QUAI4EO

Quantum computing for Earth Observation and Particle Physics

QUANTUM TECHNOLOGY INITIATIVE

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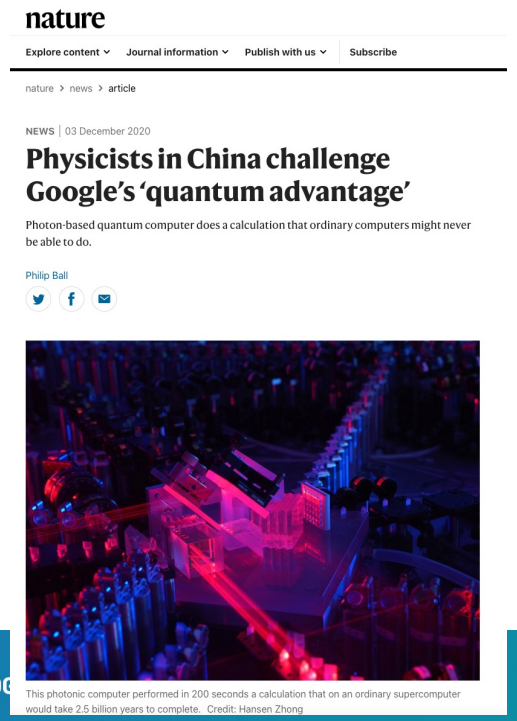
Quantum Computing: Hype and Potential

2019: Google

https://www.nature.com/articles/s41586-019-1666-5

2020: Hefei National Lab


nature

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NEWS | 03 December 2020

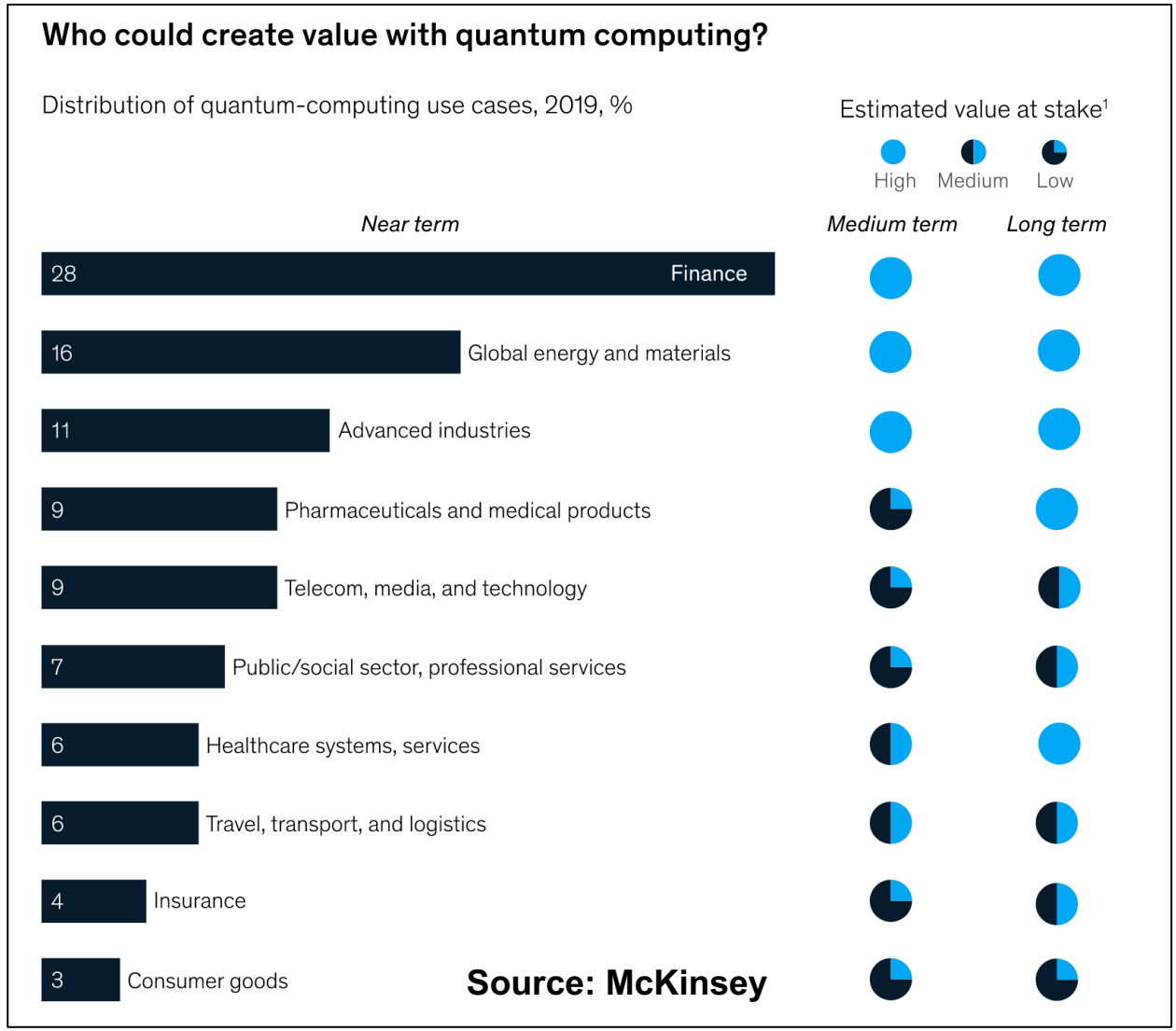
Physicists in China challenge Google's 'quantum advantage'

Photon-based quantum computer does a calculation that ordinary computers might never be able to do.

Philip Ball

This photonic computer performed in 200 seconds a calculation that on an ordinary supercomputer would take 2.5 billion years to complete. Credit: Hansen Zhong

https://www.nature.com/articles/d41586-020-03434-7



QC use cases in different sectors: the situation in 2019 with the estimated **medium** (2025) **and long** (2035) **term impact**.

Algorithms & Applications

Quantum effects (superposition entanglement, no-cloning theorem, …) improve and accelerate complex algorithms

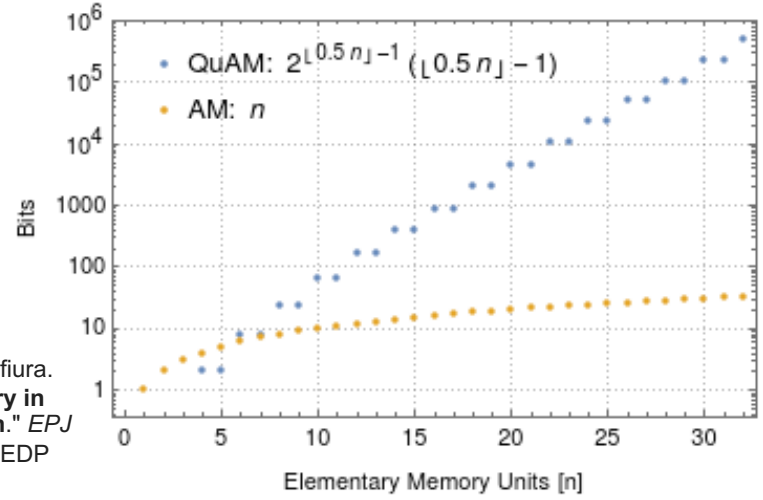
- Efficient **sampling**, **searches** and **optimization**
- Linear algebra, matrices and machine learning
- New algorithms/methods for **cryptography** and **communication**

Challenge is re-thinking algorithms design and define fair benchmarking and comparison to classical algorithms

Many potential applications in High Energy Physics:

- Monte Carlo and Event Generation
- Quantum Simulation
- Pattern Recognition
- QML

Ex.: Exponential data compression with a Quantum Associative memory



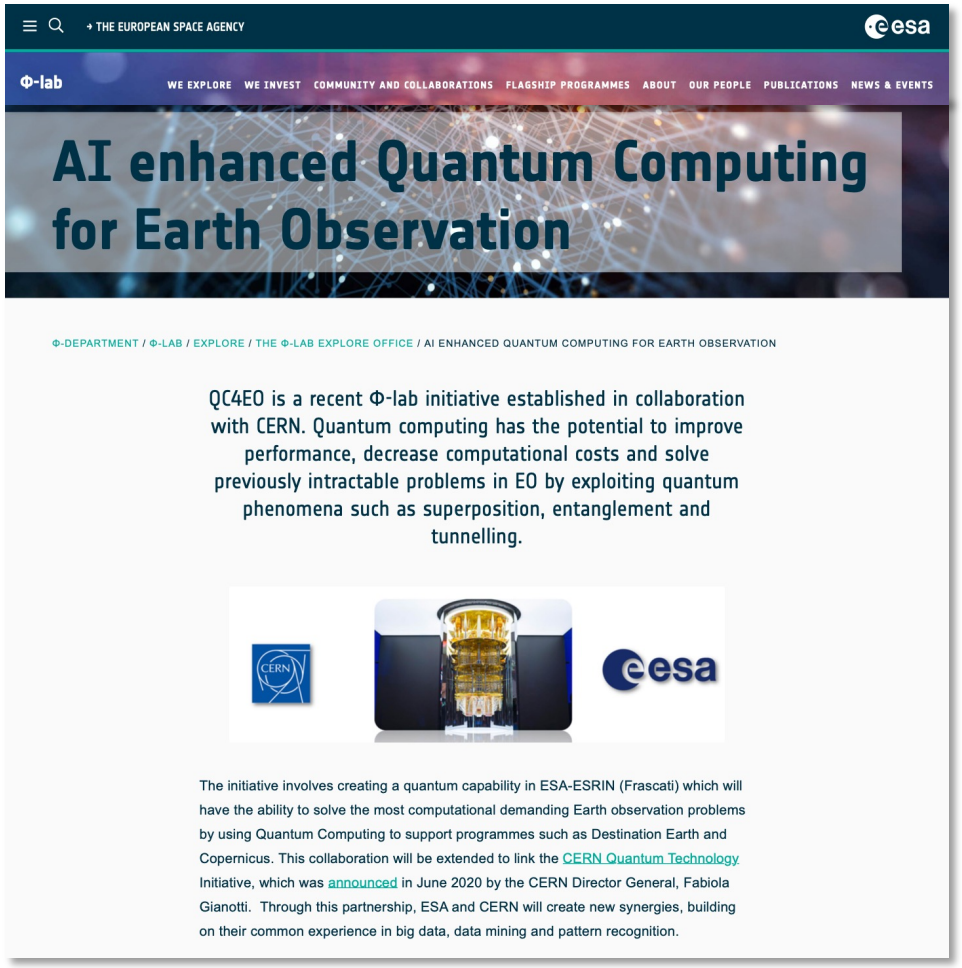
Shapoval, Illya, and Paolo Calafiura. "**Quantum associative memory in HEP track pattern recognition.**" *EPJ Web of Conferences*. Vol. 214. EDP Sciences, 2019

The ESA-CERN Cooperation Agreement

- ESA and CERN have in place a Collaboration Agreement since 2014 to explore common technologies and interests, such as hardware radiation hardening for particle detectors and spacecraft instruments
- Experiments like CLOUD are bridging the communities
- Cold Atom Technologies (CAT) are proposed as promising solutions for the Voyage 2050 programme

- **A collaboration on Artificial Intelligence and Quantum Computing has started in 2020**
- An initial programme of co-funded PhD-level research is in place since January 2021

The ESA-CERN Joint Announcement at Phi-Week 2020



Challenges and Opportunities in Earth Observation

- **Destination Earth**
  - High precision digital model of the Earth
  - Model, monitor and simulate natural phenomena and related human activities
- **Weather forecast and analysis**
- **Climate changes**
- **Natural disaster prediction / reaction**

Applications heavily relying on modelling complex dynamic systems regulated by (linear and non-linear) differential equations in high-dimensional spaces

QUAI4EO – QC Research

- Understand which EO applications can profit from quantum algorithms
  - Choose **representative use cases**
  - Understand **challenges and limitations** (on NISQ and fault tolerant hardware)
  - **Optimize** quantum algorithms
- Quantum Machine Learning algorithms are a primary candidate for investigation
  - Increasing use of ML in many computing and data analysis flows
  - Can be built as **hybrid models** where quantum computers act as accelerators
  - Efficient data handling is a challenge

QML for image analysis

- **First PhD project started in January 2021**
- **CERN – ESA – EPFL**

Quantum CNN for multi-class classification

Su Yeon Chang
[CERN openlab, EPFL]
Bertrand Le Saux [ESA phi-lab], Sofia Vallecorsa, Michele Grossi [CERN openlab]

14. April 2022

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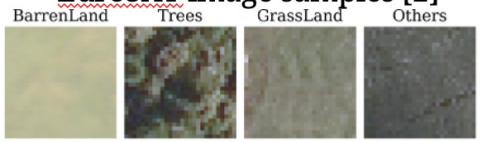
Challenge

- Large dimension of input data → How to reduce its dimension ?
- Choice of quantum embedding method → How to embed data into quantum circuit?
- Architecture of quantum circuit → How to construct Quantum Convolutional NN?
- Noise of current quantum devices → How to train while mitigating the errors?

EuroSAT image samples [2]



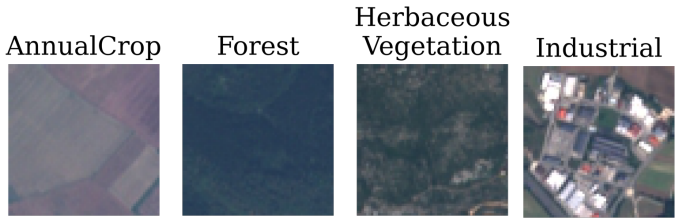
SAT4 image samples [3]

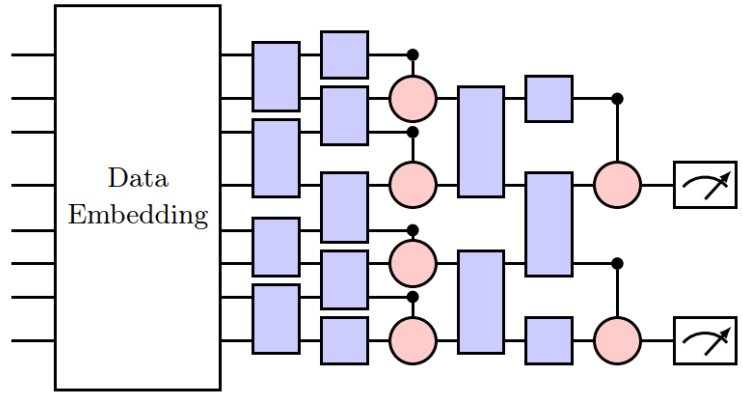
Hybrid multi-class classification

- Quantum analogue of CNN[1]
- Convolutional filters & pooling layers

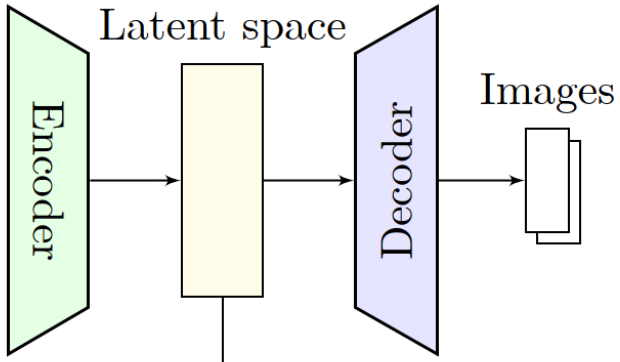
→ Modified : Different parameters for each filters

- Hybrid classical-quantum qCNN for multi-class classification (EuroSAT dataset for land cover classification from Sentinel-2)



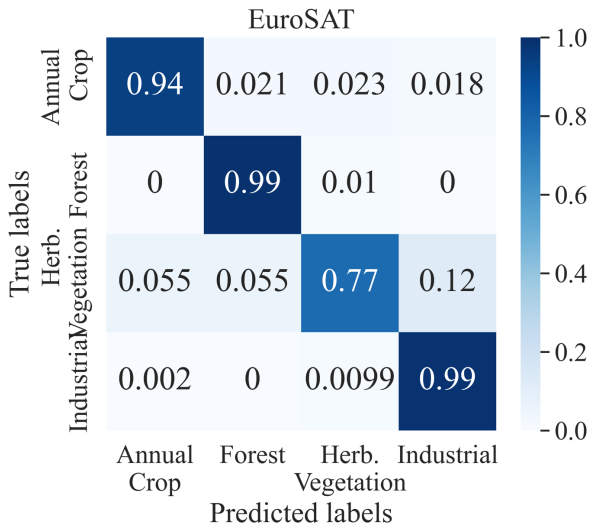


5 Hur, T., Kim, L., & Park, D.K., (2021). **Quantum convolutional neural network for classical data classification.**

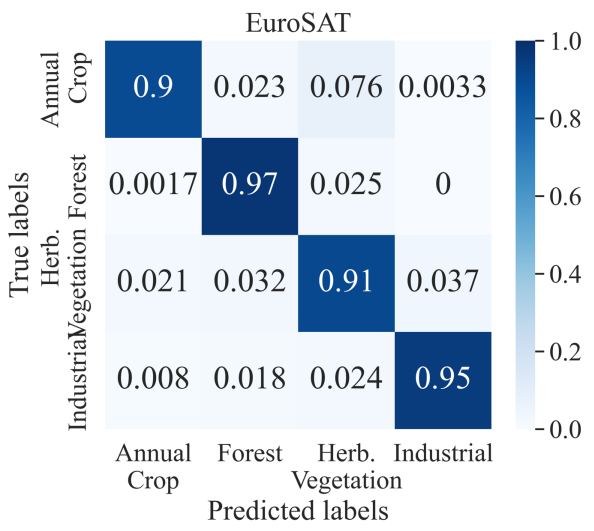


Chang, Su Yeon et al., "**Multi-class classificaion with hybrid classical-quatum CNN**", IGARRS2022

Classical classifier



Quantum classifier



QML for time series and sequences

- **PhD project started in June 2022**
- **CERN – ESA – U. of Leiden**

Challenges:

- **Efficiently map the state of a dynamic system to a Hilbert space where the time evolution is a linear operator?**
  - Can we derive properties of the dynamical system?
  - Can the quantum circuit learn from data, i.e. time series generated by the dynamical system ?
  - For which dynamical systems and which tasks would there be an advantage over classical model?

Broadening the scope: QC4EO Joint Project

- **Larger collaboration** creates **synergies** between disciplines like **High Energy Physics**, **Numerical Weather Prediction and Simulation**
- Developing relevant EO use cases demonstrating QC4EO advantages in the medium (<5 years) to long term (<20 years) to the EO field
- Defining a strategic objectives in a White Paper

European Laboratory for Learning and Intelligent Systems