Scalable Preparation of Matrix Product States with Sequential and Brick Wall Quantum Circuits

Tomasz Szoldra[1]
Rick Mukherjee[2], Peter Schmelcher[1]

[1] *Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany*
[2] *University of Tennessee, Chattanooga, TN 37403, USA*

tomasz.szoldra@uni-hamburg.de

Preparation of initial states is a core subroutine of quantum computing. While arbitrary quantum states require exponential resources, Matrix Product States (MPS) admit more efficient preparation schemes, particularly when accuracy is traded for circuit complexity. Existing approaches to MPS preparation largely fall into two categories. Heuristic constructions [1,2] deterministically generate approximate states but typically saturate quickly in fidelity, whereas variational optimization methods [3,4] can, in principle, reach high accuracies but are often hindered by barren plateaus and poor scalability. These paradigms have so far been explored mostly in isolation. In this work, we introduce a practical MPS preparation framework that combines the strengths of heuristic and variational techniques in a single pipeline. The central idea is to use structured heuristic disentangler circuits as warm-start initializations for scalable variational optimization. Specifically, staircase-like [1] and brick wall [2] circuits are employed to initialize the Evenbly–Vidal [3] and Riemannian [4] variational optimizers, leading to substantially improved fidelities, mitigation of barren plateaus, and practical scalability to larger systems and circuit depths. Target MPSs are either specified as physical quantum states or constructed from classical datasets via amplitude encoding, using step-by-step singular value decompositions or tensor cross interpolation. The pipeline further incorporates entanglement-based qubit reordering, formulated here as a quadratic assignment problem, and low-level circuit optimizations that significantly reduce circuit depth and gate count. We evaluate the full pipeline on classical datasets of varying complexity, ranging from smooth probability distributions to real-world financial time series, on systems of 19–50 qubits. Depending on the dataset and the chosen figure of merit—such as target fidelity, gate count, or circuit depth—we identify optimal combinations of circuit architectures, optimization methods, and hyperparameters. While optimized sequential circuits typically minimize gate counts, brick wall circuits are generally preferable when circuit depth is the dominant constraint. Overall, our results provide principled and scalable protocols for preparing MPSs as quantum circuits, supporting utility-scale applications on near-term quantum devices.

References

[1] S.-J. Ran, Phys. Rev. A, 101, (2020) 032310
[2] R. Mansuroglu, N. Schuch, arXiv:2504.21298 (2025)
[3] G. Evenbly, G. Vidal, Phys. Rev. B 79 (2009) 144108
[4] A. Melnikov et al., Quantum Science and Technology 8, (2023) 035027

Figures

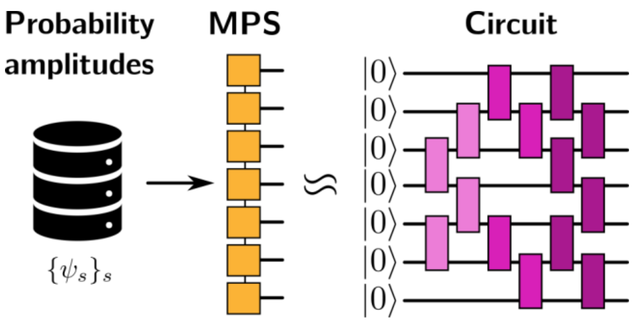

Figure 1: Quantum state, defined by a set of probability amplitudes, is prepared as a circuit, with an intermediate MPS representation.