Offer #2025-08662

PhD Position F/M [Allocation Région 2025] Towards quantum-utility multi-objective variational optimisers (F/M)

Contract type : Fixed-term contract

Level of qualifications required : Graduate degree or equivalent

Fonction : PhD Position

About the research centre or Inria department

Created in 2008, the Inria center at the University of Lille employs 360 people, including 305 scientists in 15 research teams. Recognized for its strong involvement in the socio-economic development of the Hauts-De-France region, the Inria center at the University of Lille maintains a close relationship with large companies and SMEs. By fostering synergies between researchers and industry, Inria contributes to the transfer of skills and expertise in the field of digital technologies, and provides access to the best of European and international research for the benefit of innovation and businesses, particularly in the region.

For over 10 years, the Inria center at the University of Lille has been at the heart of Lille's university and scientific ecosystem, as well as at the heart of Frenchtech, with a technology showroom based on avenue de Bretagne in Lille, on the EuraTechnologies site of economic excellence dedicated to information and communication technologies (ICT).

Context

The PhD thesis will be conducted under the co-supervision of Dr. Z.A. Dahi (ISFP, Inria Starting Faculty Position) and Prof. Bilel Derbel. Both supervisors belong to the BONUS research group at the Inria research center of the Univesity of Lille. The

BONUS team specialises in solving big optimisation problems, which goes along with the thesis perspective, and therefore provides an adequate environment for both the PhD and the thesis to be conducted.

Assignment

Quantum Computing paradigm (QC) is based on quantum mechanical principles, which allows it to provide computation acceleration regarding its classical counterpart. Optimisation problem-solving is one of the major domains where QC can provide advances. Variational Quantum Algorithms (VQAs) are a promising class of quantum optimisers capable of providing promising efficiency despite the noisy-limited nature of today's quantum devices. Initially, VQAs have been designed to solve single-objective problems, although, real-life scenarios require dealing with multiple ones. Thus, extending this class of algorithms to MO domain is challenging and paramount towards realistic applicability and eventually attaining a possible quantum advantage. So far, only some efforts have been made to design multi-objective counterparts of VQAs (MO-VQAs). In addition, the limited literature that attempted to do so presents shortfalls preventing the applicability and efficiency of such proposals.

This thesis aims to (I) correct shortfalls of previous research, and (II) push the boundaries of research on MO-VQAs beyond current state-of-the-art by exploring never-research-before approaches. The main challenge in both cases is to design utile MO-VQAs that are feasible, error-robust and efficient considering the noisy and limited nature of today's quantum hardware.

Main activities

Scope

Quantum computing is a computing paradigm that relies on phenomena from quantum mechanics (e.g. interference, state superposition, etc.) [1]. This provides it a computational speed-up with respect to its classical counterpart. Such calculation acceleration turns to be useful for several purposes, most importantly optimisation problem solving [2]. Regarding the former, some promising quantum algorithms have been already proposed under several quantum computation paradigms such asadiabatic annealers and discrete gate-based QC. This proposal focuses on the second type considering its wider range of applicability, and its support by industrials (e.g. Google, Microsoft, IBM, etc.). This being said, the noisy and the limited capacities of today’s gate-based quantum machines make it very tricky, sometimes impossible, to apply most of them. One of the quantum algorithms classes that can still ensure promising efficiency under such noise-limitation is the Quantum Variationl Algorithms (VQAs) [3]. The former are hybrid quantum-classical solvers, that solve the Hamiltonian of problems using parametrisable ansatz. Most of the VQAs have been devised for solving single-objective optimisation problems. Although, realistic scenario include, in general, dealing with several conflicting optimisation objectives, known as Multi/Many Objective Problems (MOPs) [4]. In such class of problems, the goal is to seak a set of equally-efficient solutions. The former constitutes a set of fronts that are subject to some dominance criteria that considers all the objective functions of the MOP. Devising a multi-objective counterpart of VQAs for dealing with this class of problems is paramount for advancing reasearch in MOP solving solving, as well as the VQAs' applicability, and eventually leading the path to potential quantum advantage and even supremacy. In the last 10 years, only few works attempted to devise a VQA that can solve MOPs [5, 6]. Those works suffered from a set of design and implementation shortfalls making those proposals inefficient and even unfeasible. Design-wise, those works rely on trivial weighted-sum decomposition designed with sub-optimal penalty functions and unable to deal with peculiar Pareto fronts such as the non-convex ones. From expectation value perspective, the authors consider the hypervolume, although it has several drawbacks regarding other metrics such as the inverted generational distance and its variant (e.g. computationally expensive, nadir point selection, etc.). In addition, the problem Hamiltonian used has a linearly more complex number of ansatz parameters, and is not clear that it traces back to quantum annealing. Eventually, dominance is extracted in the classical part of the VQAs with a quadratic complexity. Now, from an implementation point of view, one of those works use qudits which is exponentially more expensive to simulate, while real machines are unavailable and less mature than qubits-based systems. Also, the proposals' design does not consider the exponentially-increasing simulation memory proportional to the problem size, as well as the long queuing when using real quantum computers. Considering these facts, a third and final work in [2] done by the supervisors of this PhD proposal solved the aforementioned issues by designing distributed MO-QAOA using a penalty-corrected weighted-sum scalarisation, as well as proposing a mathematical and algorithmic approximation of the Tchebycheff scalarisation. This being said, the work still suffers from key shortfalls. (I) The mathematical Tchebycheff approximation might be tricky and even impossible to be applied when the radican end behaviour is not increasing or positive. (II) Other robust scalarisation methods exist in the literature, and could lead to more efficient solutions. (III) The scalarisation-based methods are costly and dependent of the scalarisation settings. (IV) Computing non-dominance is done classically in a quadratic time, which requires a quantum-to-classical interaction that is computationally penalising.

Objectives

The objectives of this proposal is to advance research in the design of quantum MO-VQA optimisers that are utile and
practical despite the noisy-limited state of today's quantum computers and VQAs' design. This proposal aims at doing so by (I) coping/enhancing the findings of previous literature, and (II) research never-explored-before paths. Concretely, we will focus on (I) efficient handling of the multi-objectivity of the problems considering the QC and VQA's features, and (II) pursue any possible computational acceleration by leveraging both the classical and quantum parts of the VQAs especially that it is not always clear where quantum computation can outperform classical one. This PhD proposal will be divided to three parts/years pursuing, each, one research question at a time from both classical perspective and quantum one.

1. Scalarisation-based MO-VQA. This first part goes in the continuity of the work done by the supervisors in [2], by (I) enhancing the mathematical formulation of the Tchebycheff scalarisation, more especifically finding a mathematical alternative that allows tackling non-positive polynomials. The second goal, is to explore other more robust scalarisation techniques, by designing their quantum counterpart, able to run on quantum computers. (II) moving to the calculation acceleration, it will be sought by leveraging the acceleration provided by classical parallelism paradigms using several quantum simulators and eventually computers in a classical fashion where the parallelism will not be provided by the quantum search but instead, by the number of quantum machines/simulators being used. This first part is thought to be low-risk and more adequate for
introducing the PhD candidate to the necessary background to undertake more advanced parts in the remaining years.
2. Scalarisation-Free MO-VQA. The solving efficiency when dealing with problem multi-objectivity via scalarisation depends on the type and settings of the used decomposition, which is not trivial and requires substantial computational resources according to the classical parallelism used in the first part [2]. So, the second part/year will attempt to develop a quantum MO-VQA that allows removing the need of scalarisation. Eventually, this will remove the need of multiple quantum machines or simulators to overcome the computational complexity induced by a large number of scalarisation points, especially that today's quantum computers are noisy with queuing and latency access. From a quantum perspective, the challenge stands in building a quantum ansatz that can be (I) fault-tolerent and mathematically sound with regard to the multi-objective nature of the
problem, and (II) if possible, ensure some quantum advantage such as solution optimality or computational acceleration.
3. Quantum Dominance-based MO-VQA. Multi-objective optimisation deals with several objectives at the same time. Since the algorithms are elitist looking only for the best solutions, the dominance concept is paramount to discriminate between solutions, and is unavoidable during the optimisation of suchlike problems. However, extracting the best non-dominated solutions' front requires a complexity in time that is quadratic in the number of objectives and the solutions and is generally done classically in the MO-VQAs' literature. This part will focus on (I) designing a quantum heuristic that can be used within the VQAs in order to perform this task quantum-wise and therefore reduce the quantum-classical machine interaction that might induce several drawbacks and computation infeasibility (e.g. loss of acceleration, latency, etc.). Eventually, the goal is to (II) reduce, if possible, the quadratic time complexity of non-dominance calculation to achieve some quantum acceleration in that sense.

References

[1] Zakaria Abdelmoiz Dahi, Chaker Mezioud, Amer Draa: A quantum-inspired genetic algorithm for solving the antenna positioning problem. Swarm Evol. Comput. 31: 24-63 (2016)
[2] Zakaria Abdelmoiz Dahi, Francisco Chicano, Gabriel Luque, Bilel Derbel, and Enrique Alba. Scalable quantum approximate optimiser for pseudo-boolean multi-

objective optimisation. In Parallel Problem Solving from Nature, pages 268–284. Springer, 2024
[3] E. Farhi, J. Goldstone, and S. Gutmann. A quantum approximate optimization algorithm, 2014.
[4] José Á. Morell, Zakaria Abdelmoiz Dahi, Francisco Chicano, Gabriel Luque, Enrique Alba: A multi-objective approach for communication reduction in federated learning under devices heterogeneity constraints. Future Gener. Comput. Syst. 155: 367-383 (2024)
[5] S.-H. Chiew, K. Poirier, R. Mishra, U. Bornheimer, E. Munro, S. H. Foon, C. W. Chen, W. S. Lim, and C. W. Nga. Multiobjective optimization and network routing with near-term quantum computers, 2024
[6] L. Ekstrom, H. Wang, and S. Schmitt. Variational quantum multi-objective optimization, 2024.

Skills

Skills/knowledge : combinatorial optimization, parallel computing, mathematical modelling, heuristic search algorithms, solid background in computer science and programming

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Remuneration

2200 € monthly gross salary from October to December 2025

2300 € monthly gross salary after January 1st 2026

General Information

- **Theme/Domain :** Optimization, machine learning and statistical methods
- **Town/city :** Lille
- **Inria Center :** Centre Inria de l'Université de Lille
- **Starting date :** 2025-10-01
- **Duration of contract :** 3 years
- **Deadline to apply :** 2025-04-20

Contacts

- **Inria Team :** BONUS
- **PhD Supervisor :**
  Derbel Bilel / Bilel.Derbel@inria.fr

About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

The keys to success

The candidate must demonstrate strong communication and organizational skills, as well as motivation to thrive in a high-level research environment with an international focus.

Warning : you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

Instruction to apply

Please send your CV and cover letter.

For further questions, please don't hesitate to contact Zakaria Abdelmoiz DAHI, co-supervisor, at abdelmoiz-zakaria.dahi@inria.fr

Defence Security :
This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST).Authorisation to enter an area is granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

Recruitment Policy :
As part of its diversity policy, all Inria positions are accessible to people with disabilities.