Usage Report for Fiscal Year 2023

Project Title:

Deep Learning of Quantum Matrix Models

Name:
○Enrico Rinaldi (1,2), Farad Khoyratee (1)

Laboratory at RIKEN:

1. **Cluster for Pioneering Research, Theoretical Quantum Physics Laboratory**
2. **RIKEN Center for Quantum Computing, Quantum Information Physics Theory Research Team**

1. Background and purpose of the project, relationship of the project with other projects

Neural Network Quantum States (NNQS, or NQS for short) are an efficient representation of quantum many body states based on parameterized nerula network architectures.
We extend the use of NQS from condensed matter physics, where the degrees of freedom are localized on a regular lattice in 1D, or 2D, to the theory of Matrix Quantum mechanics.
This project is connected to quantum information science and quantum gravity, because we study the wavefunction of a system of matrices representing a dual theory of gravity in a quantum regime.

2. Specific usage status of the system and calculation method

We have used Hokusai BIGWATERFALL to extend our previous publication on PRX Quantum which was also highlighted in RIKEN Research Highlights[1].

The publication above shows the application of NQS to the SU(2) and SU(3) Matrix quantum mechanics system where the degrees of freedom are bosons. This is sometimes referred to as Bosonic BMN model. We have extended this work by considering larger symmetry groups of SU(4), SU(5), etc… up to SU(8). Moreover we have extended the number of matrices in the model from d=2 matrices, to d=9 matrices. Both these extensions are relevant to understand how the method scale to systems that are relevant for quantum gravity.

In addition to this endeavor we have implemented a new method based on Markov Chain Monte Carlo that can help investigate bosonic many-body systems after their degrees of freedom have been discretized on qubits. This is relevant to understand the precision of physical observables that can be achieved when such bosonic systems are studied on quantum computing architectures made of qubits.

3. Result

The results of the neural networks to approximate the wavefunction of a theory with large matrices are promising for the case of bosonic degrees of freedom and we plan to publish them in a forthcoming paper.

We are still clarifying which is the best neural network architecture to use because we see a small but systematic discrepancy with results coming from Markov Chain Monte Carlo methods that can not be explained with a statistical uncertainty.

[1] Enrico Rinaldi, Xizhi Han, Mohammad Hassan, Yuan Feng, Franco Nori, Michael McGuigan, Masanori Hanada, "Matrix Model simulations using Quantum Computing, Deep Learning, and Lattice Monte Carlo", PRX Quantum 3, 010324, 2022

４． Conclusion

Deep learning paired with Variational Monte Carlo methods is a very promising avenue to study quantum many-body systems, from spin glasses to matrix models. Our project demonstrates the accuracy of this method on different quantum matrix models that are more and more similar to the ones used to investigate the gauge/gravity duality.

５． Schedule and prospect for the future

We expect to continue this project in the next fiscal year, by trying different neural network architectures that can scale better to large SU(N) groups and more matrices.

Fiscal Year 2023 List of Publications Resulting from the Use of the supercomputer

[Paper accepted by a journal]
None

[Conference Proceedings]
None

[Oral presentation]
None

[Poster presentation]
None

[Others (Book, Press release, etc.)]
None