In quantum mechanics, the pigeon and the letter do not always travel together

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Concept of counterfactual communication, where the pigeon and the message do not travel in the same direction. Credit: University of Vienna, created by Jon Ladrón de Guevara

In standard communication the pigeon always carries the message; the information is linked to a physical entity/particle. Counter to intuition, in a new counterfactual communication protocol published in NPJ Quantum Information, scientists from the University of Vienna, the

University of Cambridge and the MIT have experimentally demonstrated that in quantum mechanics this is not always true, thereby contradicting a crucial premise of communication theory.

Whether it is pigeons in the air, electrons in a telegraph wire, radio waves from a cell phone or single photons in an optical fiber, in standard communication, there is always a particle or wave involved in the information exchange between two parties; say Alice and Bob. However, in quantum mechanics, one can send information from Alice to Bob while the particle or wave involved in this information exchange travels from Bob to Alice.

In an international collaboration led by Philip Walther, scientist from the University of Vienna teamed up with the University of Cambridge and the Massachusetts Institute of Technology to implement a new counterfactual communication protocol. In standard photonic communication, the information is encoded in single photons; thus, the information and the single photons travel in the same direction. However, in counterfactual communication there is no carrier found travelling in the same direction as the message. In this implementation, single photons would travel from Alice to Bob while information would travel from Bob to Alice.

What carries the message then? Even before receiving the single photon, Bob prepares his setup according to the information bit that he wants to send, either 0 or 1. In this way, he sends the single photon back if he wants to send a bit 1 or keeps the photon in his laboratory if he wishes to send a bit 0. Counterintuitively, the Zeno effect, which was first discovered by cryptanalyst Alan Turing, enables Bob to send the photon back without actually interacting with it. Alice will then interpret Bob's message by observing whether the sent photon is returned or not. Thus, the presence and the absence of single photons is enough to encode any message.

In previous counterfactual communication protocols, there remains some uncertainty as to whether Bob interacted with the photons or not. In this new implementation the two main drawbacks of earlier implementations, weak trace and postselection, have now been completely overcome. "In our implementation, there is no trace of the photon travelling in the same direction as the information and we are able to compensate the message errors without discarding information bits." says I. Alonso Calafell, one of the authors from the publication.

By combining an integrated photonic platform built at MIT, together with a novel theoretical proposal developed at the University of Cambridge, scientist from the University of Vienna contradicted a crucial premise of communication theory: that a message is always carried by physical particles or waves.

More information: I. Alonso Calafell et al. Trace-free counterfactual communication with a nanophotonic processor, *npj Quantum Information* (2019). DOI: 10.1038/S41534-019-0179-2

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