Adiabatic state preparation constrained on irreducible-representations subspaces

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Preparing the n-th eigenstate of a target Hamiltonian on an L-qubits quantum register is a computationally demanding task. Two widely used approaches to tackle this problem are Variational Quantum (VQ) algorithms and Adiabatic Preparation (AP) methods [1]. Each of them has its own strengths and limitations: VQ circuits require an ansatz selection and are prone to barren plateaus [2], while AP is effective only if the adiabatic Hamiltonian H(t) avoids closing energy gaps. In this work, we introduce a novel hybrid algorithm that integrates the advantages of both approaches to mitigate their respective weaknesses. In our method we construct an adiabatic Hamiltonian with enhanced symmetries at the start of the evolution, reducing the likelihood of level crossings at the cost of a higher initial degeneracy. This ensures that AP can independently evolve each eigenspace. To further distinguish between eigenstates within the same initial eigenspace, we design a VQ circuit that selectively explores the irreducible representation subspace of the initial Hamiltonian H(0). This circuit is well-defined, ansatz-free, and, crucially, it avoids the main sources of barren plateaus when the subspace scales polynomially with the number of qubits L [2]. Optimizing the VQ circuit parameters then enables precise targeting of specific eigenstates of the final Hamiltonian. We validate our approach through extensive numerical simulations on the Heisenberg model, demonstrating successful preparation of both ground and excited states. Our results suggest that this hybrid strategy offers a robust and scalable alternative for quantum eigenstate preparation.

References

[1] M.Born and V.Fock, Zeitschrift f ̈ur Physik 51, Beweis des adiabatensatzes (1928), 165

[2] Ragone,et al. "A Lie algebraic theory of barren plateaus for deep parameterized quantum circuits." Nature Communications (2024): 7172.

Figures

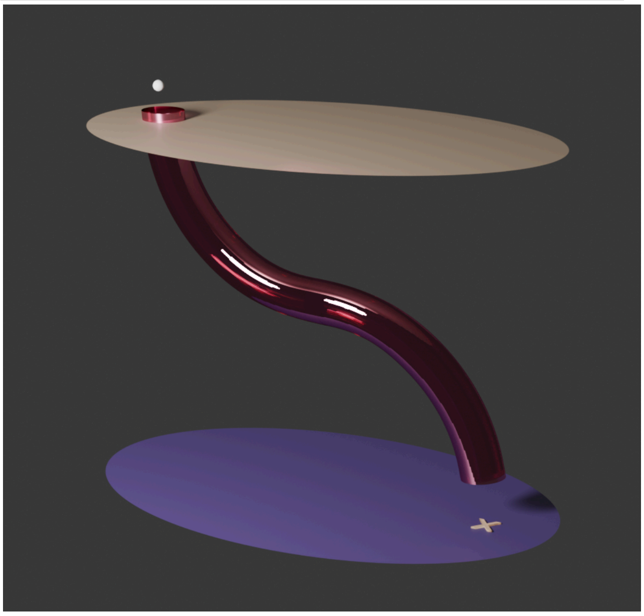

Figure 1: Schematic of the adiabatic protocol mapping an irreducible-representation subspace of the initial Hamiltonian H(0) to a subspace of the target Hamiltonian that includes the desired target state. Exploring the initial subspace allows preparing the target state.