Experimental Reconstruction of Local Integrals of Motion for Quantum Many-Body Dynamics

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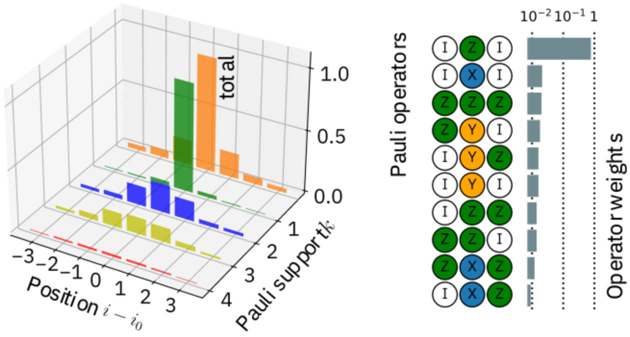

Figure 1. Average structure of the detected LIOMs. Left: Spatial structure with contributions from 1-local (green), 2-local (blue), 3-local (yellow), 4-local (red), and all (orange) Pauli operators. Right: Distribution over Pauli operators.

Abstract

When studying complex quantum systems on a classical computer, researchers typically rely on finding exact eigenvalues and eigenvectors that correspond to the system's energy levels and eigenstates. Despite the potential of quantum computers to outperform classical ones, they currently lack a comparable framework. In this talk, I will show that in some cases the structure of quantum systems can be studied on quantum hardware using local conservation laws.

Conservation laws are fundamental to physical description because they constrain the behavior of a system. While most systems have a limited number of observable laws, others, such as strongly disordered systems exhibiting many-body localization [1], can be completely described by a large set of them. Mathematically, these laws are expressed by many conserving operators, commonly referred to as local integrals of motion (LIOMs) [2,3]. Finding a complete set of LIOMs for a large localized quantum system provides its complete description, comparable to eigenstates.

Using our method, we faithfully reconstruct a complete set of LIOMs for 1D and 2D disordered interacting systems, with the cost independent of system size. The results, on up to 124 qubits, depth 60, error-mitigated quantum circuits, focus on the paradigmatic setting of Floquet systems, which exhibit disorder-induced ergodicity breaking. In regions where ergodicity is violated, we efficiently reconstruct complete sets of LIOMs. From the LIOMs, we extract signature system properties, such as site-dependent localization lengths. In ergodic regions, we show the absence of LIOMs by hallmark signatures. In 1D, we validate the experiments against classical numerics and find good agreement.

Our work demonstrates a new path for studying many-body quantum systems using quantum hardware, and provides new insights into the many-body localized regime of a two-dimensional system of qubits.

References

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