Quantum Sensing Using Multi-Qubit Quantum Systems and the Pauli Polytope

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Quantum information science, at its core, relies on understanding the interplay between quantum entanglement and the structure of many-qubit systems — a pivotal step in harnessing noisy intermediate-scale quantum (NISQ) devices for practical applications. However, to benefit from entanglement, it is necessary to understand the environmental fluctuations affecting the dynamics of the system of interest. Here, we address the effect of noise on many-qubit quantum states by leveraging one- and two-particle theories and the generalized Pauli exclusion principle.

First, we demonstrate the violation of the generalized Pauli constraints (GPCs) on a noisy IBM quantum computer, providing a framework for understanding and predicting the role of noise as the bath in open quantum systems [Commun. Phys. 6, 180 (2023)]. Next, we introduce an open-system quantum sensing theory, which gauges the openness of multi-qubit quantum systems through qubit occupation measurements. This methodology was validated using experimental ultrafast spectroscopic data from a photosynthetic complex in green sulfur bacteria, showcasing its applicability to decode system relaxation due to environmental noise across diverse multi-qubit quantum systems [Phys. Rev. Research 5, 043097 (2023)]. Finally, we derive pure-state N-representability conditions for two-qubit reduced density matrices, providing universally applicable constraints to detect physical violations induced by noise in quantum measurements.