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Quantum Indefiniteness of Causal Relations

Quantum mechanics differs from classical physics in that no definite values can be attributed to unobserved physical quantities. However, the notion of time and of causal order preserves such an objective status in the theory: all operations are assumed to be ordered such that every operation is either in the future, in the past or space-like separated from any other operation. Consequently, the correlations between operations respect definite causal order: they are either signalling correlations for the time-like or no-signalling correlations for the space-like separated operations. I will present a framework that assumes only that operations in local laboratories are described by quantum mechanics (i.e. are completely-positive maps), but relax the assumption that they are causally connected. Remarkably, we find situations where two operations are neither causally ordered nor in a probabilistic mixture of definite causal orders, i.e. one cannot say that one operation is before or after the other. The correlations between the operations are shown to enable communication and computation that are impossible if the operations are ordered according to a fixed background time. In a classical limit causal order always arises, which suggests that space-time and definite causal relations may emerge from a more fundamental structure in a quantum-to-classical transition.

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