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Back-Action causes the Difference between Classical and Quantum Counterfactual Effects

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We quantify the difference between classical and quantum counterfactual effects, where an output distribution is somehow changed by the removal of signal ("blocking") at some point. We show that there is a counterfactual gain in quantum counterfactual communication, which quantifies the effect it has above and beyond any classical counterfactual effect, and that this counterfactual gain comes from coherences. This counterfactual gain contains a term proportional to a Kirkwood-Dirac quasiprobability term—when this is positive or zero, this counterfactual gain can only distribute probability more equitably over a the set of outputs; however, if this Kirkwood-Dirac term is negative, blocking can cause output probability to focus on a specific outcome. We show that this difference between quantum and classical counterfactual effects results from the measurement backaction caused by this blocking. We show that we cannot explain quantum counterfactual effects simply by removing detection events. We link this to attempts to argue from counterfactuals in quantum mechanics (e.g. when forming noncontextual and Bell inequalities), and show that this backaction effect forms a natural explanation for the violation of the statistical, or measurement, independence assumption used to form these inequalities.

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