Quantum Machine Learning concepts and applications

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Abstract

We explore Machine Learning techniques and Quantum Computing concepts that could be applied in High Energy Physics considering a phenomenological and theoretical view. In this framework, we show the main tools to explore the Standard Model extensions, decay process and the parameter space. With this set of tools, we want to explore the bounds and define exclusion regions, this results might be interesting for the next generation of colliders and could prove to be useful in the understanding of phenomena.

Introduction

We recently find different literature about Artificial Intelligence, Machine Learning, Quantum Computing, Quantum Information and Quantum Machine learning, among other interesting and related topics. Besides, ideas and concepts coming from those areas are implemented in different environments: Finance, Cryptography, medicine, chemistry and social sciences; however, some concepts are unclear, in this document we want to discuss basic ideas behind those topics focusing on the mathematics, physics and computing. In this paper we talk about algorithms, Qubits, particles, matrices, standard model and new physics, classical and quantum Information whose are interesting topics for undergraduate and postgraduate students linked to the recent technological concepts

Overview

Machine Learning in HEP

Machine learning is shown to have plenty of use cases in the field of high energy physicssuch as the discovery of exotic particles, understand the underlying structure of matter, analyzing the behavior of different particles and classification of various particles based on their properties. Particle physics is an area where the density of data needed for analysis or simulation is quite large. This combined with the fact that the particles exhibit quantum mechanical behavior makes quantum machine learning a more suitable method than classical approaches. Simulation of quantum mechanical systems can be done much more efficiently using a native quantum computer. Quantum Machine Learning algorithms can be roughly divided into supervised and unsupervised learning algorithms.
Supervised Learning technique require labels to predict an unknown variable of a new data point. The quantum support vector machine, quantum boltzmann machine, quantum neural networks are some of the algorithms that can be classified as supervised.
Unsupervised Learning (UL) usually deals with clustering and generation of new data points. The quantum k-means algorithm and quantum GAN are the proposed algorithms in this section.

Theory

Beyond Standard Model

The evolution on calculation techniques and the new software tools allow to probe the Standard Model (extended models) and the experimental results. In fact machine learning (ML) becomes one of the most interesting and powerful set of techniques and tools (sometimes called paradigm) for investigating the phenomena regarding experimental and theoretical High Energy Physics (HEP). In this view, we can use Machine Learning and Quantum algorithms for:

- obtain a deep insights,
- recognize unknown patterns and
- create high perform predictive models from data.

In this paradigm there are different learning types: Supervised, such as regression and classification; and unsupervised, implemented to find a pattern more than prediction.
UL has been one technique implemented to search for new physics.In HEP the ML can be implemented in a theoretical and experimental view:

1. Higher order computational methods: OneLoop, QCDLoop, LoopTools; parton level generators NNLO, DYNNLO, N3LO.
2. Monte Carlo event generators and deep inelastic inclusive cross-sections: MadGrap, POWHEG and HERA.

In the theoretical and phenomelogical view, researchers face on some challenges to implement this ML paradigm for scrutinizing the models and the theory, however in ref. [3] shows an application in a beyond standard model with new neutral gauge boson but it is toy model. Actually in ref. [1] is shown an interesting analysis to $t\bar{t} \to W^+bW^-\bar{b}$ looking atthe physical parameters as mass.

From ML and Quantum Information to QML

- Quantum Computing/computation: states are quantum states and computes on data.
- Quantum Information Theory: storage and management of data.
- Quantum Cryptography: move data with security.

Some relevant problem (algorithms) for QC are,

Problem	Maps	Function
Deutsch	$f:\{0,1\}\to\{0,1\}$; where one bit to one bit	$f(x)$ balanced and constant
Deutsch-Jozsa	$f:\{0,1\}^n\to\{0,1\}$; where n bits to one bit.	Black box oracle function.
Bernstein-Vazirano	$f:\{0,1\}^n\to\{0,1\}$; where n bits to one bit.	$f(x)=a\cdot x$
Simon	$f:\{0,1\}^n\to\{0,1\}^n$; where n bits to one bit.	$f(x)=a\oplus x$

Proposed Quantum Algorithms (HEP)

1. Quantum SVM - Classificiation
2. Quantum Boltzmann Machine - Studying interaction, classification
3. Quantum k means - Clustering
4. Quantum GANS - classification, synthetic data generation

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