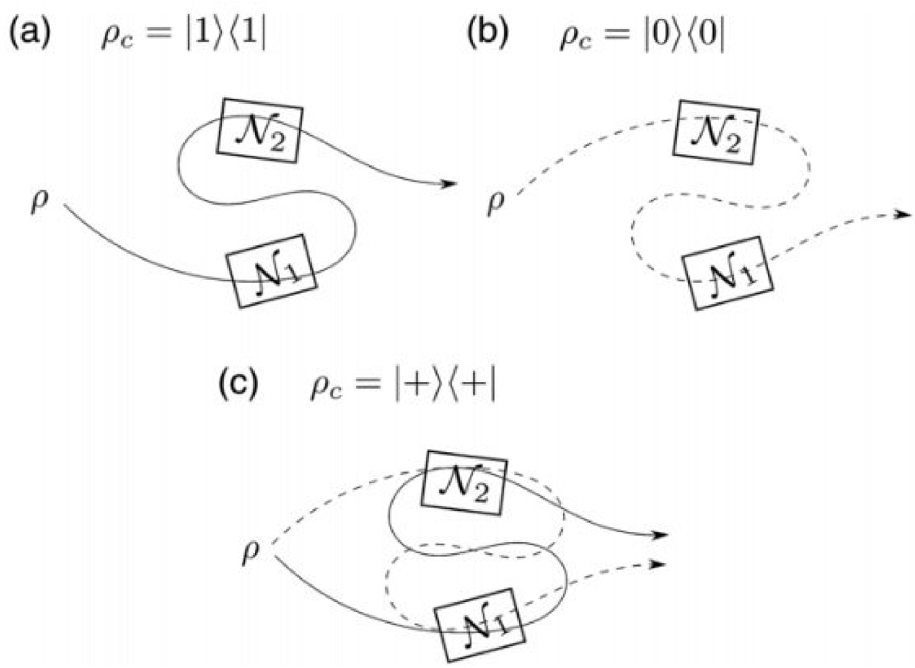
For identical quantum channels, order matters

April 9 2018, by Lisa Zyga



In (a) and (b), a quantum particle travels through two channels, N1 and N2, in a fixed order. In (c), a quantum switch creates a superposition of the two configurations in (a) and (b). Credit: Ebler et al. ©2018 American Physical Society

Physicists have demonstrated that using two quantum channels in different orders can enhance a communication network's ability to transmit information—even, counterintuitively, when the channels are identical. This result lies in stark contrast with how things work with identical classical channels (or pretty much anything else that is identical), where using them in a different order should not make any difference.

Physicists Daniel Ebler, Sina Salek, and Giulio Chiribella have published a paper on this unusual property of quantum channels and its potential advantages for quantum communication in a recent issue of *Physical Review Letters*.

"This is a new paradigm of quantum communication," Salek told *Phys.org*. "Not only are the carriers of information quantum, but also the communication channels can be combined in a quantum way. In this new paradigm, it is possible to communicate in situations where normally no communication would be possible."

Information theory, pioneered by the seminal work of Claude Shannon, was originally formulated as a classical theory, but in recent years has given rise to quantum Shannon theory. Although quantum communication networks use quantum particles and quantum processes to encode and decode information, the actual channels are still connected in a classical way—that is, in a fixed order. This means that quantum particles traveling through the network will always pass through the channels in the same order every time.

In the new study, the physicists investigated the possibility of connecting two identical channels in a quantum superposition of different orders. To do this, they used an operation called a "quantum switch" that takes two identical channels as inputs and creates a new channel in which the order of the two input channels is entangled with a control system. They then showed that the resulting quantum superposition of channel orders can be used to communicate classical information in this network, which is impossible to do when the order is fixed.

As the physicists explain, the results may seem paradoxical because exchanging the order of two identical channels does not appear to have any effect in an ordinary quantum circuit. However, quantum channels are inherently noisy, and so each channel can be decomposed into a random mixture of different processes. Some of these processes do not commute with each other—that is, using the processes in different orders produces different outcomes—and so these differences carry over to the channels themselves.

This underlying randomness leads to the ability to create a channel that transmits information—information that is contained neither in the state of the system alone nor in the state of the control alone, but rather in the correlations between them.

The physicists calculated the maximum amount of information that can be transmitted by switching two identical channels, and they expect that it may be possible to communicate more information by using additional copies of these channels. In collaboration with the group of Professor Philip Walther in Vienna, they are now planning to implement their communication protocol with photons.

"The goal is to develop a full theory of communication, extending Shannon's theory to situations where different transmission lines can be combined in a quantum way," Salek said.

More information: Daniel Ebler, Sina Salek, and Giulio Chiribella. "Enhanced Communication with the Assistance of Indefinite Causal Order." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.120.120502

Also at: arXiv:1711.10165 [quant-ph]

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Citation: For identical quantum channels, order matters (2018, April 9) retrieved 24 April 2024 from https://phys.org/news/2018-04-identical-quantum-channels.html

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