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Quantum computation with indefinite causal structures

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ABSTRACT

The laws of quantum mechanics allow for the superposition not only of momentum, polarization, spin, but also of causal structures, by superposing the direction of signalling between two parties. This quantum-controlled order of signalling is known as the quantum switch, and is the simplest example of an indefinite causal structure. We show that using it allows us to solve a computational problem with asymptotically less queries than are needed in a quantum computer where the direction of signalling is fixed. The quantum switch was implemented experimentally and this advantage demonstrated at the University of Vienna. We extend the ideas behind this demonstration into a general tool to detect the indefiniteness of any causal structure - a causal witness. Such a causal witness, tailored for the quantum switch, was also experimentally demonstrated at the University of Vienna.
We want to investigate also the physical implementability of causal structures beyond the quantum switch -- especially the ones that display indefinite causality in a stronger sense, by violating a causal inequality. We show then that several indefinite causal structures cannot be reconciled with the reversibility of physical laws, and propose that they should therefore be considered unphysical.