Detecting Measurement-Induced Entanglement Transitions With Unitary Mirror Circuits

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Monitored random circuits, consisting of alternating layers of entangling two-qubit gates and projective single-qubit measurements applied to some fraction p of the qubits, have been a topic of recent interest [1]. In particular, the resulting steady state exhibits a phase transition from highly correlated states with "volume-law" entanglement at $p < p_c$ to localized states with "area-law" entanglement at $p > p_c$. It is hard to access this transition experimentally, as it cannot be seen at the ensemble level. Naively, to observe it one must repeat the experiment until the set of measurement results repeats itself, with likelihood that is exponentially small in the number of measurements. To overcome this issue, we present [2] a hybrid quantum-classical algorithm which creates a matrix product state (MPS) based "unitary mirror" of the projected circuit. Polynomial-sized tensor networks can represent quantum states with area-law entanglement, and so the unitary mirror can well-approximate the experimental state above p_c but fails exponentially below it. The breaking of this mirror can thus pinpoint the critical point.

References

[1] B. Skinner, J. Ruhman, and A. Nahum, Phys. Rev. X 9 031009 (2019)
[2] Y. Yanay, B. Swingle and C. Tahan, arXiv:2401.17367 (2024)

Figures

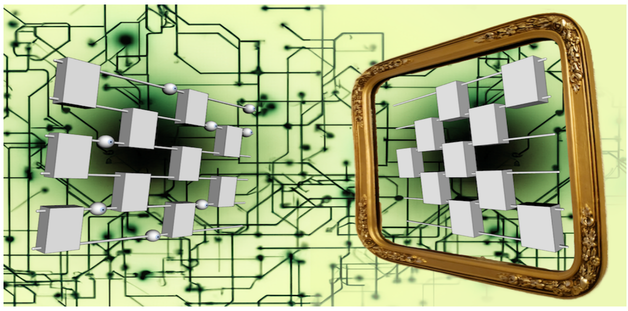

Figure 1: The output of a monitored random circuit, consisting of alternating layers of entanglers and projection operators (left) deterministically generates a state that can be approximated by its "unitary mirror" (right), a circuit composed purely of unitary gates. From the overlap between the two we can learn about the state's entanglement properties.

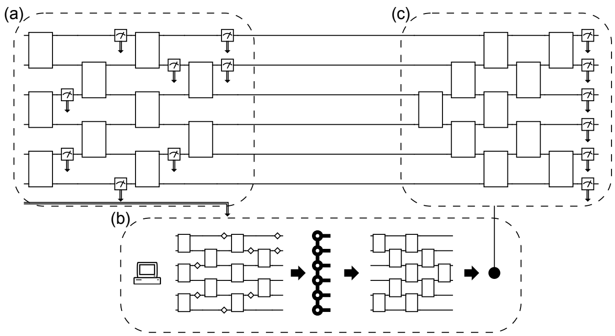

Figure 2: The proposed scheme: (a) A randomly monitored circuit is run on a quantum device generating a state $|\psi\rangle$. (b) The circuit and measurement results are fed into a classical processor. We classically calculate an MPS $|\psi_D\rangle$ approximating the output of this circuit, and from it the "unitary mirror" circuit. (c) Finally, we apply the inverted mirror to $|\psi\rangle$ and measure the probability of returning to the initial state to obtain the overlap $F = |\langle\psi|\psi_D\rangle|^2$.