

The Power of Power-of-SWAP: Postselected Quantum Computation with the Exchange Interaction

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We introduce Exchange Quantum Polynomial Time (XQP) circuits, which comprise quantum computation using only computational basis SPAM and the isotropic Heisenberg exchange interaction. Structurally, this sub-universal model captures decoherence-free subspace computation without access to singlet states. We show that XQP occupies an intermediate position between BPP and BQP, as its efficient multiplicative-error simulation would collapse the polynomial hierarchy to its third level. We further provide evidence that additive-error simulation of XQP would enable efficient additive-error simulation of arbitrary BQP computations. Remarkably, the restricted family of XQP circuits consisting solely of $\sqrt{\text{SWAP}}$ gates remains hard to simulate to multiplicative error. We additionally prove that circuits generated by $\sqrt{\text{SWAP}}$ gates are semi-universal, generate t -designs for the uniform distribution over $\text{SU}(2)$ -invariant unitaries, and maximise the entangling power within XQP. Finally, we derive structural results linking computational basis states in XQP to the Gelfand-Tsetlin basis of the symmetric group, and expressing XQP output probabilities as partition functions of the six-vertex and Potts models. Our findings indicate that XQP circuits are naturally suited to near-term hardware and provide a promising platform for experimental demonstrations of quantum computational advantage.

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