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Statistical physics empowers quantum information: scalable methods for entanglement detection in multipartite systems

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Demonstrating the ability to manipulate quantum-entangled states in scalable multipartite systems represents an important challenge for quantum simulators and computers. Beyond a few tens of qubits, one cannot rely on tomographically-complete information about the prepared quantum state, for at least two reasons: 1) implementing the required measurements might not be currently possible; 2) the number of required measurements, scaling exponentially with the number of qubits, might be unreasonably large. It is therefore crucial to develop methods to probe entanglement from only partial information. Specifically, we will focus on a given set of expectation values for some observables (typically: few-body correlations). Entanglement is then revealed by the violation of a certain entanglement witness by the available data. How can one exhaustively test the capability of a given data set to demonstrate entanglement? Clearly, even if no existing entanglement witness is violated, this does not exclude the possibility that another witness, yet to be discovered, is violated by the same data. In this talk, I will present two complementary approaches to solve this problem in a flexible and scalable way, that is, with a computational cost which scales polynomially with the number of qubits. These approaches are inspired by statistical physics, and take advantage of the classical nature of correlations in separable states. One approach (https://arxiv.org/abs/2101.02038, https://arxiv.org/abs/2004.07796) is a variational search over all separable states, trying to reproduce the data at hand. The failure of this optimization marks the success of entanglement detection. In the second approach, we test positive semidefinite constraints obeyed by the data if they are compatible with a separable state. Both approaches deliver, as an output, a specific entanglement witness violated by the data if the latter cannot be reproduced by a separable state – providing qualitative insight into the driving mechanism for many-body entanglement. These approaches complement each other, systematically sandwiching the boundary of the convex set defined by separable states, at a scalable computational cost. I will explain these methods, and present results obtained by investigating theoretical many-body states.

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