Flying qubits make for a highly resilient quantum memory

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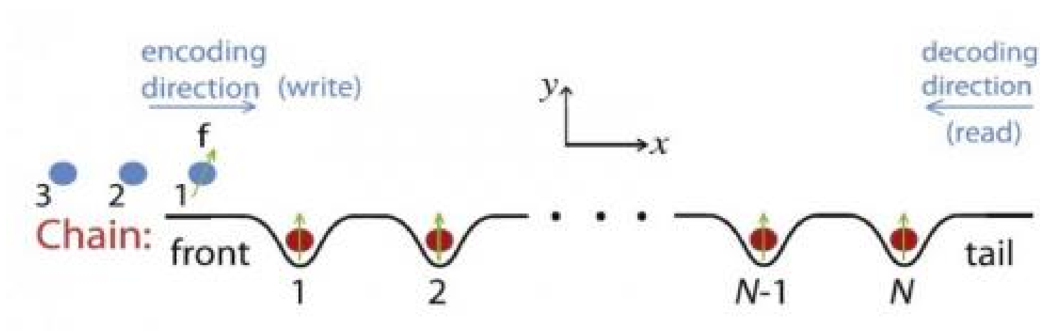

Illustration of the passive memory system, in which flying qubits (blue) enter the front end of the chain of polarized spins (red). The qubits interact with the spins and become polarized when they emerge at the tail end. To read the stored information, the polarized qubits are injected back from the tail end, and their states are recovered from the front end. Credit: Y. Ping, et al. ©2014 IOP Publishing Ltd

(Phys.org) —In a quantum memory, the basic unit of data storage is the qubit. Because a qubit can exist in a superposition state of both "1" and "0" at the same time, it can process much more information than a classical bit. However, qubits are often very unstable due to decoherence, currently making them impractical for real-life memory storage.

In a new paper published in the *New Journal of Physics*, physicists Yuting Ping at the University of Oxford, John H. Jefferson at Lancaster

University, and Brendon W. Lovett at the University of St. Andrews have designed a quantum memory that is resilient to decoherence and various other imperfections. The design is based on qubits that are mobile, called "flying qubits," which move along a chain of quantum processors that store the qubits' states.

"Since quantum information processing typically takes place on static, controlled qubits, but quantum networking would need 'flying' qubits to move from one location to another, it is important to develop ways of transferring information from one type to the other," Lovett told *Phys.org*. "Since it is typically not known exactly when a flying qubit might arrive at a quantum register, it is crucial to find ways of doing this conversion without requiring precisely timed active control. We do exactly this here, proposing a completely passive way in which we might capture the information from flying qubits."

In the new theoretical protocol, flying qubits (which could take the form of ultracold atoms) travel single-file across a long, polarized chain of spin particles, which act as quantum processors. Each flying qubit interacts with the spins sequentially, transporting its quantum state to the spin. When the flying qubit eventually emerges at the opposite end of the chain, it has become polarized in the direction of the majority of the spins. In this scenario, the spin particles act as a long memory chain, storing the quantum states of the qubits.

In order to read out the quantum states stored in the spin particles, the process is basically reversed. One by one, each polarized qubit is injected backwards through the chain of spin particles, and their states are recovered at the front end. Crucially, the system does not need to be reset between the encoding and decoding processes, since that would result in a loss of all of the information stored.

As Lovett explained, one of the biggest advantages of this flying-qubit-based quantum memory is that it is completely passive. Most quantum memories developed so far require a level of active control, which is where errors are often introduced. By using a more passive protocol, these errors may be reduced. In addition, the fact that the quantum information is spread over many spins in the memory chain makes the design further resistant to decoherence and other imperfections.

The physicists conjecture that this process can be used to store the quantum states of any number of flying qubits, although fully proving this conjecture is still an open challenge. The scientists do, however, prove that the process works for one or two flying qubits of arbitrary quantum states, as well as for any number of flying qubits in an up state plus one flying qubit in a down state.

The scientists anticipate that it will be possible to experimentally implement the quantum memory chain using ultracold "flying" atoms in optical traps. The atoms could be ballistically transported in a controlled way across a chain of spin particles by using a spatial light modulator.

"Our future research will be focused mainly on working with experimentalists to demonstrate the idea," Lovett said. "The atom trap is perhaps the most immediately promising route, but one could also imagine a solid state device where the passive qubits might be donors in silicon or nitrogen vacancy defects in diamond."

More information: Yuting Ping, et al. "Coherent and passive one dimensional quantum memory." *New Journal of Physics*. DOI: 10.1088/1367-2630/16/10/103025