Simulations of 'backwards time travel' can improve scientific experiments

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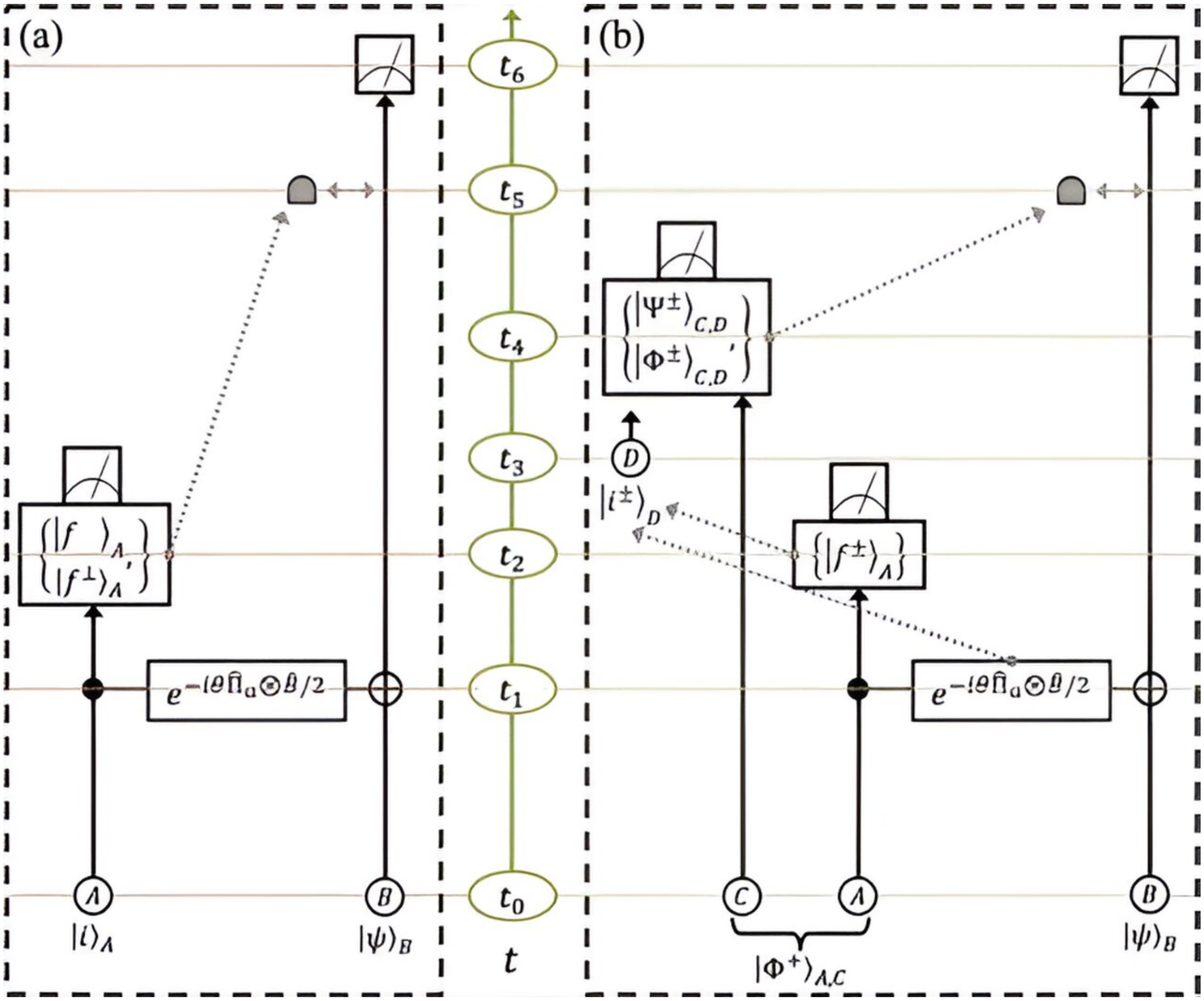

Circuit diagrams for (a) standard and (b) PCTC-powered weak-value amplification. Time progresses in the laboratory's rest frame as one proceeds upward along the central, vertical axis. Black lines represent qubits. Dashed gray lines represent classical information. Credit: *Physical Review Letters* (2023).

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Physicists have shown that simulating models of hypothetical time travel can solve experimental problems that appear impossible to solve using standard physics.

If gamblers, investors and quantum experimentalists could bend the arrow of time, their advantage would be significantly higher, leading to significantly better outcomes.

Researchers at the University of Cambridge have shown that by manipulating entanglement—a feature of quantum theory that causes particles to be intrinsically linked—they can simulate what could happen if one could travel backwards in time. So that gamblers, investors and quantum experimentalists could, in some cases, retroactively change their past actions and improve their outcomes in the present.

Whether particles can travel backwards in time is a controversial topic among physicists, even though scientists have previously simulated models of how such spacetime loops could behave if they did exist. By connecting their new theory to quantum metrology, which uses quantum theory to make highly sensitive measurements, the Cambridge team has shown that entanglement can solve problems that otherwise seem impossible.

The study appears in *Physical Review Letters*.

"Imagine that you want to send a gift to someone: you need to send it on day one to make sure it arrives on day three," said lead author David Arvidsson-Shukur, from the Cambridge Hitachi Laboratory. "However, you only receive that person's wish list on day two. So, in this chronologyrespecting scenario, it's impossible for you to know in advance what they will want as a gift and to make sure you send the right one."

"Now imagine you can change what you send on day one with the information from the wish list received on day two. Our simulation uses quantum entanglement manipulation to show how you could retroactively change your previous actions to ensure the final outcome is the one you want."

The simulation is based on quantum entanglement, which consists of strong correlations that quantum particles can share and classical particles—those governed by everyday physics—cannot.

The particularity of quantum physics is that if two particles are close enough to each other to interact, they can stay connected even when separated. This is the basis of quantum computing—the harnessing of connected particles to perform computations too complex for classical computers.

"In our proposal, an experimentalist entangles two particles," said co-author Nicole Yunger Halpern, researcher at the National Institute of Standards and Technology (NIST) and the University of Maryland. "The first particle is then sent to be used in an experiment. Upon gaining new information, the experimentalist manipulates the second particle to effectively alter the first particle's past state, changing the outcome of the experiment."

"The effect is remarkable, but it happens only one time out of four," said Arvidsson-Shukur. "In other words, the simulation has a 75% chance of failure. But the good news is that you know if you have failed. If we stay with our gift analogy, one out of four times, the gift will be the desired one (for example a pair of trousers), another time it will be a pair of trousers but in the wrong size, or the wrong color, or it will be a jacket."

To give their model relevance to technologies, the theorists connected it to quantum metrology. In a common quantum metrology experiment, photons—small particles of light—are shone onto a sample of interest and then registered with a special type of camera. If this experiment is to be efficient, the photons must be prepared in a certain way before they reach the sample.

The researchers have shown that even if they learn how to best prepare the photons only after the photons have reached the sample, they can use simulations of time travel to retroactively change the original photons.

To counteract the high chance of failure, the theorists propose to send a huge number of entangled photons, knowing that some will eventually carry the correct, updated information. Then they would use a filter to ensure that the right photons pass to the camera, while the filter rejects the rest of the 'bad' photons.

"Consider our earlier analogy about gifts," said co-author Aidan McConnell, who carried out this research during his master's degree at the Cavendish Laboratory in Cambridge, and is now a Ph.D. student at ETH, Zürich. "Let's say sending gifts is inexpensive and we can send numerous parcels on day one. On day two we know which gift we should have sent. By the time the parcels arrive on day three, one out of every four gifts will be correct, and we select these by telling the recipient which deliveries to throw away."

"That we need to use a filter to make our experiment work is actually pretty reassuring," said Arvidsson-Shukur. "The world would be very strange if our time-travel simulation worked every time. Relativity and all the theories that we are building our understanding of our universe on would be out of the window."

"We are not proposing a time travel machine, but rather a deep dive into the fundamentals of quantum mechanics. These simulations do not allow you to go back and alter your past, but they do allow you to create a better tomorrow by fixing yesterday's problems today."

More information: David R. M. Arvidsson-Shukur et al, Nonclassical Advantage in Metrology Established via Quantum Simulations of Hypothetical Closed Timelike Curves, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.150202

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