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Tensor network methods to compute many-body magic

Quantum resources have played a crucial role in our understanding of many-body systems over the past two decades. While entanglement has been extensively studied, the role of other quantum resources—such as magic, which is essential for quantum computational advantage—remains less explored.

I will begin by reviewing stabilizer Rényi entropies as a powerful measure of magic and their utility in characterizing complex quantum states. Building on this framework, I will present three complementary approaches based on tensor networks to measure and understand the role of magic in quantum many-body dynamics.

First, I will introduce a Markov chain sampling method for measuring many-body magic via Pauli strings. By leveraging tree tensor networks, this approach enables efficient extraction of long-range magic in one-dimensional critical systems and two-dimensional gauge theories, revealing novel connections between magic, conformal criticality, and confinement-deconfinement transitions [1].

Second, I will discuss a new framework for computing nonstabilizerness in matrix product states (MPS) by directly expressing them in the Pauli basis. This method allows for the efficient evaluation of stabilizer Rényi entropies, stabilizer nullity, and Bell magic. I will showcase its application to the ground states of spin chains and to recent Rydberg atom circuit experiments, providing benchmarks for logical qubit encoding [2].

Finally, I will explore the classical simulability of quantum many-body systems through a combination of tensor network methods and the stabilizer formalism. I will present results on efficiently computing Pauli expectation values in Clifford circuits doped with non-Clifford gates, and discuss the use of matchgate circuits alongside tensor networks for simulating many-body systems near free-fermion integrability [3].

I will conclude by discussing experimental implications, outlining potential avenues for realizing these phenomena in near-term quantum devices, and addressing the challenges in probing and controlling magic in many-body settings.

[1] PS Tarabunga, E Tirrito, T Chanda, M Dalmonte, PRX Quantum 4 (4), 040317 (2023)
[2] PS Tarabunga, E Tirrito, MC Bañuls, M Dalmonte Phys. Rev. Lett. 133 (1), 010601 (2024)
[3] G. Fux, B. Beri, R. Fazio, E. Tirrito, arXiv:2410.09001

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