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QUANTUM COMPUTING | RESEARCH UPDATE

Cat qubits open a faster track to fault-tolerant quantum computing

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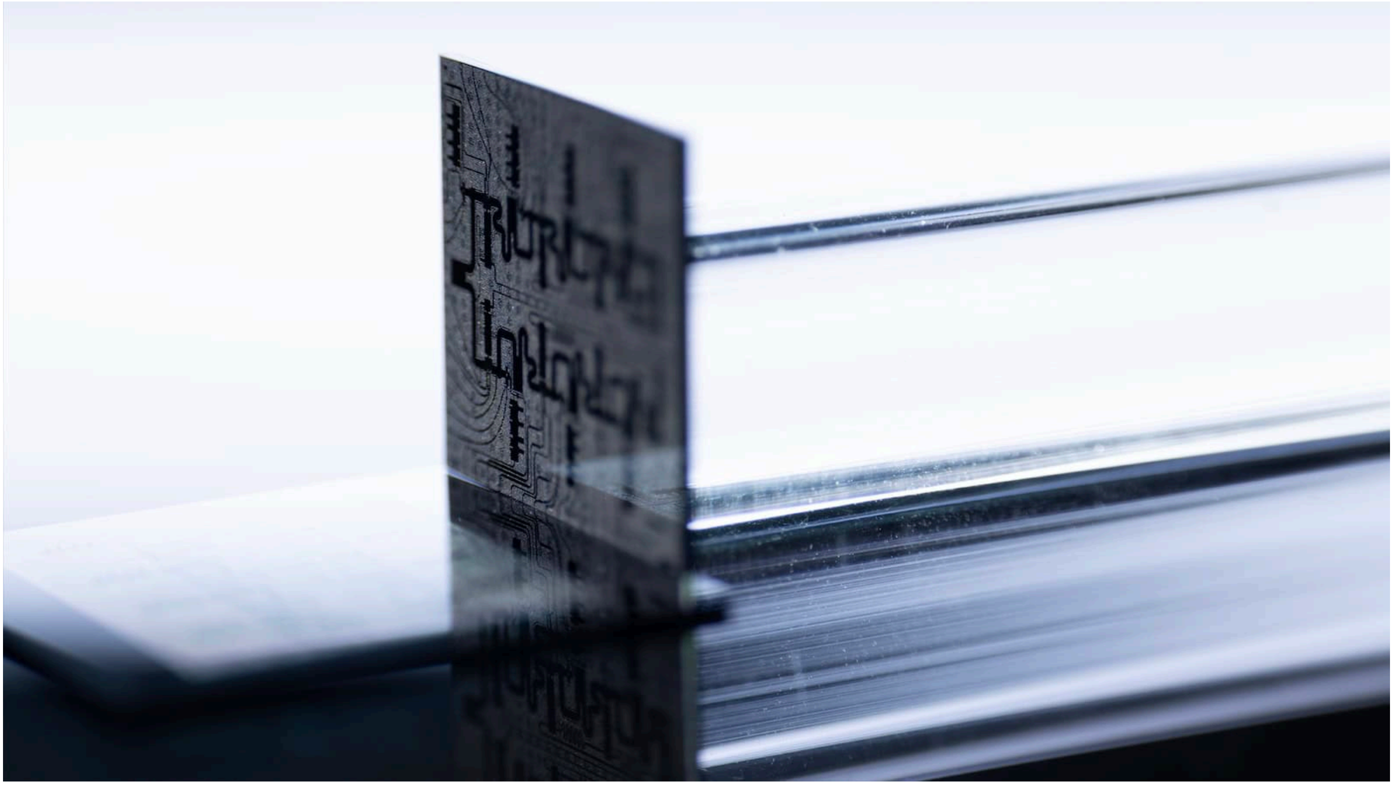

Here, kitty kitty: The Ocelot quantum computer chip. (Courtesy: AWS)

Researchers from the Amazon Web Services (AWS) Center for Quantum Computing have announced what they describe as a "breakthrough" in quantum error correction. Their method uses so-called cat qubits to reduce the total number of qubits required to build a large-scale, fault-tolerant quantum computer, and they claim it could shorten the time required to develop such machines by up to five years.

Quantum computers are promising candidates for solving complex problems that today's classical computers cannot handle. Their main drawback is the tendency for errors to crop up in the quantum bits, or qubits, they use to perform computations. Just like classical bits, the states of qubits can erroneously flip from 0 to 1, which is known as a bit-flip error. In addition, qubits can suffer from inadvertent changes to their phase, which is a parameter that characterizes their quantum superposition (phase-flip errors). A further complication is that whereas classical bits can be copied in order to detect and correct errors, the quantum nature of qubits makes copying impossible. Hence, errors need to be dealt with in other ways.

One error-correction scheme involves building physical or "measurement" qubits around each logical or "data" qubit. The job of the measurement qubits is to detect phase-flip or bit-flip errors in the data qubits without destroying their quantum nature. In 2024, a team at Google Quantum AI showed that this approach is scalable in a system of a few dozen qubits. However, a truly powerful quantum computer would require around a million data qubits and an even larger number of measurement qubits.

Cat qubits to the rescue

The AWS researchers showed that it is possible reduce this total number of qubits. They did this by using a special type of qubit called a cat qubit. Named after the Schrödinger's cat thought that illustrates the concept of quantum superposition, cat qubits use the superposition of coherent states to encode information in a way that resists bit flips. Doing so may increase the number of phase-flip errors, but special error-correction algorithms can deal with these efficiently.

The AWS team got this result by building a microchip containing an array of five cat qubits. These are connected to four transmon qubits, which are a type of superconducting qubit with a reduced sensitivity to charge noise (a major source of errors in quantum computations). Here, the cat qubits serve as data qubits, while the transmon qubits measure and correct phase-flip errors. The cat qubits were further stabilized by connecting each of them to a buffer mode that uses a non-linear process called two-photon dissipation to ensure that their noise bias is maintained over time.

According to Harry Putterman, a senior research scientist at AWS, the team's foremost challenge (and innovation) was to ensure that the system did not introduce too many bit-flip errors. This was important because the system uses a classical repetition code as its "outer layer" of error correction, which left it with no redundancy against residual bit flips. With this aspect under control, the researchers demonstrated that their superconducting quantum circuit suppressed errors from 1.75% per cycle for a three-cat qubit array to 1.65% per cycle for a five-cat qubit array. Achieving this degree of error suppression with larger error-correcting codes previously required tens of additional qubits.

On a scalable path

AWS's director of quantum hardware, Oskar Painter, says the result will reduce the development time for a full-scale quantum computer by 3-5 years. This is, he says, a direct outcome of the system's simple architecture as well as its 90% reduction in the "overhead" required for quantum error correction. The team does, however, need to reduce the error rates of the error-corrected logical qubits. "The two most important next steps towards building a fault-tolerant quantum computer at scale is that we need to scale up to several logical qubits and begin to perform and study logical operations at the logical qubit level," Painter tells *Physics World*.

According to David Schlegel, a research scientist at the French quantum computing firm Alice & Bob, which specializes in cat qubits, this work marks the beginning of a shift from noisy, classically simulable quantum devices to fully error-corrected quantum chips. He says the AWS team's most notable achievement is its clever hybrid arrangement of cat qubits for quantum information storage and traditional transmon qubits for error readout.

However, while Schlegel calls the research "innovative", he says it is not without limitations. Because the AWS chip incorporates transmons, it still needs to address both bit-flip and phase-flip errors. "Other cat qubit approaches focus on completely eliminating bit flips, further reducing the qubit count by more than a factor of 10," Schlegel says. "But it remains to be seen which approach will prove more effective and hardware-efficient for large-scale error-corrected quantum devices in the long run."

The research is published in *Nature*.

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