Time warp: Researchers show possibility of cloning quantum information from the past

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(Phys.org) —Popular television shows such as "Doctor Who" have brought the idea of time travel into the vernacular of popular culture. But problem of time travel is even more complicated than one might think. LSU's Mark Wilde has shown that it would theoretically be possible for time travelers to copy quantum data from the past.

It all started when David Deutsch, a pioneer of quantum computing and a physicist at Oxford, came up with a simplified model of time travel to deal with the paradoxes that would occur if one could travel back in time. For example, would it be possible to travel back in time to kill one's grandfather? In the Grandfather paradox, a time traveler faces the problem that if he kills his grandfather back in time, then he himself is never born, and consequently is unable to travel through time to kill his grandfather, and so on. Some theorists have used this paradox to argue that it is actually impossible to change the past.

"The question is, how would you have existed in the first place to go back in time and kill your grandfather?" said Mark Wilde, an LSU assistant professor with a joint appointment in the Department of Physics and Astronomy and with the Center for Computation and Technology, or CCT.

Deutsch solved the Grandfather paradox originally using a slight change to quantum theory, proposing that you could change the past as long as you did so in a self-consistent manner.

"Meaning that, if you kill your grandfather, you do it with only probability one-half," Wilde said. "Then, he's dead with probability one-half, and you are not born with probability one-half, but the opposite is a fair chance. You could have existed with probability one-half to go back and kill your grandfather."

But the Grandfather paradox is not the only complication with time travel. Another problem is the no-cloning theorem, or the no "subatomic Xerox-machine" theorem, known since 1982. This theorem, which is related to the fact that one cannot copy quantum data at will, is a consequence of Heisenberg's famous Uncertainty Principle, by which one can measure either the position of a particle or its momentum, but not both with unlimited accuracy. According to the Uncertainty Principle, it is thus impossible to have a subatomic Xerox-machine that would take one particle and spit out two particles with the same position and momentum – because then you would know too much about both particles at once.

"We can always look at a paper, and then copy the words on it. That's what we call copying classical data," Wilde said. "But you can't arbitrarily copy quantum data, unless it takes the special form of classical data. This no-cloning theorem is a fundamental part of quantum mechanics – it helps us reason how to process quantum data. If you can't copy data, then you have to think of everything in a very different way."

But what if a Deutschian closed timelike curve did allow for copying of quantum data to many different points in space? According to Wilde, Deutsch suggested in his late 20th century paper that it should be possible to violate the fundamental no-cloning theorem of quantum mechanics. Now, Wilde and collaborators at the University of Southern California and the Autonomous University of Barcelona have advanced Deutsch's 1991 work with a recent paper in *Physical Review Letters*. The new approach allows for a particle, or a time traveler, to make multiple loops back in time – something like Bruce Willis' travels in the Hollywood film "Looper."

"That is, at certain locations in spacetime, there are wormholes such that, if you jump in, you'll emerge at some point in the past," Wilde said. "To the best of our knowledge, these time loops are not ruled out by the laws of physics. But there are strange consequences for quantum information processing if their behavior is dictated by Deutsch's model."

A single looping path back in time, a time spiral of sorts, behaving according to Deutsch's model, for example, would have to allow for a particle entering the loop to remain the same each time it passed through a particular point in time. In other words, the particle would need to maintain self-consistency as it looped back in time.

"In some sense, this already allows for copying of the particle's data at many different points in space," Wilde said, "because you are sending the particle back many times. It's like you have multiple versions of the particle available at the same time. You can then attempt to read out more copies of the particle, but the thing is, if you try to do so as the particle loops back in time, then you change the past."

To be consistent with Deutsch's model, which holds that you can only change the past as long as you can do it in a self-consistent manner, Wilde and colleagues had to come up with a solution that would allow for a looping curve back in time, and copying of quantum data based on a time traveling particle, without disturbing the past.

"That was the major breakthrough, to figure out what could happen at the beginning of this time loop to enable us to effectively read out many copies of the data without disturbing the past," Wilde said. "It just worked."

However, there is still some controversy over interpretations of the new approach, Wilde said. In one instance, the new approach may actually point to problems in Deutsch's original closed timelike curve model.

"If quantum mechanics gets modified in such a way that we've never observed should happen, it may be evidence that we should question Deutsch's model," Wilde said. "We really believe that quantum mechanics is true, at this point. And most people believe in a principle called Unitarity in quantum mechanics. But with our new model, we've shown that you can essentially violate something that is a direct consequence of Unitarity. To me, this is an indication that something weird is going on with Deutsch's model. However, there might be some way of modifying the model in such a way that we don't violate the no-cloning theorem."

Other researchers argue that Wilde's approach wouldn't actually allow for copying quantum data from an unknown particle state entering the time loop because nature would already "know" what the particle looked like, as it had traveled back in time many times before.

But whether or not the no-cloning theorem can truly be violated as Wilde's new approach suggests, the consequences of being able to copy quantum data from the past are significant. Systems for secure Internet communications, for example, will likely soon rely on quantum security protocols that could be broken or "hacked" if Wilde's looping time travel methods were correct.

"If an adversary, if a malicious person, were to have access to these time loops, then they could break the security of quantum key distribution," Wilde said. "That's one way of interpreting it. But it's a very strong practical implication because the big push of quantum communication is this secure way of communicating. We believe that this is the strongest form of encryption that is out there because it's based on physical principles."

Today, when you log into your Gmail or Facebook, your password and information encryption is not based on physical principles of quantum mechanical security, but rather on the computational assumption that it is very difficult for "hackers" to factor mathematical products of prime numbers, for example. But physicists and computer scientists are working on securing critical and sensitive communications using the principles of quantum mechanics. Such encryption is believed to be unbreakable – that is, as long as hackers don't have access to Wilde's looping closed timelike curves.

"This ability to copy quantum information freely would turn quantum theory into an effectively classical theory in which, for example, classical data thought to be secured by quantum cryptography would no longer be safe," Wilde said. "It seems like there should be a revision to Deutsch's model which would simultaneously resolve the various time travel paradoxes but not lead to such striking consequences for quantum information processing. However, no one yet has offered a model that meets these two requirements. This is the subject of open research."

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