Quantum Chaos = Volume-Law Spatiotemporal Entanglement

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Abstract: Chaotic systems are highly sensitive to a small perturbation, be they biological, chemical, classical, ecological, political, or quantum. Taking this as the underlying principle, we construct an operational notion for quantum chaos. Namely, we demand that the whole future state of a large, isolated quantum system is highly sensitive to past multitime operations on a small subpart of that system. This immediately leads to a direct link between quantum chaos and volume-law spatiotemporal entanglement. Remarkably, our operational criterion already contains the routine notions, as well as the well-known diagnostics for quantum chaos. This includes the Peres-Loschmidt Echo, Dynamical Entropy, and Out-of-Time-Order Correlators. Our principle therefore unifies these existing diagnostics within a single structure. Within this framework, we also go on to quantify how several mechanisms lead to quantum chaos, such as unitary designs. Our work paves the way to systematically study exotic many-body dynamical phenomena like Many-Body Localisation, many-body scars, measurement-induced phase transitions, and Floquet dynamics. We anticipate that our work may lead to a clear link between the Eigenstate Thermalization Hypothesis and quantum chaos.

References:
Quantum Chaos = Volume-Law Spatiotemporal Entanglement.
N. Dowling, K. Modi. arXiv:2210.14926 (2022)