EVENT CLASSIFICATION FOR HIGGS PARTICLE WITH QUANTUM MACHINE LEARNING IN HIGH-ENERGY PHYSICS

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ABSTRACT

Machine Learning Algorithms like Deep Neural Network (DNN), Binary Decision Tree (BDT), has been used in high energy physics for a long time, specifically in track signal identification and supervised classification tasks. Meanwhile, quantum computing was proposed by Richard Feynman in the early 1980s as a way to performs computations that would be unreachable by classical computers. Over the past 40 years, the noisy intermediate-scale quantum computing devices have been developed and multiple new algorithms are proposed with such device. In this paper, we present the studies of quantum algorithms exploiting machine learning to classify the events of interest from background.

***K*eywords** Quantum Machine Learning · Variational Quantum Circuit · Variational Shadow Quantum Learning · Quantum Kernel Method ·

1 Introduction

In High-Energy Physics experiments, particles created by collisions are observed by layers of high precision detectors. In this field, many early attempts to use quantum computing for HEP exist. For example, the data analysis [3], identification of charged particles[], reconstruction of particles collision points []. ([] indicates adding citation based on those paper) As discussed in many literatures, the quantum machine learning (QML) is considered as one of the QC algorithms that could bring quantum advantages over classical methods[[1], 16].

2 Task description and data construction

Discrimination of events of interests is always the most frequently used ML techniques in HEP data analysis. In this research, we examine the most frequently used variational quantum classider (VQC), Quantum Kernel Methods, Variational Shadow Quantum Learning (VSQL) [2] and Quantum Generative Adversarial Network (Quantum GAN).

Dataset Here we use the dataset from UCI's Machine Learning Repository [Lib].

Task modeling. We approach this task as a regression problem. For every item and shop pair, we need to predict its next month sales(a number).

Construct train and test data. The dataset provided has 28 features, 21 low-level features and 7 high-level features.

2.1 Method 1: Variational Quantum Classifier

2.2 Method 2: Variational Shadow Quantum Learning

2.3 (

Method 3: Variational Shadow Quantum Learning) Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

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3 Examples of citations, figures, tables, references

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The documentation for `natbib` may be found at

`http://mirrors.ctan.org/macros/latex/contrib/natbib/natnotes.pdf`

Of note is the command `\citet`, which produces citations appropriate for use in inline text. For example,

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\citet{hasselmo} investigated\dots
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produces

> Hasselmo, et al. (1995) investigated…

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3.1 Figures

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3.2 Tables

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[1] Sample of the first footnote.

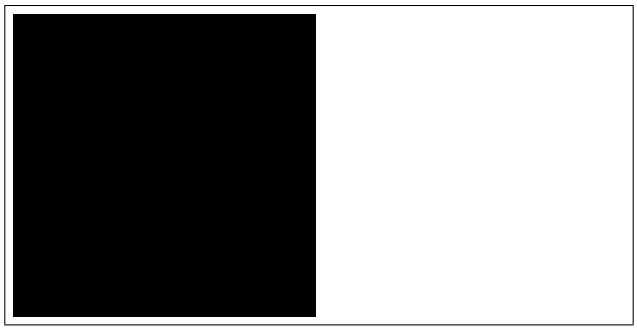

Figure 1: Sample figure caption.

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1	!ABBYY FineReader 12 Professional Edition Full...	1	76
2	***В ЛУЧАХ СЛАВЫ (UNV) D	2	40
3	***ГОЛУБАЯ ВОЛНА (Univ) D	3	40
4	***КОРОБКА (СТЕКЛО) D	4	40

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3.3 Lists

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- consectetur adipiscing elit.
- Aliquam dignissim blandit est, in dictum tortor gravida eget. In ac rutrum magna.

References

[1]

[2] Li, G., Song, Z., & Wang, X. (2021). VSQL: Variational Shadow Quantum Learning for Classification. Proceedings of the AAAI Conference on Artificial Intelligence, 35(9), 8357-8365. `https://doi.org/10.1609/aaai.v35i9.17016`

[3] Mott, A., Job, J., Vlimant, JR. et al. Solving a Higgs optimization problem with quantum annealing for machine learning. Nature 550, 375–379 (2017). `https://doi.org/10.1038/nature24047`

[4] George Kour and Raid Saabne. Real-time segmentation of on-line handwritten arabic script. In *Frontiers in Handwriting Recognition (ICFHR), 2014 14th International Conference on*, pages 417–422. IEEE, 2014.

Table 1: Sample table title

	Part	
Name	Description	Size (μm)
Dendrite	Input terminal	$\sim$100
Axon	Output terminal	$\sim$10
Soma	Cell body	up to 10^6

[5] George Kour and Raid Saabne. Fast classification of handwritten on-line arabic characters. In *Soft Computing and Pattern Recognition (SoCPaR), 2014 6th International Conference of*, pages 312–318. IEEE, 2014.

[6] Guy Hadash, Einat Kermany, Boaz Carmeli, Ofer Lavi, George Kour, and Alon Jacovi. Estimate and replace: A novel approach to integrating deep neural networks with existing applications. *arXiv preprint arXiv:1804.09028*, 2018.