Breaking the chain: geometry-native state preparation with ASPIRE

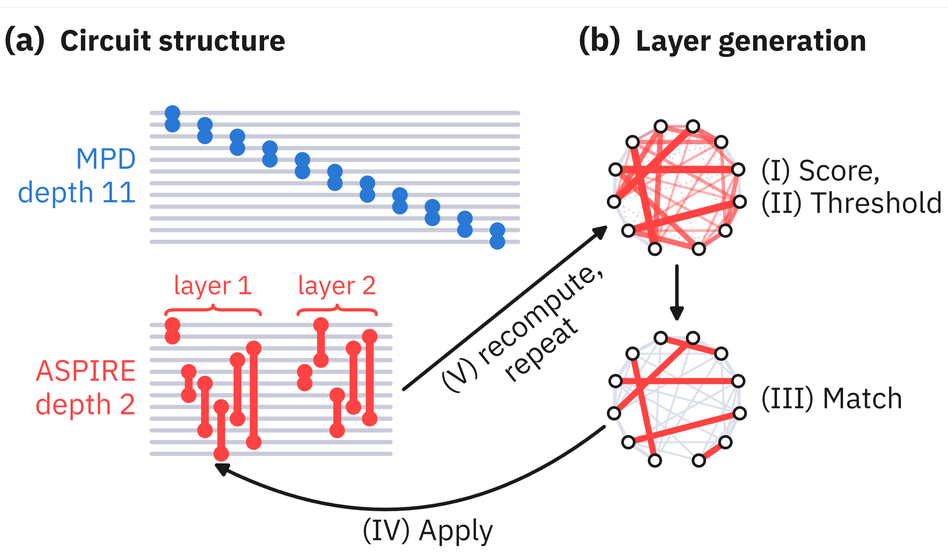
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QUANTUM MOTION

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To prepare a matrix-product state on a quantum computer at equal gate count, the matrix product disentangler (MPD) [1] uses a staircase of nearest-neighbour gates, whilst Adaptive State Preparation via Iterative Removal of Entanglement (ASPIRE, this work) uses two layers of long-ranged gates **(a)**. Each layer scores every pair, then matches and applies a disjoint set **(b)**. The MPD-gates are only sensitive to the nearest-neighbor mutual-information **(c)**; **(d)** sketches where the difference pays off.



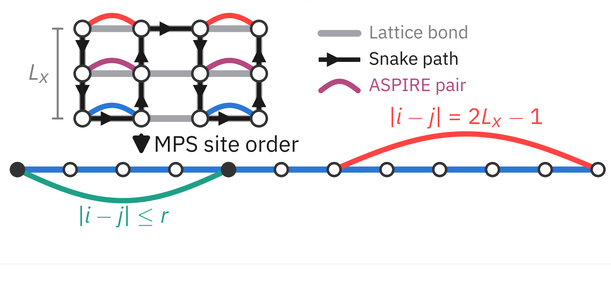
Context /

Loading data is a bottleneck for quantum algorithms. Matrix product states (MPS) make it tractable for structured data, but the MPD [1] protocol prepares them using only places gates between neighbors on the MPS. ASPIRE places each gate where the entanglement is.

A matrix product state (MPS) represents a quantum state $|\psi\rangle$ as a chain of tensors:

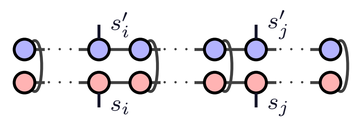
$$\Psi_{\boldsymbol{s}} = A_1^{s_1} A_2^{s_2} \cdots A_{N-1}^{s_{N-1}} A_N^{s_N}$$

Snaking a lattice into an MPS chain moves most of its bonds out of nearest-neighbor reach.



Method /

$$I(i{:}j) = S(\rho_i) + S(\rho_j) - S(\rho_{ij}), \qquad \rho_{ij} =$$



I Score each coupled pair by its removable mutual information [2] calculated from $I(i{:}j)$.
II Discard pairs below a threshold.
III Select the maximum-weight matching: the best disjoint set of pairs.
IV Apply their gates to the MPS as one layer.
V Recompute and repeat; the inverted circuit prepares the state.

Multivariate functions /

$$|\psi\rangle = \sum_{j_1,\ldots,j_d} f(x_{j_1},\ldots,x_{j_d})\,|j_1\rangle \otimes \cdots \otimes |j_d\rangle, \qquad x_j = \sum_{b=1}^{n} \frac{\sigma_b}{2^b} = 0.\sigma_1\sigma_2\cdots\sigma_n$$

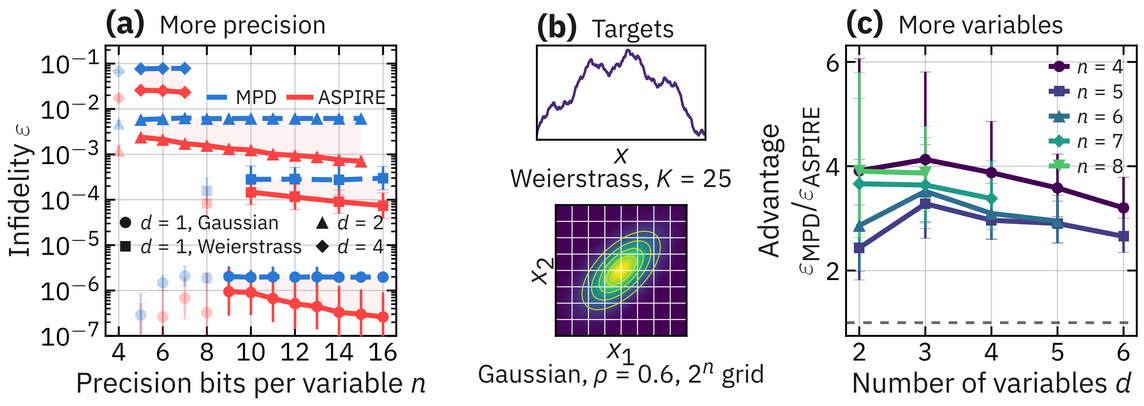


Fig. 3 Quantics Gaussian at the gate count of eight MPD layers. **(a)** Extra precision bits leave the MPD's infidelity flat while ASPIRE keeps improving. **(b)** Target functions. **(c)** ASPIRE is advantageous for all systems considered.

Conclusions /

For long-range entangled states ASPIRE typically reaches higher fidelity than existing methods, even after classical optimization: a resource-frugal protocol for fidelity-tolerant applications such as guide states for quantum phase estimation.

Lattices and noisy hardware /

$$H_{\mathrm{TFIM}} = -J\sum_{\langle ab\rangle} \frac{\sigma_a^z}{2}\frac{\sigma_b^z}{2} - h\sum_a \frac{\sigma_a^x}{2}, \qquad H_{\mathrm{Heis}} = J\sum_{\langle ab\rangle} \frac{\vec{\sigma}_a}{2}\cdot\frac{\vec{\sigma}_b}{2}$$

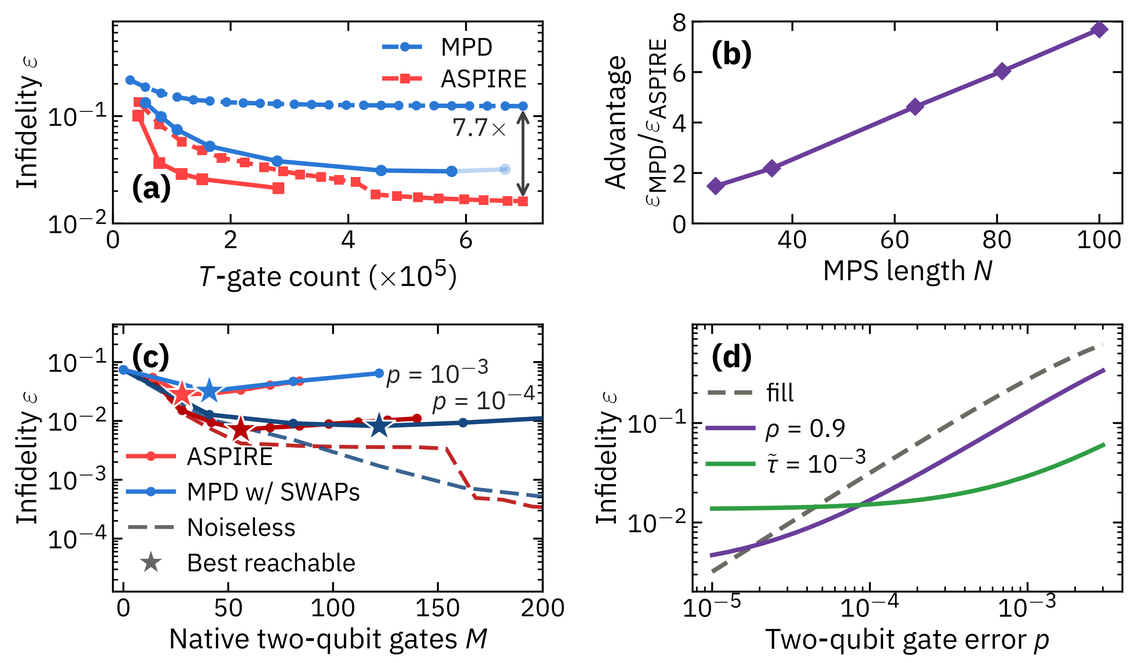


Fig. 1 **(a)** 10 × 10 TFIM ground state, $N = 100$: ASPIRE ends at 7.7× lower infidelity at equal T-gate count; solid lines are optimized [3] at equal classical cost. **(b)** The advantage grows linearly with N. **(c)** Kicked-Ising state [4] on 30 heavy-hex qubits. ASPIRE attains lower infidelity (stars) in fewer gates than the MPD, which has to pay for SWAPs on this restricted topology. **(d)** Selective admission pays off under strong noise: ASPIRE can select gates that clear an absolute removal threshold (green) or one relative to the other possible moves (purple).

Connectivity /

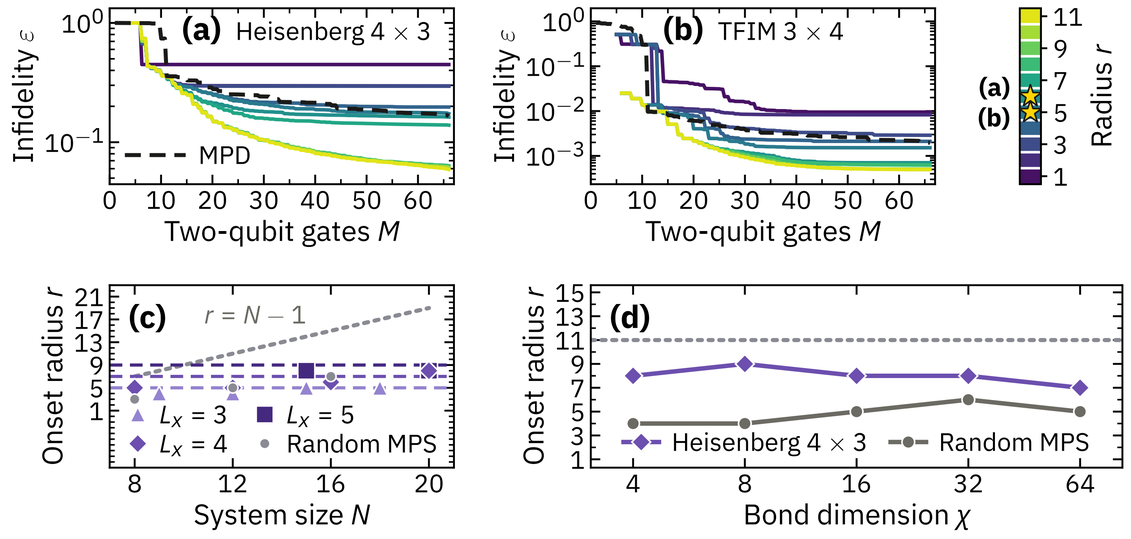


Fig. 2 (a, b) 12-site Heisenberg and TFIM ($h = 2$) lattices, ASPIRE at radius r (colour) against the MPD (dashed) at 66 gates; stars mark the first radius that beats the MPD. **(c)** Some-to-some connectivity covering the snake-mapped bonds (dashed) is enough for an advantage to set in, roughly constant in N, and **(d)** the onset is flat in χ. Dotted: all-to-all limit.

REFERENCES

[1] S.-J. Ran, *Phys. Rev. A* **101**, 032310 (2020). [2] K. Hyatt, J. R. Garrison, B. Bauer, *Phys. Rev. Lett.* **119**, 140502 (2017). [3] M. S. Rudolph *et al.*, *Quantum Sci. Technol.* **9**, 015012 (2024). [4] Y. Kim *et al.*, *Nature* **618**, 500 (2023).

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