Abstract Submitted
for the MAR14 Meeting of
The American Physical Society

Inferring causal structure: a quantum advantage KATJA RIED, ROBERT SPEKKENS, Perimeter Inst for Theo Phys — The problem of inferring causal relations from observed correlations is central to science, and extensive study has yielded both important conceptual insights and widely used practical applications. Yet some of the simplest questions are impossible to answer classically: for instance, if one observes correlations between two variables (such as taking a new medical treatment and the subject's recovery), does this show a direct causal influence, or is it due to some hidden common cause? We develop a framework for quantum causal inference, and show how quantum theory provides a unique advantage in this decision problem. The key insight is that certain quantum correlations can only arise from specific causal structures, whereas pairs of classical variables can exhibit any pattern of correlation regardless of whether they have a common cause or a direct-cause relation. For example, suppose one measures the same Pauli observable on two qubits. If they share a common cause, such as being prepared in an entangled state, then one never finds perfect (positive) correlations in every basis, whereas perfect anticorrelations are possible (if one prepares the singlet state). Conversely, if a channel connects the qubits, hence a direct causal influence, perfect anticorrelations are impossible.

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Date submitted: 11 Nov 2013 Electronic form version 1.4