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Grant targets quantum computing's error control challenge

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A team of researchers led by Duke University and the University of Maryland has been tapped by the nation's "Q Branch" to take quantum computing efforts to the next level using one of the field's leading technologies—ion traps.

The Intelligence Advanced Research Projects Activity (IARPA) invests in high-risk, high-payoff research programs to tackle some of the most difficult challenges in the intelligence community. One of these challenges is dealing with encryption. Codes considered unbreakable by today's best supercomputers could be handled in a matter of hours by quantum computers.

The basic building blocks of a quantum device are qubits. These are the quantum mechanical analogue of a traditional logical bit, which can be in a "1" or a "0" state. Quantum physics allows for qubits to take on multiple configurations simultaneously (e.g. an equally-weighted superposition of 0 and 1), which is forbidden in conventional computing. When scientists in the 1990s proved that this strange property could be harnessed for solving certain tasks, such as decryption, the quantum information revolution began.

While researchers have proven that robust qubits can be built, scaling them into large networks while detecting and correcting errors remains a challenge.

IARPA has selected the Duke/Maryland/Georgia Tech partnership as one of the awardees in its program dubbed LogiQ. Their goal is to bring together a large number of atomic qubits to realize modular "super-qubits" that can be scaled up while correcting for errors. This major multi-year award is led by Jungsang Kim (Duke University), Christopher Monroe (University of Maryland and the Joint Quantum Institute) and Ken Brown (Georgia Tech).

The effort also includes industry partners AOSense, Inc. (Sunnyvale, California), ColdQuanta, Inc. (Boulder, Colorado) and Harris Corporation (Melbourne, Florida), as well as theoretical support from Andrew Childs (University of Maryland and the Joint Center for Quantum Information and Computer Science) and Luming Duan (University of Michigan).

"Our ion trapping approach is one of the leading technologies that can accomplish this goal," said Jungsang Kim, professor of electrical and computer engineering, computer science, and physics at Duke University, and the principal investigator on the project. "We're excited that IARPA sees our group as one of the leaders in the field and has entrusted this important task to us."

Quantum systems are fundamentally delicate, and superpositions collapse if they are observed. In other words, before useful information can be extracted, computational resources can be compromised and even destroyed by interactions with the environment.

But this obstacle is not insurmountable.

One of the first steps is to construct an extremely robust physical realization of a qubit. In this regard, physicists have demonstrated that trapped atomic ions have quantum staying power. In this system, each qubit is stored in the internal energy levels of a single atomic ion—the same states that are used in atomic clocks. Such states boast coherence times unmatched in any other physical system. The qubits are manipulated through laser and microwave radiation to form quantum logic gates and extended circuits for calculations.

Ion trappers have become quite adept at controlling a handful of individual qubits. This collaboration has previously proposed and performed demonstrations that their approach is scalable and modular, a necessity because many qubits are needed for useful quantum computation.

"Atomic ion qubits are fundamentally scalable, because they can be replicated with virtually identical characteristics: an isolated ytterbium atom is exactly the same in Washington, D.C. as it is in Los Angeles," said Christopher Monroe, professor of physics at the University of Maryland and the Joint Quantum Institute, and co-leader on the project.

"Quantum computing is going through the same research and design processes that conventional computing went through decades ago," said Kim. "Just as the first digital computer was constructed once we had reliable switching devices, we are ready to explore the construction of more complex quantum circuits based on the robust multi-qubit manipulation that is possible in trapped ions."

But all potential quantum computing technologies still face the same problem that is central to the new IARPA LogiQ program: quantum error correction.

"We know how to build a quantum computer with 50-100 qubits with trapped ions right now," said Monroe. "This is a big enough system that we cannot simulate what happens, even with all the conventional computers in the world. But some killer applications of quantum computing require thousands or millions of qubits, and error correction will be crucial to getting there."

As with a conventional computer, scientists can encode quantum systems in a way that corrects for errors that happen along the way, such as an accidental bit flip where a 1 becomes 0, or vice versa.

Even in record-breaking pristine ion-trapping systems, errors grow fairly rapidly as qubits are added. Because of that sneaky rule that makes quantum systems collapse due to measurement—intentional or otherwise—simply interrogating the qubits directly and fixing the broken ones destroys the quantum computation.

The idea of a modular super-qubit or logical qubit begins to address this problem. In this system, the information stored in a logical qubit is encoded into specialized quantum states comprising multiple physical qubits. Distributing the information in this way not only adds protection—it allows for errors to be detected and corrected, all without actually knowing (or needing to know) the exact details of the quantum state as a whole.

"The engineering required to achieve the goal of stopping qubits from degrading through error correction will go a long way toward making quantum computers practically viable," said Kim.

Provided by University of Maryland

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