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Teleportation exits realm of sci-fi

By R. Colin Johnson , EE Times
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The problem with teleportation — the real beam-me-up-Scotty kind — is not its principles, which appear to be sound, but in the devil's details. Fact: There is no way to "encode" all the detailed information in a single quantum state, much less the entire human body (which is composed of about 100,000,000,000,000,000,000,000,000,000,000 "quantum bits," or qubits). It would take a 1,000-km cube to house that much information on CD-ROMs. Even if you could automatically assemble them into Captain Kirk, just to transmit their data with theoretically perfect fat-pipe optical fibers would take more than 100 million centuries.

Nevertheless, researchers in the lab have begun to demonstrate true teleportation — not the sort that disassembles Kirk and puts him back together on the planet surface, but the kind that delivers the devil's details from point A (for Alice) to B (for Bob) despite there being no way to encode all that data.

How? By not encoding it. Instead, Alice mixes the unencodable data with the quantum state of an entangled pair for which Bob has the twin — and presto! The phenomenon that Albert Einstein called "spooky action at a distance" teleports the unencodable quantum states, qubit per qubit.

Historically speaking

Einstein wrote his seminal paper that enabled quantum mechanics in 1905, and by the 1930s he had put his head together with Boris Podolsky and Nathan Rosen to predict quantum entanglement (officially the Einstein-Podolsky-Rosen effect). In the 1960s, John Bell showed that an entangled pair can remain linked independent of how far apart they are moved — what Einstein had predicted to be spooky action at a distance.

Since then, experiments on photons, electrons and atoms have repeatedly confirmed the entanglement phenomenon. Originally it was thought to be useful only in proving the validity of quantum mechanics, but now it is being used to perform actual beam-me-up teleportation, albeit for a single qubit, of which the human body has about 1032.

Quantum teleportation was shown to be theoretically possible in 1993 by an international group of six scientists, including IBM fellow Charles Bennett. "Teleportation is possible because you don't have to extract all the information from an object to teleport it — the unscanned part can be passed by the Einstein-Podolsky-Rosen effect," said Bennett (see story, this page).

Before Bennett's group published its results, most scientists assumed that the inability to simultaneously measure both the particle and wave properties of subatomic particles (Heisenberg's uncertainty principle) would prevent sufficient in- formation from being gathered, much less encoded, to enable teleportation. Bennett and colleagues, however, convinced the scientific community that teleportation of quantum states could be achieved if Alice destroyed them while Bob recovered them by virtue of two entangled particles (one held by the sender, Alice, and the other held by the receiver, Bob).

A quantum state involves everything there is to know about a particle, such as spin, velocity, position, momentum, mass and an indeterminate number of other properties we don't even understand yet. Heisenberg's uncertainty principle maintained that measurement of particle-type information destroyed the wave-type information and visa versa.

However, Bennett demonstrated that the Einstein-Podolsky-Rosen effect (entanglement, or spooky action at a distance) enables teleportation to sidestep Heisenberg's uncertainty. When

Alice destroys the original datum by combining it with her half of the entangled pair, Bob's entangled pair is compelled to react exactly as Alice's just did, thereby enabling Bob to unravel the original datum without the need to measure all its properties.

Several groups between 1997 and 2003 subsequently demonstrated various techniques for teleporting qubits using light polarization, but the National Institute of Standards and Technology (NIST) this year became the first to teleport the state of one of Captain Kirk's atoms. "Others have demonstrated teleportation with light beams, but ours is the first demonstration with atomic qubits," said NIST physicist David Wineland. "Teleporting between locations in a quantum computer is the way we will move the information around and perform the kind of error correction you need to make quantum computing work" (see story, opposite page).

NIST has had so much success with quantum computation, quantum encryption, quantum key distribution and now quantum teleportation that it has set up a national Quantum Communication Testbed that routinely exchanges uncrackable sifted quantum cryptographic keys over a 730-meter free-space link at rates of up to 1 Mbit/second.

NIST demonstrated the actual real-time beam-me-up teleportation of the state of a single qubit over a distance of 600 microns, making it suitable for real-time quantum-error correction of future quantum-computing chips.

NIST's demonstration teleported a beryllium ion's qubit among ion traps on a substrate made of gold deposited onto alumina. (The University of Innsbruck, Austria, also reported in 2004 replicating the Bennett-style teleportation between substrate-bound ion traps similar to NIST's, but using calcium ions.) The maximum distance, 600 microns, was not as far as from the Enterprise down to the surface of a planet, but it's a start.

The second, less-publicized fact about teleportation is that scientists now believe that you don't have to exactly duplicate an atom's state to completely replicate it. There appears to be some "noise" in matter that eliminates the need for what was previously assumed to be impossible-to-achieve accuracy, something that Einstein explained in his second major paper, even before relativity: that is, that random "jiggling" of atoms in gases and fluids (called Brownian motion) sets a lower limit on how accurately you need to measure atoms to teleport them.

"If you were teleporting Captain Kirk, you wouldn't need impossible accuracy, even while retaining all his current memories and emotions. Samuel Braunstein has even made a calculation that shows this quite well," said IBM's Bennett.

In particular, Braunstein, a professor at England's University of York and a member of one of the first experimental groups to teleport light, claims that to teleport the analog value of, say, the velocity of a hydrogen atom, your measurement accuracy would need to be no more accurate than 1,000 meters per second.

Why? Because the random jiggling of Brownian motion introduces a fudge factor of about that much.

Further, according to Braunstein's calculation, when you check the uncertainly inherent in quantum-state measurements, they are already more accurate than necessary. Quantum-mechanical measurements of velocity, according to Braunstein, have an accuracy of about 300 meters/second. That's accurate enough to teleport, since the random jiggling of atoms is more than that by a factor of three.

"The detailed quantum state is not important to get right when you want to copy a person and make a new one from the partial information," said Braunstein. "People routinely go to hospitals for NMR [nuclear magnetic resonance] and ESR [electron-spin resonance], and these procedures mix up the quantum states of the people being scanned. And yet it doesn't even seem to disturb their appetites."

Conclusion: Teleportation does not have to be impossibly exact. In fact, the qubits that have already been transmitted by NIST would have been good enough to transport one of Captain Kirk's atomic qubits.

Only 100,000,000,000,000,000,000,000,000,000,000,000 to go.