Erasmus Mundus Master QuanTEEM
Master Internship

TITLE	Entanglement in Variational Quantum Algorithms
SUPERVISOR	Frédéric Holweck - frederic.holweck@utbm.fr
INSTITUTION	Université Technique Belfort-Montbéliard (UTBM)
LAB / DEPARTMENT / TEAM	ICB / Interaction and Quantum Control Department / DyTeQ
COLLABORATIONS	ColibriTD
TYPE OF PROJECT (theory / experiment)	Theory

Summary

Variational Quantum Algorithms (VQA) [1] are a class of quantum algorithms which are getting more and more popular as they are considered as a potential solution to achieved quantum advantage using Noisy Intermediate Quantum (NISQ) computers. The principle is as follows : a quantum circuit, called the ansatz, that depends on parameters, generates a state. This state encapsulates the information of a problem one wants to solve which is retrieved by measuring some observable of that state. At first the state is not close to the solution but a classical optimiser is bridged on the quantum circuit to iterate changes of the parameters in order to converge through the desired state.

The structure of the ansatz, and what make an ansatz more efficient than an other one for a given problem is a bit mysterious. In this respect, VQA are very often compared to neural networks where the understanding of the structure of the network in relation to the problem to solve is not well understood yet.

The goal of this master internship would be to study the ansatz from the entanglement perpsective. What kind of entanglement is genererated from a given ansatz and more generally which part of the Hilbert space is covered by the ansatz when varying the parameters.

More precisely the goals of the internship will be :

- Provide a review on VQA and in particular on the standard types of ansatz that are used in the litterature
- Analyze in very simple cases n=2,3 and 4 qubits the type of entanglement that can be generated by one and two layers ansatz in the spirit of [3]
- Describe the geometry of the set of the states generated by a simple ansatz
- Run experiences on a quantum computer and/or simulators to illustrate the change of entanglement classes

Bibliography

[1] Cerezo, Marco, Andrew Arrasmith, Ryan Babbush, Simon C. Benjamin, Suguru Endo, Keisuke Fujii, Jarrod R. McClean et al. "Variational quantum algorithms." *Nature Reviews Physics* 3, no. 9 (2021): 625-644.

[2] Holweck, Frédéric, Jean-Gabriel Luque, and Jean-Yves Thibon. "Entanglement of four qubit systems: A geometric atlas with polynomial compass I (the finite world)." *Journal of Mathematical Physics* 55.1 (2014).

[3] Jaffali, Hamza, and Frédéric Holweck. "Quantum entanglement involved in Grover's and Shor's algorithms: the four-qubit case." *Quantum Information Processing* 18 (2019): 1-41.

Additional Information

The candidate should have interest in quantum computing and have followed the course on quantum algorithms. A good mathematical background is also necessary.

Even if the problem is theoretical, companies that are developing quantum algorithms for use-case scenario are interested in understanding better VQA. At some point of the internship a meeting with the R&D team of the start-up ColibriTD which uses VQA in one of their algorithms will be organized.

The internship will take place at UTBM (University of Technology of Belfort-Montbéliard) in Belfort.

The project may continue with a PhD grant.