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Error-prone quantum bits could correct themselves, physicists show

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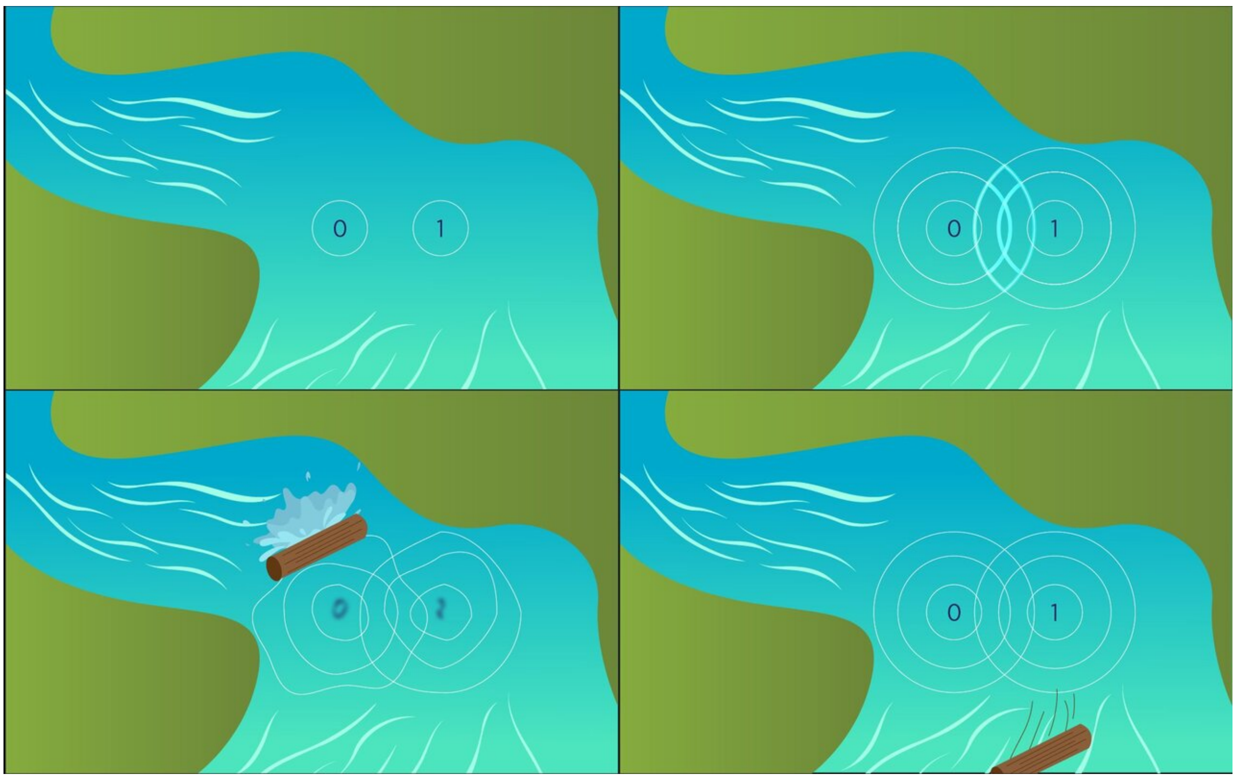

This artist’s conception simplifies the ideas in the paper to illustrate the new qubit design’s overall concept. Photons flow continuously into the cavity like water flowing down a stream (#1), and the photons' wavelike natures interact with one another as an interference pattern, forming a superposition of the values 0 and 1 and storing them as the qubit’s information (#2). Noise represented by the log falling into the stream (#3) can easily destroy an ordinary qubit’s interference pattern, but refreshing the photons keeps the source of the waves strong, allowing the pattern to reestablish itself (#4) in short order, thereby keeping the qubit’s information robust against some common threats. Credit: B.

Hayes/NIST

One of the chief obstacles facing quantum computer designers—correcting the errors that creep into a processor's calculations—could be overcome with a new approach by physicists from the National Institute of Standards and Technology (NIST), the University of Maryland and the California Institute of Technology, who may have found a way to design quantum memory switches that would self-correct.

The team's theory paper, which appears today in the journal *Physical Review Letters*, suggests an easier path to creating stable quantum bits, or qubits, which ordinarily are subject to environmental disturbances and errors. Finding methods of correcting these errors is a major issue in quantum computer development, but the research team's approach to qubit design could sidestep the problem.

"Error correction complicates an already complicated situation. It usually requires that you build in additional qubits and make additional measurements to find the errors, all of which typically leads to large hardware overhead," said first author Simon Lieu, who works at the Joint Quantum Institute (JQI) and the Joint Center for Quantum Information and Computer Science (QuICS), both collaborations between NIST and the University of Maryland. "Our scheme is passive and autonomous. It does all that extra work automatically."

Designers are experimenting with many approaches to building qubits. One promising architecture is called a photonic cavity resonator. Within its tiny volume, multiple photons can be driven to bounce back and forth between the cavity's reflective walls. The photons, manifesting their wavelike properties in the cavity, combine to form ripple-like interference patterns. The patterns themselves contain the qubit's information. It's a delicate arrangement that, like ripples on a pond's surface, tends to dissipate quickly.

It is also easily perturbed. To work, qubits need peace and quiet. Noise from the surrounding environment—such as heat or magnetic fields emitted by other nearby components—can disturb the interference pattern and ruin the calculation.

Rather than construct an elaborate system to detect, measure and compensate for noise and errors, the team members perceived that if the supply of photons in the cavity is constantly refreshed, the qubit's quantum information can withstand certain amounts and types of noise.

Because the cavity can hold many photons, a qubit involves a substantial number of them, building in some redundancy. In some qubit designs, leaking photons to the environment—a common occurrence—means information gets lost. But rather than defend against this sort of leakage, the team's approach incorporates it. Their cavity's remaining photons would sustain the interference pattern long enough for more photons to enter and replace the missing ones.

A constant stream of fresh photons also would mean that if some photons in the cavity became corrupted by noise, they would be flushed out quickly enough that the damage would not be catastrophic. The interference pattern might waver for a moment, as a pond's ripples would if a small rock fell in with a disturbing splash, but the ripples' pulsating sources would remain consistent, helping the pattern—and its quantum information—to reassert itself quickly.

"It's like adding fresh water," Lieu said. "Any time the information gets contaminated, the fact that you're pushing in water and cleaning out your pipes dynamically keeps it resistant to damage. This overall configuration is what keeps its steady state strong."

The approach would not make the qubits resistant to all types of errors, Lieu said. Some disturbances would still qualify as splashes too dramatic for the system to handle. In addition, the concept applies primarily to the photonic cavities the team considered and would not necessarily help strengthen other leading qubit designs.

The proposed method adds to an arsenal of promising quantum computer error-correction techniques, such as "topological" qubits, which would also be self-correcting but require yet-to-be-made exotic materials. While the team expects the new approach to be particularly useful for quantum computing based on microwave photons in superconducting architectures, it might also find applications in computing based on optical photons.

The team's work builds on previous theoretical and experimental efforts on photonic qubits. Lieu said that other physicists already have laid most of the necessary groundwork to test the team's proposal experimentally.

"We are planning to reach out to experimentalists to test the idea," he said. "They would just need to put a couple of existing ingredients together."

More information: Simon Lieu et al. Symmetry Breaking and Error Correction in Open Quantum Systems, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.125.240405

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