Research plan

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"Formulation of Non-perturbative Quantum Field Theory: Tensor Networks and Discretized Supersymmetric Quantum Mechanics"

Abstract: The aim of this project is to develop new non-perturbative methods in quantum field theory in two complementary directions: i) the analysis of non-Hermitian quantum field theories using tensor networks, and ii) the construction of a new discretized formulation of supersymmetric quantum mechanics. Non-Hermitian quantum field theories are known to provide physically meaningful descriptions via parity-time (PT) symmetry, but progress in their non-perturbative study has been limited by the sign problem in conventional numerical approaches. On the other hand, supersymmetric quantum mechanics plays a central role in the fundamental study of quantum field theory and string theory, yet supersymmetry is typically broken once the theory is discretized. This project proposes a new theoretical framework to address these challenges.

Analysis of Non-Hermitian Quantum Field Theories with GILT-TNR

We will formulate non-Hermitian field theories within the framework of tensor networks and carry out non-perturbative analyses. In conventional quantum field theory, Hermitian operators are usually assumed in order to ensure real eigenvalues. However, recent studies have revealed that even when the Hamiltonian is non-Hermitian, systems with PT symmetry can possess real spectra and provide physically meaningful descriptions. In this project, we will express such PT-symmetric non-Hermitian theories as tensor networks and analyze them using GILT-TNR (Graph-Independent Local Truncation Tensor Network Renormalization), a recently developed tensor network renormalization scheme. As a concrete application, we will apply this method to the non-Hermitian quantum field theory known as the PT-symmetric -g phi^4 model and investigate its phase structure.

Construction of a New Discretized Supersymmetric Quantum Mechanics

Supersymmetry provides a powerful framework that relates bosons and fermions, but it is well known that supersymmetry is generally broken once the theory is discretized. This issue is a major obstacle in lattice field theory and numerical simulations. Developing a discretized formulation that preserves supersymmetry remains an important open problem.

In this project, we will introduce a discretization on the circle S^1 and construct a difference formulation that preserves supersymmetry. Its validity will be tested through the computation of the Witten index, a topological invariant that counts zero-energy states. We will further investigate how the theory is modified when a topological term is included. These formulations are also aimed at future applications to quantum computing algorithms, for example in simulations of supersymmetric theories.