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Indefinite causal structures: physical implementability and applications

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Abstract:

We examine the consequences of lifting the assumption of a global causal order from a quantum information perspective. Building upon the “processes matrix” formalism, we first investigate how quantum processes can violate constraints on the probability distributions satisfied by all causally ordered processes. Second, we study a class of physically implementable processes, in which the order in which two parties, Alice and Bob, apply their operations is put in a coherent superposition of “Alice before Bob” and “Bob before Alice” and demonstrate that these resources allow for a scalable reduction of the communication required to complete a certain task. Third, we apply the formalism to a fixed causal order with three parties, where the causal relationship between Alice’s and Bob’s event is in a quantum superposition of a direct causal link and a shared common cause. We develop a criterion to distinguish such a situation from classical mixtures of causal structures and propose a physical implementation.