Exploring Quantum Machine Learning through Kernel Methods

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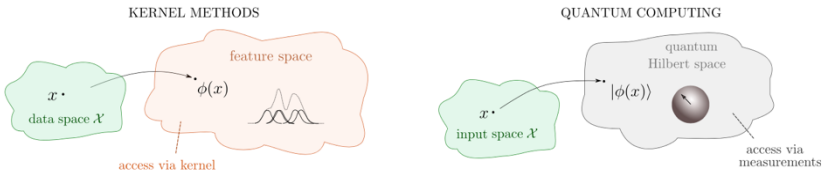
Domain: Quantum Technologies, Machine Learning, Global Optimisation

Introduction

Kernel methods enable machine learning algorithms to handle complex, non-linear data by applying simple linear algorithms in higher-dimensional spaces. These methods are currently of great interest in quantum machine learning due to the striking similarity between the mathematical frameworks of quantum computing and kernel methods. For instance, as illustrated in the figure [taken from Ref. 1] below, both approaches describe how information is processed by mapping it to vectors that exist in potentially large, inaccessible spaces.



In this project, we aim to study quantum kernel machine learning models based on recent research [1-3] and explore the role of fundamental quantum characteristics, such as many-body quantum entanglement and nonlocality, in these models. By constructing universal quantum machine learning models, we intend to qualitatively compare quantum and classical approaches to addressing real-world problems, such as "**air quality and pollution assessments**" and similar challenges. The primary goal is to develop a universal quantum kernel-based machine learning framework and investigate how quantum entanglement can provide advantages in solving complex real-world challenges.

Task

Within the scope of this project, the primary task is to develop universal quantum kernel models and formulate the characterization of entanglement as a global optimization problem within these models. The objective function will be implemented in Python, with optimization routines developed using PyTorch or TensorFlow. We begin with a small-scale problem involving a few-qubit system and gradually increase the complexity to address systems with a larger number of qubits.

Required expertise

1. Good understanding of Python programming
2. Basic understanding of machine learning / willingness to learn about machine learning, neural networks and quantum information processing

References:

1. M. Schuld, Supervised quantum machine learning models are kernel methods, https://arxiv.org/abs/2101.11020 (2021).
2. S. Jerbi et al., Quantum machine learning beyond kernel methods, *Nature Communications* 14.1, 1-8 (2023).
3. C. Wood, S. Shrapnel, and G. J. Milburn. A Kerr kernel quantum learning machine, https://arxiv.org/abs/2404.01787 (2024).