Overhead-constrained circuit knitting for variational quantum dynamics

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Simulating the dynamics of large quantum systems is a formidable yet vital pursuit for obtaining a deeper understanding of quantum mechanical phenomena. While quantum computers hold great promise for speeding up such simulations, their practical application remains hindered by limited scale and pervasive noise. In this work, we propose an approach that addresses these challenges by employing circuit knitting [2-3] to partition a large quantum system into smaller subsystems that can each be simulated on a separate device. The evolution of the system is governed by the projected variational quantum dynamics (PVQD) [2] algorithm, supplemented with constraints on the parameters of the variational quantum circuit, ensuring that the sampling overhead imposed by the circuit knitting scheme remains controllable. We test our method on quantum spin systems with multiple weakly entangled blocks each consisting of strongly correlated spins, where we are able to accurately simulate the dynamics while keeping the sampling overhead manageable. Further, we show that the same method can be used to reduce the circuit depth by cutting long-ranged gates.

References

[1] G.G., F. Metz and G. Carleo. *arXiv:2309.0785* (2023).
[2] S. Bravyi, G. Smith, J. A. Smolin. *Phys. Rev. X 6, 021043* (2016).
[3] K. Mitarai, K. Fujii. New Journal of Physics 23, 023021 (2021).
[4] S. Barison, F. Vicentini, G. Carleo. *Quantum 5, 512* (2021).

Figures

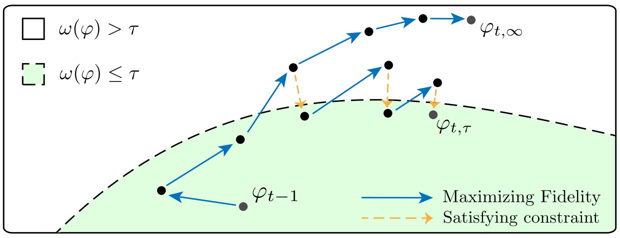

Figure 1: Solving the PVQD optimization problem with a constrained sampling overhead. The fidelity in the PVQD-loss is maximized using gradient descent. Once the sampling overhead imposed by the parameters exceeds the threshold, the corresponding parameters are projected back to satisfy the constraint.

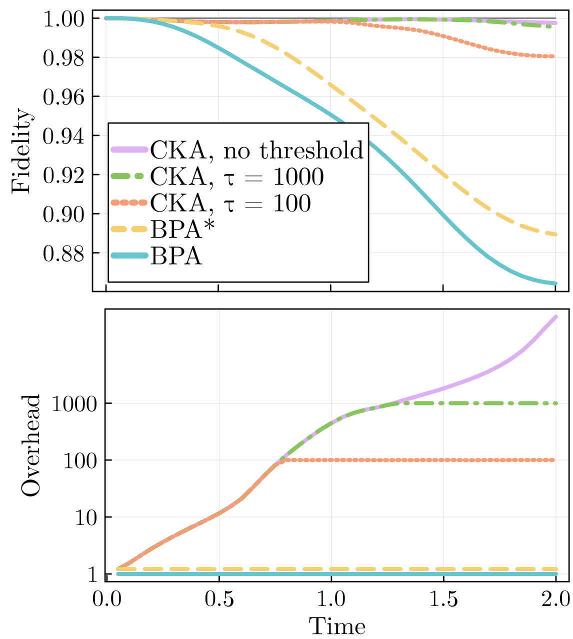

Figure 2: Simulating the dynamics of a TFIM spin chain consisting of 3 blocks with 2 spins each. On the top panel, we show the fidelity of our time evolved ansatz with respect to the exact solution. The lower panel shows the sampling overhead required to measure the full circuit on multiple quantum devices using the circuit knitting scheme. We compare a block product approximation (BPA) with the circuit knitting ansatz (CKA) with different thresholds for the sampling overhead.