RESEARCH PROPOSALS

Jung-Shen Kao

(A) Quantum Phases and Quantum Phase Transition

[1] **Machine Learning Fracton Phases with X-cube Model and Haah's Code:** While the renormalization group and adiabatic continuity are traditionally employed for capturing phase classification, some systems appear to defy this approach. Fractons, distinguished by immobile excitations, present challenges for conventional analytical methods. I intend to utilize machine learning to differentiate between phases described by the X-cube model and Haah's code, exploring possibilities for generalization to gain insights into unknown mechanisms.

Reference:

- Carrasquilla, J., Melko, R. G. (2017). "Machine learning phases of matter." *Nature Physics*, 13(5), 431.
- Nandkishore, R. M., Hermele, M. (2019). "Fractons." *Annual Review of Condensed Matter Physics*, 10, 295–313.

[2] **Establish Exotic Quantum Phases in Quantum Simulation Paradigm:** Exploring exotic quantum phases using quantum circuits is exciting. I aim to investigate the incorporation of feedback and appropriate combinations for achieving structured long-range-entangled states, exploring how machine learning can contribute.

Reference:

- Satzinger, KJ., et al. (2021). "Realizing topologically ordered states on a quantum processor." *Science*, 374 (6572), 1237-1241.
- Fisher, MPA., et al. (2023). "Random Quantum Circuits." *Ann. Rev. Condensed Matter Physics*.
- Mitarai, K., et al. (2018). "Quantum circuit learning." *Physical Review A*, 98, 032309.

[3] **Computer-Inspired Methods for Classification of Quantum Phases:** While my understanding in this field is currently limited, I am fascinated by the potential of employing more rigorous methods to categorize quantum phases. Given the recent close connection between stabilizer codes and machine learning, I believe that machine learning will also play a crucial role in this direction.

Reference:

- Lavasani, A., Gullans, M., Albert, V., Barkeshli, M. (2023). "Stability of k-local phases of matter." *Bulletin of the American Physical Society*.

(B) Non-Equilibrium Quantum Many-Body Dynamics

[1] **Ergodicity Breaking Mechanisms and Conserved Quantities:** Studying ergodicity breaking mechanisms related to conserved quantities or symmetries from the perspective of information scrambling and operator spreading is exciting. I am interested in building an algorithm with machine learning that can incorporate Out-of-Time-Order Correlators (OTOC) to effectively detect information scrambling and operator spreading.

Reference:

- Larkin, A. I., Ovchinnikov, Yu. N. (1969). "Quasiclassical Method in the Theory of Superconductivity."
- Nahum, A., Ruhman, J., Vijay, S., Haah, J. (2017). "Quantum Entanglement Growth under Random Unitary Dynamics." *Phys. Rev. X*, 7, 031016.
- Swingle, B. (2018). "Unscrambling the physics of out-of-time-order correlators." *Nature Physics*, 14, 988.
- Mohseni, N., et al. (2023). "Deep Learning of many body observables and quantum information scrambling." *arXiv:2302.04621*.

[2] **Guiding Driven Quantum Systems with Machine Learning:** Using machine learning, perhaps reinforcement learning, to guide the driving force in exploring interesting driven quantum systems beyond the Floquet regime, contributing to material design.

[3] **Same as (A) [2]**

(C) Machine Learning and Physics

[1] **Neural Network Quantum States:** I am interested in various aspects of Neural Network Quantum States, including their capability to capture classical or quantum correlations, imposing more interesting symmetries, and advancing techniques for simulating quantum dynamics.

Reference:

- Carrasquilla, J., Melko, R. G. (2017). "Machine learning phases of matter." *Nature Physics*, 13(5), 431.
- Carleo, G., Troyer, M. (2017). "Solving the quantum many body problem with artificial neural networks." *Science*.
- "Neural tensor contractions and the expressive power of deep neural quantum states." *Physical Review B*, 106, 205136 (2022).
- "Restricted Boltzmann Machines for quantum states with non-abelian or anyonic symmetries." *Physical Review Letters*, 124, 097201 (2020).
- Schmidt, M., et al. (2020). "Quantum many body dynamics in two dimensions with artificial neural networks." *Physical Review Letters*, 125, 100503.

[2] **Quantum Tomography:** I have a keen interest in generative models, particularly in their direct application in quantum tomography. Quantum tomography is a key task in the NISQ era for verifying large quantum systems. Besides studying generative models, I aim to develop more protocols combining with the measurement process to reduce the computational cost of quantum tomography.

Reference:

- Wu, D., et al. (2023). "Variational Benchmarks for Quantum Many-Body Problems." *arXiv:2302.04919*.
- Torlai, G., et al. (2018). "Neural-network quantum state tomography." *Nature Physics*, 14(5), 447-450.
- Torlai, G., et al. (2023). "Quantum process tomography with unsupervised learning and tensor networks." *Nature Communications*, 14(1), 2858.

[3] **Quantum Machine Learning:** I am interested in studying ansatz in the framework of Graph. Recognizing many models as special cases of Graph, such as graphical models being a type of Factor Graph, inspires my exploration into the characteristics of ansatz from mathematical solvability to trainability for ML tasks. Generalizing Graph to Quantum Graph, especially with Quantum Factor Graph, presents challenges but holds potential for training. I believe this research direction can offer insights for the future development of Quantum Machine Learning.

Reference:

- Dalzell, A. M., et al. (2023). "Quantum algorithms: A survey of applications and end-to-end complexities." *arXiv:2310.03011*.
- Chen, CF., Lucas, A. (2021). "Operator growth bounds from graph theory." *Communications in Mathematical Physics*, 385(3), 1273-1323.