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Quantum Information Transfer Between Energy Scales

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14. ABSTRACT
The broad aim of the “Transfer of Quantum Information Between Energy Scales” proposal is a detailed study of quantum operator dynamics in many-body systems, with a special focus on the way initially simple operators become increasingly complex as time passes. This operator dynamics translates directly into the transfer of quantum information from simple to complex degrees of freedom associated with different energy scales. Looking over the entire span of the project, we successfully developed and implemented several novel computation algorithms to compute operator dynamics at large size and long times. In this previously inaccessible regime, our tools led to the discovery of a new universal form of chaotic operator spreading and gave insights into the physics of localization. We have also taken the first steps to extend this work to consider the effects of quantum measurements and to connect to other manifestations of quantum chaos like hydrodynamics and random matrix universality.

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Award: FA9550-17-1-0180
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Activity:

The broad aim of the “Transfer of Quantum Information Between Energy Scales” proposal is a detailed study of quantum operator dynamics in many-body systems, with a special focus on the way initially simple operators become increasingly complex as time passes. This operator dynamics translates directly into the transfer of quantum information from simple to complex degrees of freedom associated with different energy scales.

Looking over the entire span of the project, we successfully developed and implemented several novel computation algorithms [8,5] to compute operator dynamics at large size and long times. In this previously inaccessible regime, our tools led to the discovery of a new universal form of chaotic operator spreading [7] and gave insights into the physics of localization [6]. Having completed the main goals of the project, work has extended in two directions.

First, we have begun to study how quantum measurements affect information transfer. Building on recent insights showing a novel measurement-driven quantum phase transition between high and low entanglement phases, we developed an analytically tractable mean-field model [3] to describe this physics which extends our previous Brownian circuit model [7].

Second, we have begun to study how operator dynamics is related to a measure of quantum chaos known as random matrix universality. The energy eigenvalues of the Hamiltonian of a quantum chaotic system are supposed to be random-matrix-like, and we have established a novel link between this characterization and operator dynamics in the form of hydrodynamics [4,1,2]. In essence, random matrix theory onsets when quantum information about the initial state has been completely transferred from simple operators (describing diffusion, etc.) to complex degrees of freedom.

The grant supported my student Subhayan Sahu for the entire period. Subhayan has been actively involved in all aspects of the operator dynamics computations and in particular developed and implemented the finite temperature algorithm [5] that extends our earlier method [8]. The grant has also partially supported my student Michael Winer who has been leading the work connecting random matrix universality and ergodicity with operator dynamics.

The project resulted in eight papers on arXiv, all of which are either published or will be submitted, including one paper in Nature Physics, one paper in Physical Review X, and two papers in Physical Review Letters. Plans are in progress to submit a new proposal to either Computational Mathematics or Quantum Information Sciences to build on these successes.

Papers:

[1] “Spontaneous Symmetry Breaking, Spectral Statistics, and the Ramp”. Michael Winer, Brian Swingle. https://arxiv.org/abs/2106.07674. To be submitted to Physical Review B.

[2] “Hydrodynamic Theory of the Connected Spectral Form Factor”. Mike Winer, Brian Swingle. https://arxiv.org/abs/2012.01436. Submitted to Physical Review X.

[3] “Measurement-induced purification in large-N hybrid Brownian circuits”. Subhayan Sahu, Greg Bentsen, Brian Swingle. https://arxiv.org/abs/2104.07688. Submitted to Physical Review B.

[4] “An exponential ramp in quadratic Sachdev-Ye-Kitaev model”. Michael Winer, Shaokai Jian, Brian Swingle. https://arxiv.org/abs/2006.15152. Phys. Rev. Lett. 125, 250602 (2020).

[5] “Information scrambling at finite temperature in local quantum systems”. Subhayan Sahu, Brian Swingle. https://arxiv.org/abs/2005.10814. Phys. Rev. B 102, 184303 (2020).

[6] “Scrambling dynamics across a thermalization-localization phase transition”. Subhayan Sahu, Shenglong Xu, Brian Swingle. https://arxiv.org/abs/1807.06086. Phys. Rev. Lett. 123, 165902 (2019).

[7] “Locality, Quantum Fluctuations, and Scrambling”, Shenglong Xu and Brian Swingle, https://arxiv.org/abs/1805.05376. Phys. Rev. X 9, 031048 (2019).

[8] “Accessing Scrambling Using Matrix Product Operators”, Shenglong Xu and Brian Swingle, https://arxiv.org/abs/1802.00801. Nat. Phys. 16, 199-204 (2020).

Personnel:

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