MASTER IN PHOTONICS – PHOTONICS BCN
EUROPHOTONICS-POESII MASTER COURSE

PROPOSAL FOR A MASTER THESIS

Dates: April - September 2017

Laboratory : Quantum Information Theory
Institution: ICFO-The Institute of Photonic Sciences
City, Country : Castelldefels, Spain

Title of the master thesis: Deep Learning in Quantum Physics

Name of the master thesis supervisor: Antonio Acín, Peter Wittek
Email address: antonio.acin@icfo.es, peter.wittek@icfo.es
Phone number: +34 93 553 40 62
Mail address: Av. Carl Friedrich Gauss, 3

Summary of the subject (maximum 1 page) :
Statistical physics and machine learning have a long shared history, and new connections are being discovered. In many-body quantum physics, tensor networks have already provided significant breakthroughs, such as the method of projected entangled pair states in studying two-dimensional systems, and multi-scale entanglement renormalization ansatz for the one-dimensional case. Boltzmann machines and deep learning bear strong similarities with these methods, and an emergent body of work studies the accuracy and computational cost of using neural networks for representing quantum systems with some promising results [1-3], albeit a complete characterization of what is possible is still lacking.

Of particular interest are the layers of abstraction in a deep learning network, and the representation accuracy of a matching tensor network method to study physical systems, and how these could lead to novel numerical methods that draw on efficient machine learning libraries, such as TensorFlow, instead of the computational tools typically used in computational physics. The interesting insight here is that these machine learning libraries have a much broader developer and user base, they are tested just as rigorously as scientific tools, but given the larger number of contributors, their overall performance is potentially better tuned.

Parallel to this, there is a growing interest in using reinforcement learning schemes in quantum control [4-5]. Reinforcement learning enables controlling quantum systems in realistic settings, accounting for the presence of noise, decoherence, loss, and other factors that arise in implementations. Most approaches until now focused on reinforcement learning that used global heuristic search, but this has a very high computational cost [6]. The purpose of this project is to rely on more recent developments in reinforcement learning that combine a deep learning network with heuristic search to keep the problem computationally feasible [7]. Applications include quantum phase estimation [4] and generating Bose-Einstein condensates [8].

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[2] Carleo, G. and Troyer, M. (2016). Solving the quantum many-body problem with artificial neural networks. *ArXiv:1606.02318*.
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[4] Hentschel, A. & Sanders, B. C. Machine Learning for Precise Quantum Measurement. *Physical Review Letters*, 2010, **104**, 063603.
[5] Tiersch, M.; Ganahl, E. J. & Briegel, H. J. Adaptive quantum computation in changing environments using projective simulation. *Scientific Reports*, 2015, **5**, 12874.
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[7] Silver, D.; Huang, A.; Maddison, C. J.; Guez, A.; Sifre, L.; van den Driessche, G.; Schrittwieser, J.; Antonoglou, I.; Panneershelvam, V.; Lanctot, M.; Dieleman, S.; Grewe, D.; Nham, J.; Kalchbrenner, N.; Sutskever, I.; Lillicrap, T.; Leach, M.; Kavukcuoglu, K.; Graepel, T. & Hassabis, D. Mastering the game of Go with deep neural networks and tree search. *Nature*, 2016, **529**, 484-489.
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Keywords : Reinforcement learning, deep learning, heuristic search, genetic algorithmm differential evolution, quantum phase estimation, quantum control, Bose-Einstein condensate, high-performance computing, multi-scale entanglement renormalization ansatz, projected entangled pair states, Boltzmann machines

Additional information :
* Required skills : C++ or Python, machine learning, numerical methods
* Miscellaneous :