Usage Report for Fiscal Year 2023

Project Title:

Simulation-based learning for open quantum systems

Name:
○Enrico Rinaldi (1,2), Franco Nori (1,2)

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

We propose to investigate the dynamics of open quantum systems using statistical inference, probabilistic models, and machine learning techniques. Our goal is to develop a comprehensive understanding of the behavior of these systems, which are essential for emerging technologies such as quantum metrology, quantum computing, and quantum communications.

2. Specific usage status of the system and calculation method

We focus our approach on a driven two-level system, corresponding to an atom in a cavity under the influence of a laser pulse. This can be considered as a model for controlling a qubit, but it can also be seen as a toy model for quantum metrology. Photons escaping the system are detected as “clicks” in a measurement instrument.

We use Bayesian inference and nested sampling methods to obtain the parameters of the two-level system, by using the photons click time intervals as observation data.

Our code is based on a python library called “ultranest” which supports multi-threading and also MPI communications. We ran inference for multiple observations in parallel and the calculation of the likelihood function for each of the observations is multi-threaded using the linear algebra package \`numpy\`.

3. Result

We validate our inference procedure by using simulated data for which we know the true hidden parameters of the system. While this inference is trivial to do with a single parameter, when it amounts to computing a one-dimensional integral and sampling from a probability distribution, it becomes more and more complex as the dimension of the parameter space increases.

We compute the posterior for a single parameter, and the joint posterior for two parameters.

4. Conclusion

We compare the results from our Bayesian inference procedure with an estimate obtained by training neural networks on simulated data. The neural network does not know the likelihood and therefore it has to extract all the hidden quantum information from the data alone. Nonetheless, for this simple two-level system, we find neural network architectures that perform as well as the Bayesian inference, which we use as a benchmark. The results obtained from Hokusai have been used to clarify the performance of the neural network-based method. In fact, it gives the NN method more credibility.

5. Schedule and prospect for the future

In the next year we will perform inference for a more complicated three-level system, where the quantum information is harder to extract from the data alone. In this case, neural networks will have to be engineered with some inductive bias or structure in order to perform well. Hokusai does not have GPUs that we can use for the training of neural networks, so we will continue using Hokusai to perform the Bayesian inference in high dimensional parameter spaces for the three-level system. This again will serve as a necessary benchmark.

Fiscal Year 2022 List of Publications Resulting from the Use of the supercomputer

[Paper (preprint)]

Enrico Rinaldi, Manuel González Lastre, Sergio García Herreros, Shahnawaz Ahmed, Maryam Khanahmadi, Franco Nori, Carlos Sànchez Muñoz, "Parameter estimation by learning quantum correlations in continuous photon-counting data using neural networks", arxiv:2310.02309

[Conference Proceedings]

None

[Oral presentation]

Enrico Rinaldi, "**Deep Learning of Quantum Correlations for Quantum Parameter Estimation of Continuously Monitored Systems**", SQAI General Meeting, September 2023

Enrico Rinaldi, "**Deep Learning of Quantum Correlations for Quantum Parameter Estimation of Continuously Monitored Systems**", QTML 2023, CERN, November 2023

[Poster presentation]

None

[Others (Book, Press release, etc.)]

None