Seminar/Talk

Entanglement Dynamics of Integrable and Chaotic Quantum Cellular Automata: Towards a Quantum Many-body Kolmogorov-Arnold-Moser Theory

Lincoln Carr

Host: Maksym Serbyn

Abstract: One-dimensional Quantum cellular automata (QCA) in quantum circuits provide an experimentally realizable quantum computing testbed for quantum entangled dynamics, spanning both integrable and quantum many-body chaotic extremes. In this work, we establish a quantum many-body Kolmogorov-Arnold-Moser (KAM) framework in 1D QCA, characterizing the breakdown of integrability through a state-dependent hierarchy of conservation laws. Starting from the integrable limit of Goldilocks rules that map exactly onto free-fermion dynamics, we introduce controlled, locality-preserving perturbations via symmetric Strang splitting. We investigate the breakdown of integrability by tracking the deformation of the first 13 local conserved charges directly within the native discrete-time circuit dynamics.Our central finding in the circuit picture is the emergence of a stability hierarchy of charges determined by the algebraic structure of the perturbation generator, classified into three distinct tiers: (i) robust invariants which remain exactly conserved independent of perturbation strength; (ii) resonant actions which drift immediately at first order; and (iii) KAM-like candidates, in particular . We identify as weakly non-resonant: it exhibits anomalous super-delayed deformation under general initial conditions but remains conserved when initialized in an eigenstate of a specific Abelian charge subset.Complementing this study of quantum circuits in discrete time, we demonstrate rigorously that the associated continuous-time QCA Hamiltonian --- constructed via projector embeddings --- defines a fundamentally distinct dynamical system, conserving only an Abelian subclass of the 13 first charges from Goldilocks QCA. Within this QCA-like Hamiltonian model, we characterize the broader phenomenology of the integrability-to-chaos crossover. We observe a universal transition from Poisson to Wigner-Dyson spectral statistics and analyze the power-law growth of out-of-time-ordered correlators. Furthermore, using Hamiltonian-based charge autocorrelators, we map the stability of to a regime of “confined chaos,” where algebraic symmetries shield specific Hilbert space sectors from rapid thermalization, providing a continuous-time counter-part of the KAM stability observed in the discrete circuit.References: Marc Andrew Valdez, Daniel Jaschke, David L. Vargas and Lincoln D. Carr, “Quantifying Complexity in Quantum Phase Transitions via Mutual Information Complex Networks,” Phys. Rev. Lett., v. 119, p. 225301

(2017)Bhuvanesh Sundar, Marc Andrew Valdez, Lincoln D. Carr, and Kaden R. A. Hazzard, “A complex network description of thermal quantum states in the Ising spin chain,” Phys. Rev. A, v. 97, p. 052320 (2018)Bhuvanesh Sundar, Mattia Walschaers, Valentina Parigi, and Lincoln D Carr, “Response of quantum spin networks to attacks,” J. Phys. Complexity, v.2, p. 035008 (2021)LE Hillberry, MT Jones, DL Vargas, P Rall, N Yunger Halpern, N Bao, S Notarnicola, S Montangero, LD Carr, “Entangled quantum cellular automata, physical complexity, and Goldilocks rules,” Quantum Science and Technology, v. 6, p. 045017 (2021)EB Jones, LE Hillberry, MT Jones, M Fasihi, P Roushan, Z Jiang, A Ho, C Neill, E Ostby, P Graf, E Kapit, and LD Carr, “Small-world complex network generation on a digital quantum processor,” Nature Communications v. 13, p. 4483 (2022)Mattia Walschaers, Nicholas Treps, Bhuvanesh Sundar, Lincoln D Carr, and Valentina Parigi, “Emergent complex quantum networks in continuous-variables non-Gaussian states,” Quantum Science and Technology, v. 8, p. 035009 (2023)LE Hillberry, M Fasihi, L Piroli, N Yunger Halpern, T Prosen, and LD Carr, “Classical simulability, thermodynamics, and integrability of Goldilocks quantum cellular automata,” Quantum Science and Technology, under review, arXiv:2404.02994 (2024)P Patnaik, LE Hilberry, T Prosen, and LD Carr, “Entanglement Dynamics of Integrable and Chaotic Quantum Cellular Automata: Towards a Quantum Many-body Kolmogorov-Arnold-Moser Theory,” In preparation (2026)

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