Scientists have overcome a major hurdle facing quantum computing: how to protect quantum information from degradation by the environment while simultaneously performing computation in a solid-state quantum system. The research was reported in the April 5 issue of *Nature.*

A group led by U.S. Department of Energy's Ames Laboratory physicist Viatsheslav Dobrovitski and including scientists at Delft University of Technology; the University of California, Santa Barbara; and University of Southern California, made this big step forward on the path to using the motions of single electrons and nuclei for quantum information processing. The discovery opens the door to robust quantum computation with solid-state devices and using quantum technologies for magnetic measurements with single-atom precision at nanoscale.

Quantum information processing relies on the combined motion of microscopic elements, such as electrons, nuclei, photons, ions, or tiny oscillating joists. In classical information processing, information is stored and processed in bits, and the data included in each bit is limited to two values (0 or 1), which can be thought of as a light switch being either up or down. But, in a quantum bit, called a qubit, data can be represented by how these qubits orient and move in relationship with each other, introducing the possibility for data expression in many tilts and movements.

This power of quantum information processing also poses a major challenge: even a minor "bump" off course causes qubits to lose data. And qubits tend to interact quite sensitively with their environment, where multiple forces bump them off track.

But, because the key to quantum information processing is in the relationship between qubits, the solution is not as easy as isolating a single qubit from its environment.

"The big step forward here is that we were able to decouple individual qubits from the environment, so they retain their information, while preserving the coupling between the qubits themselves," said Dobrovitski.

Solid-state hybrid systems are useful for quantum information processing because they are made up of different types of qubits that each perform different functions, much like different parts of a car combine to move it down the road. In the case of Dobrovitski's work, the hybrid system includes magnetic moments of an electron and a nucleus.

"This type of hybrid system may be particularly good for quantum information processing because electrons move fast, can be manipulated easily, but they also lose quantum information quickly. Nuclei move very slow, are difficult to manipulate, but they also retain information well," said Dobrovitski. "You can see an analogy between this hybrid quantum system and the parts of a classical computer: the processor works fast but doesn't keep information long, while the memory works slowly but stores information for a long time."

Usually, when you decouple qubits from their environment to protect their quantum data, you decouple them from everything, even from each other.

But, Dobrovitski found a narrow window of opportunity where both the electron and nucleus can be decoupled from their environment, while retaining their relationship to each other.

"The solution is applying a certain pattern of kicks to the electron's magnetic moment, so that tiny rotations between each kick accumulate and coincide with the rotation of the nucleus," said Dobrovitski. "We can separate out this particular single electron movement from thousands of others because it is synchronized with the motion of the nuclear magnetic moment."

As a result, the electron's and nucleus' movements stay linked, while they are both protected from being bumped off course and retain their quantum information processing capabilities.

Experiments carried out by a team of scientists from Delft University of Technology in the Netherlands and University of California, Santa Barbara, showed that theoretical development of this technique worked well in practice.

The researchers took the technique one step further and showed that it can be used for small-scale quantum information processing. Scientists at Delft and UCSB successfully carried out Grover's quantum search algorithm, a method for searching random lists. In this case, they used the solid-state hybrid system to correctly search a list of four random items.

"This is the first time a robust quantum computation has been demonstrated using a solid-state system with individual spins," said Dobrovitski. "We showed that even with the inevitable imperfections of experiments, we can use this system to do quantum information processing in a way that beats its classical counterpart. Indeed, for a list of four items, the quantum device finds with certainty the desired entry by looking into the list only once, while classically we must inspect all four items one by one."

While a four-item list is a small list, consider the possibility of a random list of a million entries. Using classical computing, 500,000 queries would be needed. But, using quantum information processing, only 1,000 queries are required, showing just how much faster tomorrow's quantum information processing will be than today's classical computers.

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