Quantum Chaos and Entanglement

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Quantum Chaos is a ubiquitous phenomena which, despite much effort, is not fundamentally understood or agreed upon. A deterministic, catch-all definition for isolated, finite quantum systems remains an open question. Within current literature there is a wide ranging 'web' of diagnostics [1]. These range from: the divergence of time-evolved states given a weak source of noise, measured by the Loschmidt Echo [2]; to the spreading of local operators, measured by Out-of-Time-Order Correlators [3]; to the uncertainty of measurement statistics, measured by dynamical entropy [4]. These are not all consistent with each other, and while some connections have been identified – largely through the lens of Haar averaging over dynamics [5, 6] – attempts to understand quantum chaos through a single foundational principle have thus far proved insufficient.

Inspired by the classical definition of chaos as a sensitivity to perturbation, we show that a wide range of chaos diagnostics can be classified under a single principle. From this, we use tools from quantum information theory to discover a fundamental link between chaos and quantum entanglement. We therefore unify previous diagnostics and definitions of quantum chaos in the language of entanglement, and go beyond with new, generalised probes. Further, this realisation allows us to identify insufficiencies with previous measures of chaos. Finally, we argue that this may pave the way to understanding the connection of quantum chaos to random matrix theory and therefore the foundations of the Eigenstate Thermalization Hypothesis.

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