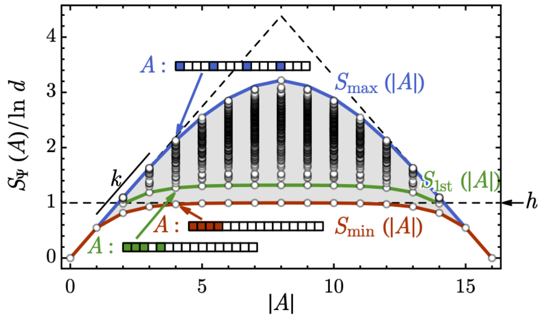
[Ahmed Ali Akhtar](#) – **Research Statement**

I work in the field of theoretical condensed matter physics and quantum information. I am interested in a diverse range of quantum physics, such as many-body entanglement, many-body localization, measurement-induced phase transitions, topological matter, tensor networks, and classical shadow tomography. All of my work utilizes a mix of theoretical and numerical tools.

I. Many-body entanglement dynamics

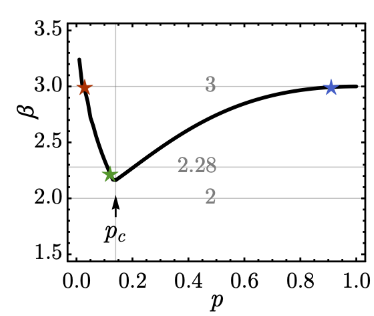
Whether quantum matter obeys an entanglement area-law or entanglement volume-law can reveal much about its phase, topology, error-correcting capacity, etc. More generally, how entanglement propagates over space and time can tell us about how quantum information spreads in a system. However, the curse of dimensionality means that there is *a lot* of entanglement data: one for every bipartition of a system.



In past works, we have studied a class of random quantum circuits which erase local basis information. We found that these ubiquitous models are amenable to analytical and numerical treatment because they admit a Markovian description. This allowed us to discover a correction to contiguous-region entanglement dynamics from disconnected regions that were missing from previous coarse-grained analyses. Furthermore, we've found that the entire entanglement spectrum, i.e. entanglements for all possible bipartitions arranged according to region size, is captured by just two parameters: the cost of creating an entanglement domain wall and the slope of entanglement with sub-system size. This insight provided numerical and analytical tools to study quantum information dynamics in random circuits. What other models of "exactly-solvable" entanglement dynamics are there and what can we learn from them?

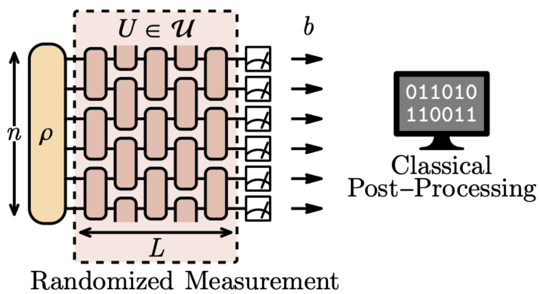
II. Dynamical Phase Transitions

Disorder can localize particles through interference and scattering. Whether such localization can persist in the presence of interactions and allow a quantum system to evade thermalization is the central question in many-body localization studies. These are a kind of dynamical phase transition which is in part characterized by a transition in the scaling of the many-body entanglement. Another such example is the measurement-induced phase transitions, where one tunes the measurement rate p to drive an entanglement transition.

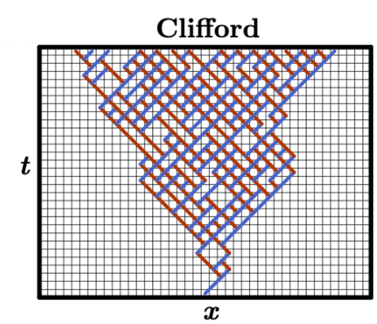


In past works, we have studied localization in the low-lying states of the massless Schwinger model through a variety of numerical techniques including simulation using matrix product states and exact diagonalization to study eigenvalue statistics. More recently, we revisited the measurement-induced phase transition when viewed as a classical shadow tomography prediction scheme. We found that the optimal scaling of the sample complexity β is obtained at precisely the critical point separating the area and volume-law phases. There are several unfinished questions I would like to explore here: what is the nature of the critical point? Will other dynamical transitions exhibit tomographic optimality, such as disorder-induced localization transitions? In what other ways can classical shadow tomography be used to study quantum information dynamics, operator spreading, learnability, etc. in a more practical setting?

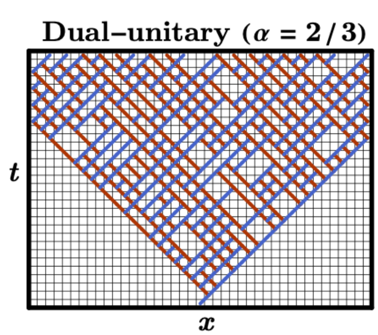
III. Classical Shadow Tomography



Classical shadow tomography is an efficient protocol for predicting properties of quantum states. Due to its simplicity, it has direct applicability on existing quantum devices. Traditionally, the literature has focused on two tomography schemes: Pauli measurements, which are useful for predicting low-weight operators, and Clifford measurements, which are useful for predicting low-rank operators. The two schemes correspond to the $t = 0$ and $t = \infty$ limits of a brick-wall circuit composed of Clifford gates. In [previous works](), we demonstrated an efficient technique for performing classical shadow tomography in the shallow circuit ($0 < t \ll \infty$) regime inspired by tensor networks. Moreover, we found that these intermediate schemes can be useful for predicting quasi-local operators, as well as estimating fidelity without having to apply global Clifford gates, which can be difficult to implement in current devices.



We also studied finite-depth circuits composed of dual-unitary gates, rather than Clifford gates, in classical shadow tomography. It is well known that dual-unitary gates are good at scrambling quantum information, and have found use in many exotic areas of physics such as modeling black hole phenomena. In our work, we show that the fast-scrambling nature of dual-unitary gates allows them to more quickly approach the Clifford measurement $t = \infty$ limit than brick-wall Clifford circuits.



We also find that the operator spreading dynamics in such circuits exhibit rich physics, including light-cones and chiral excitations. Since quantum phases can broadly be characterized by states related by some sequence of local (unitary or non-unitary) operations, and such operations can similarly define a classical shadow scheme, I would like to explore what insights into the theory of quantum phases of matter can be gleaned from this practical framework.