Combining Matrix Product States and Noisy Quantum Computers for Quantum Simulation

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Matrix Product States (MPS) and Operators (MPO) have proved to be powerful tools to simulate quantum many-body systems. While MPS can efficiently find ground states of 1D systems, they fail to simulate their dynamics, where the entanglement can increase ballistically with time. On the other hand, quantum devices are natural platforms to perform time evolution but are strongly hampered by noise. In this work [1], we use the best of both worlds: the short-time dynamics is efficiently performed by MPSs, compiled into short-depth quantum circuits, and is performed further in time on a quantum computer thanks to efficient MPO-optimized quantum circuits (Fig.1). In this scheme (that we call "QMPSO"), tensor networks provide all the ingredients to the quantum computer for a resource-efficient quantum simulation, and drastically lower the noise requirements for a practical advantage. Finally, we successfully demonstrate our method on an actual quantum device (Fig.2) from IBM: we simulate experimentally a 10-qubit system over a longer time scale than low-bond-dimension MPSs and purely quantum Trotter evolution.

References

[1] B. Anselme Martin, T. Ayral, F. Jamet, M. Rancic, P. Simon, arXiv pre-print [2305.19231] (2023)

Figures

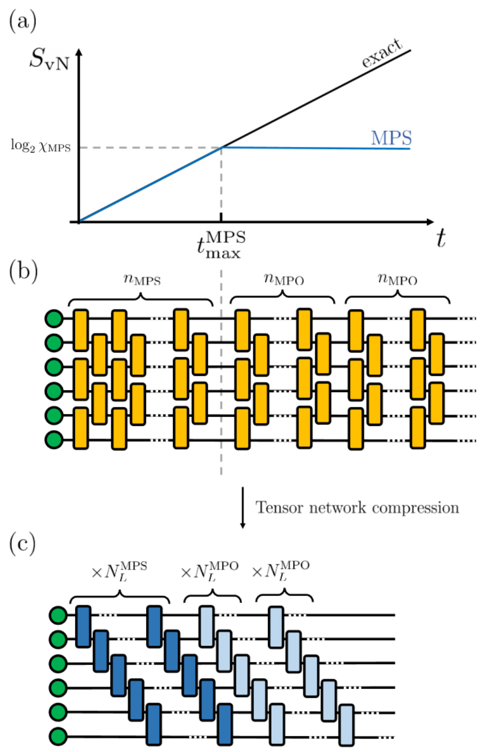

Figure 1: (a) The entanglement entropy increases with time using the Trotter quantum circuit in (b). Using tensor network techniques, we compress the circuit (b) into a short-depth entanglement-efficient quantum circuit (c).

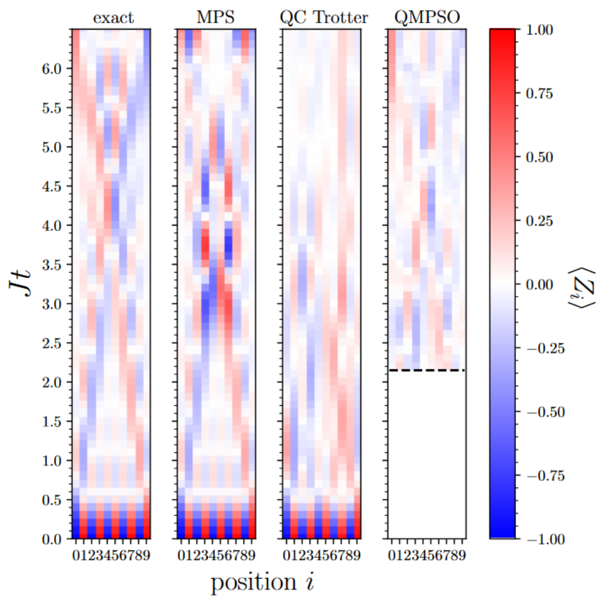

Figure 2: Evolution in time of the local magnetization in time for a L = 10 quantum Ising chain for the exact solution versus MPS, Trotter and QMPSO simulations on IBM devices.