From Chaos to Localization: Decoding Information Scrambling Through Eigenstate Correlations

Bikram Pain [1] , **Ratul Thakur** [1] , **and Sthitadhi Roy** [1]

[1]*International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru 560089, India*

We present a unified picture for various diagnostics of the spatiotemporal structure of information scrambling, such as operator entanglement entropy, out of time ordered correlators, and two-point dynamical correlations, with eigenstate correlations involving quartets of eigenstates at the heart of the picture. Our analysis reveals that capturing the essence of information scrambling necessitates considering correlations among at least four eigenstates, and we identify the specific correlations that encode different measures of scrambling. To illustrate these ideas, we analyze (i) Floquet dual-unitary circuits—an exactly solvable class of models with maximal chaotic behavior—and derive exact analytical expressions for the relevant eigenstate correlations in chaotic systems [1], and (ii) many-body localized circuits, where these correlations provide a theoretical framework for the logarithmic entanglement light cone without invoking phenomenological l-bits [2,3]. Our results provide new insights into the microscopic underpinnings of quantum information scrambling and highlight the central role of eigenstate structure in quantum dynamics.

[1] BP, Ratul Thakur, Sthitadhi Roy, arXiv 2504.xxxxx.

[2] Ratul Thakur, BP, Sthitadhi Roy, arXiv 2504.02815.

[3] BP, Sthitadhi Roy, Phys. Rev. B 110, 224201.