Measurement-Induced Phase Transition in Random Haar Monitored Quantum Circuits

Maiti, Adhrit (School: Baton Rouge Magnet High School)

Purpose: Entanglement determines how quantum information is stored and processed, but measurements impact entanglement behavior in open quantum circuits. This project studies entanglement phases in multi-qubit open quantum circuits consisting of random Haar gates with projective measurements applied at different probabilities. The primary goal is to estimate the critical probability at which measurement-induced phase transitions occur across multiple system sizes. Procedure: A mathematical framework was formulated to describe how entanglement entropy evolves in a bricklayer open quantum circuit with Haar random gates and varying measurements. This was then implemented in Python, where measurement probability and entanglement entropy were the independent and dependent variables. Average entanglement entropy was calculated as a function of time and system size for measurement probabilities, $p = 0, 0.1, 0.5$, and 0.9. Each data point represented an average over 50 independent simulation runs. Area-law and volume-law scaling behavior were examined, and entropy variance was used to estimate the critical measurement probability. Results and Conclusions: At low measurement probabilities ($p = 0$ and $p = 0.1$), entanglement entropy grew rapidly following volume-law scaling. At high measurement probability ($p = 0.9$), entanglement was suppressed and followed area-law behavior. Variance analysis identified a measurement-induced phase transition slightly above p ˜ 0.2, the critical measurement probability marking the transition between the volume-law and the area-law regimes in the modeled systems. This study quantitatively demonstrates how measurements influence entanglement scaling in open quantum circuits, relevant to quantum information processing and error correction.

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