An Efficient Classical Algorithm for Simulating Short Time 2D Quantum Dynamics

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September 17, 2024

Efficient classical simulation of the Schrödinger equation is central to quantum mechanics, as it is crucial for exploring complex natural phenomena and understanding the fundamental distinctions between classical and quantum computation. Although simulating general quantum dynamics is BQP-complete, tensor networks allow for efficient simulation of short-time evolution in 1D systems. However, extending these methods to higher dimensions becomes significantly challenging when the area law is violated. Here, we tackle this challenge by introducing an efficient classical algorithm for simulating short-time dynamics in 2D quantum systems, utilizing cluster expansion and shallow quantum circuit simulation. Our algorithm has wide-ranging applications, including an efficient dequantization method for estimating quantum eigenvalues and eigenstates, simulating superconducting quantum computers, dequantizing quantum variational algorithms, and simulating constant-gap adiabatic quantum evolution. Our results reveal the inherent simplicity in the complexity of short-time 2D quantum dynamics and highlight the limitations of noisy intermediate-scale quantum hardware, particularly those confined to 2D topological structures. Our results advances our understanding of the boundary between classical and quantum computation and the criteria for achieving quantum advantage.