi.org/10.1038/ncomms7979)

Provided by IBM

Two types of errors can occur on such a superposition state. One is called a bit-flip error, which simply flips a 0 to a 1 and vice versa. This is similar to classical bit-flip errors and previous work has showed how to detect these errors on qubits. However, this is not sufficient for quantum error correction because phase-flip errors can also be

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