

PhD proposal

Hybrid quantum graph machine learning for the detection of old-growth forests.

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- Duration : 3 years, earliest start in October 2026
- Laboratory : IRIT - Site ENSEEIHT, 2 rue Charles Camichel, Toulouse.

This PhD is funded by TIRIS¹ Q-FOREST project, a collaboration between IRIT² and DYNAFOR³ labs. It benefits as well from the Maison Quantique Occitanie⁴ and HQI⁵ hybrid quantum computing infrastructure.

Context

Q-FOREST project aims at identifying pockets of old-growth forests (both ancient and mature) that constitute remarkable reservoirs of biodiversity. They represent less than 2% of the forest area, but mapping them has become one of the priorities of Europe's Biodiversity Strategy and its French implementation via the National Action Plan "Old Woods and Subnatural Forests." Their preservation is also included in the five-year action plan of the Conservatoire d'Espaces Naturels (CEN). However, mapping these old forests is a topical issue that only a few forest ecologists have mastered.

The Q-FOREST project targets advanced large-scale remote sensing processing based on multi-modal data. A first thesis on this subject began in 2025 at DYNAFOR lab. It questions the methodology and quality of forest identification using machine learning algorithms such as convolutional or transformer neural networks, in collaboration with CEN Occitanie, ONERA, and IGN. This PhD directly works on publicly available IGN color-infrared orthophotographs (20–50 cm resolution, nationwide coverage) with canopy height models from photogrammetry, complemented by IGN LiDAR HD point-cloud variables if beneficial. European forest biomass maps will help identify areas with large old-growth trees, together capturing structural-heterogeneity patterns linked to stand maturity.

The second thesis will begin in fall 2026 to explore how hybrid high-performance computing (HPC) - quantum algorithms can perform in old-growth forest detection and is described hereafter. This PhD work is motivated by the potential quantum advantage in terms of computing capacity and energy efficiency [3] for this detection problem. It has been designed to also integrate with the work of the Maison Quantique Occitanie project, which offers access to the computing resources of the France 2030 HQI national program⁶. Both PhDs will work in collaboration, but have different objectives. The first PhD works directly with the original multi-modal dataset, while the second one concentrates on the design of hybrid quantum-classical algorithms using synthetic and reduced-size datasets that capture the core features of the original data-sets.

¹<https://tiris.univ-toulouse.fr/>

²<https://www.irit.fr/>

³<https://www.dynafor.fr/>

⁴<https://www.irit.fr/mqo>

⁵<https://www.hqi.fr/>

⁶<https://www.hqi.fr>

Problem statement: Quantum Graph Neural Networks for multi-modal image classification over time.

Old-growth forest detection leverages timeseries of images of different nature with some of the earliest records dating back 1950. A strong underlying necessary condition is that an old-growth forest patch is continuously present since 1950 in all types of records over time. But continuous presence is not sufficient since man-grown forests may have a continuous presence in some areas. It is from color-infrared orthophotographs and biomass maps that the maturity level of the forest can be captured. Thus, the problem boils down to detect specific areas in series of multi-modal images with a continuous presence over time.

The global aim of this PhD work is to investigate the possible benefits of solving this problem with hybrid quantum-classical machine learning algorithms. Since encoding images into quantum memory is particularly costly, proposed research investigates the use of quantum machine learning, with a specific emphasis on quantum graph machine learning. Graph machine learning represents data as nodes and edges rather than fixed pixel grids, making it naturally suited to multivariate sources that can be fused as node or edge attributes on a shared spatial graph rather than stacked as image channels. Because the graph itself can evolve, temporal persistence of an area is captured as a time series of graphs (nodes/edges appearing, disappearing, or changing attributes across snapshots) rather than a time series of images, directly encoding the continuity criterion central to this classification task. Moreover, this representation is also more favorable for quantum implementation: graphs map naturally onto qubit connectivity and entangling-gate structure (e.g., via graph states or Hamiltonian encodings), whereas encoding a full image into a quantum state typically requires costly amplitude or basis encodings that scale poorly with pixel count.

Quantum graph neural networks (QGNNs) extend the message-passing paradigm of their classical counterpart (GNNs) by encoding graph structure directly into quantum circuits or quantum-derived similarity measures. Four complementary architectures may be directly relevant to our multivariate, temporally-persistent area classification problem. They can be implemented with different quantum processing unit (QPU) technologies:

- Graph-Hamiltonian architectures (gate-based QPUs) [8][7] ;
- Quantum-walk architectures (gate-based and photonic/analog QPUs) [2][6];
- Graph-state architectures (gate-based and photonic/measurement-based QPUs) [1];
- Quantum-kernel architectures for SVM classification (gate-based QPUs or simulators, shallow-circuit friendly) [4][5].

Graph-Hamiltonian architectures build parameterized ansätze by exponentiating a graph Hamiltonian whose Pauli structure mirrors the target adjacency; execution requires Trotterized time evolution on a gate-based QPU (or its simulator). Continuous-time quantum walks (CTQW) generalize the Hamiltonian-evolution idea into an explicit diffusion/convolution operator that learns a quantum walk to construct a trainable diffusion operator over node features. Graph-state formalism can be leveraged to generate a QGNN’s entangling structure directly from the input graph’s topology using CZ gates along edges, which are cheap to implement in gate-based architectures. And finally, it is possible to leverage quantum-kernel architectures for SVM classification. Quantum kernels are deduced from training a quantum neural network on dimensionally-reduced data.

The diversity of these techniques together with their possible execution on today’s QPU architectures has to be investigated in this PhD to select the most promising approach in the short-term and in the long-term. A short-term solution targets today’s NISQ (Noisy Intermediate Scale Quantum Computing) QPUs, that are subject to noise and can only handle limited memory and shallow-circuit solutions. Long-term solutions target FTQC (Fault-Tolerant Quantum Computing) computers that are not limited by noise and scale to larger memory size.

The research questions this PhD has to address are the following ones :

- Is it possible to derive a QML model that solves the old-growth detection forest problem of Q-FOREST using a hybrid quantum-classical ML technique ?
- If yes, is there a short-term (NISQ) and a long-term (FTQC) solution available ?

- Is there an advantage in using a QML approach compared to using a classical GNN model for the Q-FOREST detection problem ?

Planned work

The PhD work will be split into the following tasks in the 3-year period:

- M6 Quantum computing training ; literature review on Graph ML and Quantum ML ; Synchronization with the other Q-FOREST PhD candidate ;
- M12 Derivation and implementation of a GNN model for old-growth forest detection (classical computing) ;
- M24 Derivation of a QML model for old-growth forest detection for FTQC architecture ; Investigate possible implementation on today's emulator with a reduced Q-FOREST synthetic dataset ; Question the advantage of QML model over classical implementations.
- M30 Derivation of a QML model for NISQ architecture ; Investigate its implementation on simulators and current hardware ; Measure its performance compared to classical computing ; Question the advantage of this NISQ QML model over classical implementations.
- M36 Write PhD manuscript ; Finalize publications and experiments.

The PhD results will be published in relevant conferences and journals of the field. Advancement will be shared with the French community within the HQI/Maisons du Quantique network and the TIRIS initiative of Toulouse.

IRIT laboratory

The Institut de Recherche en Informatique de Toulouse (IRIT), one of the largest joint research units (UMR 5505) in France, is a pillar of research in Occitanie with its 600 permanent and non-permanent members and around 100 external collaborators. Due to its multi-disciplinary nature (CNRS, Toulouse universities), its scientific impact, and its interactions with other fields, the laboratory is one of the driving forces behind computer science and its applications in the digital world, both regionally and nationally. From an organizational standpoint, our unit is structured into seven research departments that bring together the laboratory's 25 teams :

- Architecture, Systems and Networks (5 teams)
- HPC, Simulation, Optimization (2 teams)
- Reliability of Systems and Software (4 teams)
- Data management (3 teams)
- Artificial intelligence (4 teams)
- Collective Intelligence, Interaction (3 teams)
- Images and signals (4 teams)

Candidate's profile

- Master's or third-year engineering student specializing in computer science, mathematics, or physics.
- Machine learning skills are welcome.
- Initial experience in quantum computing is a plus, but not required.
- Good programming skills.
- Strong interest in scientific research.

The application

Interested candidates are required to submit an application that includes the following:

1. A comprehensive CV
2. A motivation letter detailing the applicant's research interests and reasons for applying
3. Master-level transcripts

Please send your complete application in one single PDF file to Katia Jaffrès-Runser (katia.jaffres-runser@irit.fr), Julien Herrmann (julien.herrmann@irit.fr) and Walid Fathallah (walid.fathallah@irit.fr). The call is open until the position is filled.

FSD requirement The IRIT laboratory is classified as a ZRR (*zone à régime restrictif*, restricted-access zone⁷). Consequently, once a candidate has been selected, a security clearance will be requested from the *Fonctionnaire Sécurité Défense* (FSD). This process takes several weeks; the start date is therefore flexible and will be adjusted to the time needed to process the application. If the FSD issues an unfavourable opinion, the offer will be withdrawn.

References

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- [7] Cenk Tüysüz, Federico Carminati, Bilge Demirköz, Daniel Dobos, Fabio Fracas, Kristiane Novotny, Karolos Potamianos, Sofia Vallecorsa, and Jean-Roch Vlimant. A quantum graph neural network approach to particle track reconstruction. In *Proceedings of Connecting The Dots 2020 (CTD2020)*, 2020.
- [8] Guillaume Verdon, Trevor McCourt, Enxhell Luzhnica, Vikash Singh, Stefan Leichenauer, and Jack Hidary. Quantum graph neural networks. In *Second Workshop on Machine Learning and the Physical Sciences (NeurIPS 2019)*, Vancouver, Canada, 2019.

⁷https://fr.wikipedia.org/wiki/Zone_%C3%A0_r%C3%A9gime_restrictif