Usage Report for Fiscal Year 2024

Project Title: Development of quantum algorithms for quantum many-body systems

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1. Background and purpose of the project, relationship of the project with other projects

Quantum simulation of thermal states is challenging due to their mixed state nature. The Thermal Pure Quantum (TPQ) state, approximating thermal ensemble averages, offers a solution. We use the canonical TPQ state and the Quantum Imaginary Time Evolution (QITE) algorithm to study the temperature-dependence of the chiral condensate in the Schwinger model. Our method is validated by comparing massless case results with analytic outcomes and exploring the massive and non-zero θ regime, challenging for the conventional Monte Carlo method.

2. Specific usage status of the system and calculation method

To express a thermal state, we prepare a TPQ state on a quantum circuit. The TPQ state approximates thermal ensemble averages. We use the QITE algorithm to perform imaginary time evolution, approximating non-unitary operators by unitary operators. We handle multiple Hamiltonian terms with different localities in a single Trotter step. By reducing computational costs, we can compute large system sizes. After taking double limits, we obtain consistent results with classical calculations and eventually determine thermodynamic quantities.

3. Result

We calculate the chiral condensate using exact diagonalization, TPQ, and QITE methods. The lattice parameters are a=0.80 and g=1.00 with N=4-12. Results show the TPQ method's discrepancy decreases with larger N. Extrapolated values agree with analytical results. The QITE method, tested with various Trotter steps, aligns with TPQ results, confirming controlled Trotter error. Both methods demonstrate potential to study local observables in the Schwinger model's finite-temperature regime. The chiral condensate is significant in small θ and large β regimes, approaching zero elsewhere, indicating chiral symmetry restoration. The results are summarized in the figure below.

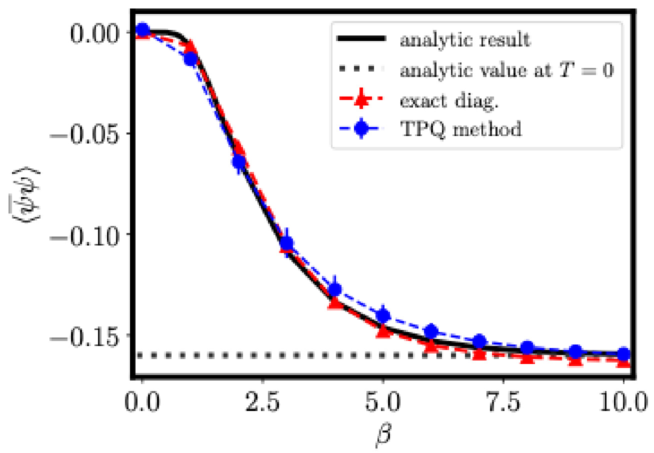

Figure: (from [1]) Comparison of the results in the thermodynamic limit obtained by the TPQ method (blue circle symbol), the exact diagonalization (red triangle symbol), and the analytical calculation, Eq. (3) (black solid curve). The black dotted line shows the value at zero temperature.

4. Conclusion

The study confirmed the TPQ and QITE methods effectively simulate the Schwinger model at finite temperatures, validating results against analytical and exact diagonalization outcomes. The chiral condensate's behavior across different parameters indicates potential for exploring finite-temperature regimes with controlled Trotter error.

[1] Pedersen, J., E. Itou, R. Y. Sun, and S. Yunoki. *"Quantum Simulation of Finite Temperature Schwinger Model via Quantum Imaginary Time Evolution."* In The 40th International Symposium on Lattice Field Theory, p. 220. 2024.

Fiscal Year 2024 List of Publications Resulting from the Use of the supercomputer

[Conference Proceedings]

1. Pedersen, J., E. Itou, R. Y. Sun, and S. Yunoki. "Quantum Simulation of Finite Temperature Schwinger Model via Quantum Imaginary Time Evolution." In The 40th International Symposium on Lattice Field Theory, p. 220. 2024.