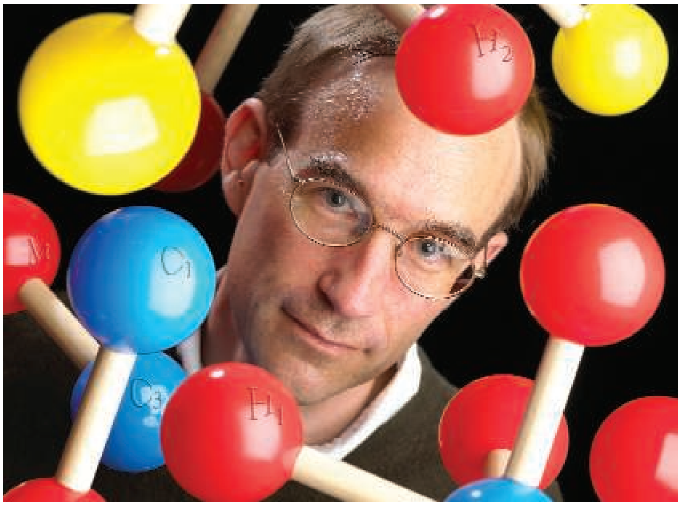
Teaching Qubits New Tricks

A novel approach to storing information could give computers with near-magic powers a boost toward reality

Quantum computers will shatter the encryption that makes Internet commerce safe, search databases at unthinkable speeds, and crank out ciphers that nature itself guarantees secure—if they can be built. For years, scientists thought that would never happen because the same laws of physics that make quantum computers so powerful seemed to make a practical prototype impossible. But in 1995, when they discovered a means of preserving fragile quantum information despite those laws, quantum computing took a step closer to reality. The heart of the discovery was a way to correct errors in quantum information without destroying the information itself. These so-called quantum error correcting codes lie at the heart of quantum-computer research.



Better way. Ray Laflamme and colleagues showed that "qubits" of data last longer when not stored on quantum objects such as atoms.

Now physicist Ray Laflamme and colleagues at the University of Waterloo in Ontario, Canada, have mathematically reframed quantum error correction in a way that shows that seemingly distinct approaches to it are really the same. This insight could make quantum error correction more efficient and may well push the field toward a much deeper understanding of the limits of quantum information.

"I think this is a very nice advance," says Peter Shor, a mathematician and physicist at the Massachusetts Institute of Technology. "Whether it's a giant leap or just a substantial step forward remains to be seen."

Information, whether it's classical bits stored on silicon or quantum "qubits" inscribed on a cluster of atoms, is extremely perishable. Nature spreads it throughout the environment, diluting it, filling it with errors, and making it unreadable. The ravages of time tend to flip bits and turn precious information into useless gobbledygook. For classical computers, the solution is simple: Make a backup. Then, if nature corrupts your original data, you can restore it from the copy. This is the most rudimentary form of error-correction, and every computer and digital communications device bristles with ever more sophisticated ways of ensuring that data gets stored or moves from place to place without being corrupted. The packets your computer sends over the Internet are padded with error-correcting information; the files on your hard drive are flush with extra data to protect from random bit flips; even your cell phone has means of detecting and compensating for damaged data that it receives.

But in quantum mechanics, copying is impossible, thanks to the "no-cloning rule": You can't duplicate information with perfect fidelity. The act of measuring a quantum object—such as an atom in a delicate state of superposition—destroys the original as you transfer its information to another medium. Any attempt to clone a chunk of quantum information is doomed to failure.

As a result, many theorists believed that it would be impossible to correct errors in quantum information. Laflamme was one of the naysayers. "I tried to write a paper about it, saying that you would not be able to build a quantum computer," he says. But a colleague scooped Laflamme and published first. "I was upset, so I decided to poke some holes in the argument," he says.

In the mid-1990s, Shor, Laflamme, and a number of other physicists began to realize that there was a way to correct errors without violating the laws of quantum theory. "What we were thinking at the time was that the way we encode information in physical systems—a qubit upon an atom or a photon—was not very reliable," says Laflamme. Instead, scientists realized, they could spread a qubit over several quantum objects such as atoms or photons at once. The key was to store the information not on a single object but in the relationship among those objects; technically, the collection of objects shares a single quantum state that encodes the information. Unlike information stored on a single object, information inscribed upon such a collection can be made error-resistant without running afoul of the no-cloning rule, because it doesn't need to be copied or read.

In a paper recently published in *Physical Review Letters*, Laflamme and colleagues took the principle of abstraction a step further. Instead of storing information on relationships between quantum objects, they argued, one should store it on the relationship among the relationships. "It's getting more abstract, getting further away from the physical system," Laflamme acknowledges. "But the usual quantum gates can do this easily, and it has some very neat applications."

Using this "operator" formalism, Laflamme says, physicists can make error-correcting codes with smaller ensembles of atoms (or photons or other quantum objects) than ever before, thanks to the improved efficiency that the method allows. The new mathematical structure also enabled Laflamme to prove that several seemingly different quantum-computational methods for controlling errors are really the same.

"Some other methods of error corrections were proposed that are more passive," says William Wootters, a physicist at Williams College in Williamstown, Massachusetts. Instead of actively correcting errors as they occur, physicists can pick a setup in which, under certain conditions, the information they inscribe on the system is immune from errors. "It seemed to be a different approach," Wootters says. "This paper shows that you can reduce the passive kind to the active kind." That means that physicists might now be able to borrow powerful tools from each of these areas and apply them to the others.

"We're not sure yet what the real power of this technique is," says Laflamme. "We haven't found the killer application." Nevertheless, it's clear that the abstract approach will give theorists a concrete ability to explore new facets of a decade-old idea. "It allows us to understand that quantum error correction is much richer than we had thought," he says.

–CHARLES SEIFE

CREDIT: BRYN GLADDING

Published by AAAS