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Fast Scrambling Transitions in Quantum Simulators

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Whether discussing interacting many-body physics with cold atoms, quantum metrology, or quantum computing, there are important questions around how large an entangled many-body state we can usefully and reliably prepare in analogue quantum simulators subject to decoherence. Given that information spreading and entanglement growth are limited by Lieb-Robinson bounds, the useful system size will typically grow only linearly with the system size. However, for systems with long-range interactions (e.g., atoms in cavities) or movable tweezer arrays, we can engineer so-called fast scrambling many-body quantum systems, where information is spread and entanglement is built up on a timescale that grows logarithmically with the system size.

We explore the requirements for fast scrambling, identifying a dynamical transition marking the onset of scrambling in quantum circuits or tweezer arrays with different levels of long-range connectivity. In particular, we show that as a function of the interaction range for circuits of different structures, the tripartite mutual information exhibits a scaling collapse around a critical point between two clearly defined regimes of different dynamical behaviour. We show that for certain parameter regimes this type of transition can be related to the statistical mechanics of a long-range Ising model. We identify how these transitions could be observed in neutral atom arrays. We also discuss more detailed modelling of dissipative dynamics of these systems.

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