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Scalable Quantum Circuits Simulation with Real-Space Parallelizable Tensor Network Methods

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Classical simulation of current noisy intermediate-scale quantum (NISQ) devices forwards the development of all the research directions in near-term quantum computing. While the simulation algorithms based on tensor network states can efficiently simulate a NISQ device with around 100 qubits, restricted by the real-space sequential nature of these algorithms, efficiently simulating a NISQ device with hundreds, or even thousands, of qubits remains elusive. One of the approaches to releasing this limitation is developing real-space parallelizable algorithms.

In this presentation, I will introduce a newly developed real-space parallelizable matrix-product state (MPS) compression method [1] that can efficiently compress all the virtual dimensions of the MPS in a constant time against increasing the system size and simultaneously stabilize the wavefunction norm [see Fig. 1(a)] without triggering sequential renormalization procedures. Moreover, the deviated canonical form is partially recovered by appended parallel regauging steps. Based on this method, we propose the parallel time-evolving block-decimation (pTEBD) algorithm for the simulation of unitary quantum circuits. After benchmarking the pTEBD algorithm with extensive simulations of typical one- and two-dimensional quantum circuits containing up to over 1000 qubits on Supercomputer Fugaku, we demonstrate that the pTEBD algorithm achieves the same simulation precision as compared with the current state-of-the-art MPS algorithm using a polynomially shorter time [see Fig. 1(b)], exhibiting a nearly perfect performance weak scaling [see Fig. 1(c)].

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Reference

[1] Rong-Yang Sun, Tomonori Shirakawa, and Seiji Yunoki. *"Improved real-space parallelizable matrix-product state compression and its application to unitary quantum dynamics simulation."* arXiv preprint arXiv:2312.02667 (2023).

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