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Unveiling order from chaos by approximate 2-localization of random matrices

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Quantum many-body systems are typically endowed with a tensor product structure.A structure they inherited from probability theory, where the probability of two independent events is the product of the probabilities. The tensor product structure of a Hamiltonian thus gives a natural decomposition of the system into independent smaller subsystems. It is interesting to understand whether a given Hamiltonian is compatible with some particular tensor product structure. In particular, we ask, is there a basis in which an arbitrary Hamiltonian has a 2-local form, i.e., it contains only pairwise interactions? I will show, using analytical and numerical calculations, that a generic Hamiltonian (e.g., a large random matrix) can be approximately written as a linear combination of two-body interaction terms with high precision; that is, the Hamiltonian is 2-local in a carefully chosen basis. Moreover, we find that these Hamiltonians are not fine-tuned, meaning that the spectrum is robust against perturbations of the coupling constants. Finally, by analyzing the adjacency structure of the couplings, we suggest a possible mechanism for the emergence of geometric locality from quantum chaos.

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