Quantum Algorithms for Earth Observation Image Processing

Satellite-based Earth observations have a broad range of applications, such as natural disaster warnings, analysis of global temperature impacts, weather conditions analysis, and land-use classification. However, current machine learning techniques for land-use classification are costly in terms of time and energy. There two possible approaches to solving this problem. The first one are Variational Quantum Algorithms. They are a class of quantum algorithms that is aimed at the application in the Near Intermediate-Scale Quantum computing era. These algorithms employ jointly parametrized quantum circuits and classical optimization techniques for finding quantum circuits or states that have desirable properties from the point of a given application. VQAs find applications typically in finding low energy states of quantum Hamiltonians, solving approximately Quadratic Unconstrained Binary Optimization problems and training Quantum Neural Networks. In the area of Earth observations, the most promising area of applications lies with QNNs since the application of VQAs allows for the creation of new classification methods that employ quantum information processing tools. The second approach is to use quantum computers for a hybrid machine-learning approach utilizing an autoencoder for dimensionality reduction and a quantum algorithm powered by quantum annealer to reduce training costs. The autoencoder, using conventional deep learning techniques, is executed on GPUs, while the Deep Belief Network is run on a D-Wave quantum annealer. This hybrid approach allows for independent training of both modules, partially reducing the time and energy required to retrain the model (see *Figure I*).

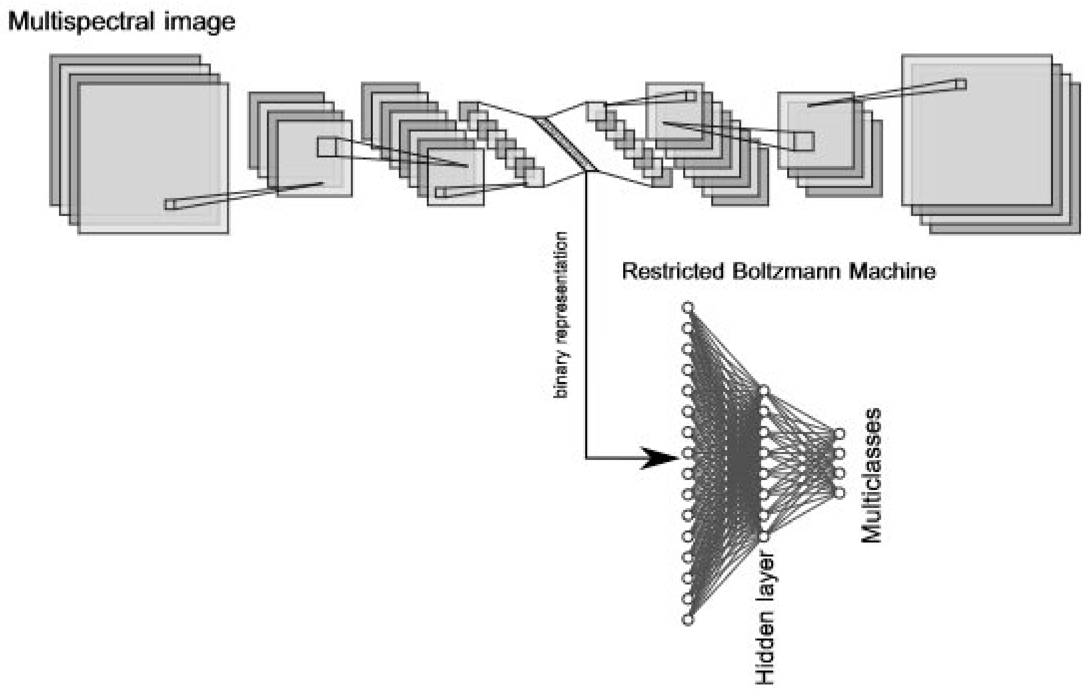

Figure I: Pictorial representation for integrating a D-Wave device in the deep learning pipeline for processing satellite images.

- **Present Day:** Current quantum computers belong to the NISQ era and can not claim any applicable advantage over classical computers. Those are experimental devices testing the limits of the existing technology. The training of a QNN on a quantum gate-based computer is currently very difficult and inefficient. Currently we can build QNN models using 10-20 qubits and train them on simulators in order to perform pixel-by-pixel segmentation or classification of EO patches in a hybrid quantum-classical setting. In the case of quantum annealers, currently we can perform processing of EO hyper-spectral images of maximally of 32 by 32 pixels. None of these applications is practical.
- **3-5 years:** It is unlikely that any practical implementation of a Variational Quantum Eigensolver or Quantum Neural Networks algorithm will be demonstrated in 3-5 years. The quality of the quantum computers will need to be higher. However, we can observe steady progress in the quality of quantum hardware, the development of new practical algorithmic ideas, and the development of a quantum software stack. Within the time-scope of 3-5 years, we might observe first experimental examples of larger-scale applications of Quantum Neural Networks applied to EO image processing, that should pave the road for future quantum advantage in this field. IBM claims that it will be able to provide QCs with about 1000 noisy qubits able to execute 10K gates in this time-scope. This should allow for creating quantum-classical NN systems able to classify patches of EO images of the size of order of hundred by hundred of pixels. Similarly quantum annealers should be able to process hyper-spectral images varying in time of the similar size in one computational cycle.
- **15 years:** While it is tough to predict the future of disruptive technology, such as quantum computing, 15 years ahead, one can hope for fully error-corrected quantum (FEC) computers with hundreds of logical qubits. Such computers could tackle machine learning problems that are impossible to solve today. Especially if supplied with coherent quantum information, e.g., acquired from quantum sensors. For example they could be able to perform context-aware segmentation of multi-source time-varying EO images consisting of 1K by 1K pixels. The quantum annealers having order of 100,000 densely connected qubits could be able to process images of similar size in a single computational cycle.

Table I: We presented the main quantum parameters of a quantum annealing device for our identified use-case.

	Present Day	3-5 years	5-15 years
Number of physical qubits	5,640	8,000	100,000
Qubit connenction	40,484	80,000	1,000,000