Usage Report for Fiscal Year 2022

Project Title:

Simulation-based learning for open quantum systems

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

We set out to study several open quantum systems using techniques from statistical inference, probabilistic models, and machine learning. The purpose of the project is to characterize systems that are routinely used in advanced engineering fields such as quantum metrology, quantum computing, and quantum communications.

2. Specific usage status of the system and calculation method

This year we focus on a two-level system, corresponding to an atom in a cavity under the influence of a laser pulse. This is a very simplistic model of controlling a qubit, but it can also be seen as a toy model for quantum metrological instruments where changes to the atom gets amplified by the laser interactions and photons escaping the system are detected as “clicks” in the instrument.
We use Bayesian inference and nested sampling methods to obtain the parameters of the two-level system interacting with a laser from the simple observational data given by “click” of photons hitting a detector.
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 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. The maximum of the posterior is the best estimate of the parameters that is possible to do thanks to the quantum information encoded in the likelihood.

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.

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 accepted by a journal]

None

[Conference Proceedings]

None

[Oral presentation]

None

[Poster presentation]

None

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

None