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A Study of Quantum Generative Adversarial Networks from an application perspective

(Independent Study Proposal)

1 Introduction

GANs(Generative adversarial networks) are a class of deep neural networks that have shown great potential for generative machine learning, which is used to generate realistic data samples [3]. It has been applied successfully in many scenarios such as image generation, image-to-image translation, text generation, etc [1]. The basic objective of the GANs is to train two learning models: a generator $\mathcal{G}$ and a discriminator $\mathcal{D}$. The training goal of the generator $\mathcal{G}$ is to generate plausible data that follows the same distribution of the real-world data, or the training data. The training goal of the discriminator $\mathcal{D}$ is to distinguish the generated samples, which is from the generator $\mathcal{G}$, from the real data.

Although GANs have achieved widely success on many applications, it suffers from the computational overhead given that it requires to train two learning models in a cooperative way. Quantum computers have the potential to address problems believed to be beyond the capability of classical computers [6]. In the era of Noisy Intermediate-Scale Quantum (NISQ) technology, it is promising to deliver feasible applications in specific domains in near term[4, 5]. Theoretical works have already shown that GANs may exhibit an exponential advantage in an quantum computing scenario [1, 2].

In this independent study, we'll first study the fundamentals of machine learning, especially generative adversarial learning models. Then we'll learn the basics of quantum computing, including qubits, entangles, decoherence, etc. Our focus of the independent study is on the quantum version of the generative adversarial networks, also short as QuGANs. More specifically, we'll study the actual implementation of QuGANs and how it can be used in real world applications.

2 Hypothesis/Objectives

Our objective in this independent study is to explore the quantum generative adversarial networks from an application perspective, more specifically, we aim to study how to apply the quantum generative adversarial networks into real world applications, such as image generation. We will learn machine learning techniques, especially deep neural networks, and generative adversarial networks. We will also explore how to implement the quantum version of the GANs in an efficient way in specific application scenarios.

3 Proposed methods and procedures

We will first study the fundamentals of machine learning, especially deep neural networks. Then extend the focus to generative adversarial models. After that, our work will focus on the quantum computing, including the basics of quantum computing terminologies such as qubits, entanglement, decoherence, etc. Based on this foundation, we will explore the quantum generative adversarial networks and how to apply it into real world scenarios such as image generation. The procedures of the study will be as follows:

- **Stage 1:** Prepare the background information, knowledge, programming environment and platforms.
- **Stage 2:** Dive into the generative adversarial networks and the corresponding quantum version, including the technical details, theoretical logic, and programming implementation.
- **Stage 3:** Applying the quantum generative adversarial networks into an real world scenario and analyze the experimental results, and see if anything could be improved.
- **Stage 4:** Work with the supervisor for potential extensions of the work to get it published if necessary.

4 Project timetable/Faculty meeting

This independent study will be conducted during the Fall semester of 2023. The participated student will work with the supervisor and meet every week. The detailed weekly schedule is shown as follows:

Time	Task
Week 1	Listing the goals, finding literature, setting up experimental platforms.
Week 2	Study the basic ideas of machine learning.
Week 3	Lean and understand the architecture of deep neural networks.
Week 4	Understand the loss function of Deep Neural Network models and the implementation.
Week 5	Study the generative adversarial networks and their applications.
Week 6	Implement the GANs in classical setting with preferred programming language.
Week 7	Understand the fundamentals of quantum computing.
Week 8	Setting up the platforms of running quantum algorithms and run some simple quantum programs.
Week 9	Be able to understand the theoretical foundations of the quantum version of generative adversarial networks.
Week 10	Using the preferred programming language to implement the quantum generative adversarial network model.
Week 11	Applying the model to image generation or other scenarios and collect the experimental results.
Week 12	Analyze the results and improve the algorithm if possible.
Week 13	Wrap up the work and work with the supervisor to get the work published if it worth to be published.

5 Project evaluation

The independent study will be evaluated from multiple perspectives. They include but not limited to:

- **Knowledge:** The student are required to understand the fundamentals of machine learning, especially Deep Neural Networks, generative adversarial networks, and fundamentals of quantum computing and quantum generative adversarial networks.
- **Programming skills:** The participated student will be required to programming and debugging deep neural networks, generative adversarial networks and their corresponding quantum versions using Python programming language or other preferred language.
- **Research experience:** The student will cooperate with the supervisor on researching the field of quantum machine learning and proposing new ideas novel to this field.
- **Academic Writing:** The student will cooperate and work with the supervisor on getting

the potential new ideas or findings published in academic conferences/journals. The student will help the writing process and other tasks capable of.

The final grade of the independent study will be decided upon the following components with the regarding weight:

- Advisor meeting (10%)
- Platform and program environment set up (10%)
- Algorithm implementation (30%)
- Results/Data analysis (25%)
- Poster and paper writing (25%)

6 Relevant bibliography

References

[1] Dallaire-Demers, Pierre-Luc and Killoran, Nathan. "Quantum generative adversarial networks". *Physical Review A* 98(1) (n.d.): 012324.

[2] Gao, Xun, Zhang, Z-Y, and Duan, L-M. "A quantum machine learning algorithm based on generative models". *Science advances* 4(12) (n.d.): eaat9004.

[3] Goodfellow, Ian et al. "Generative adversarial nets". *Advances in neural information processing systems* 27 (n.d.).

[4] Huang, He-Liang et al. "Experimental quantum generative adversarial networks for image generation". *Physical Review Applied* 16(2) (n.d.): 024051.

[5] Lloyd, Seth and Weedbrook, Christian. "Quantum generative adversarial learning". *Physical review letters* 121(4) (n.d.): 040502.

[6] Nakaji, Kouhei and Yamamoto, Naoki. "Quantum semi-supervised generative adversarial network for enhanced data classification". *Scientific reports* 11(1) (n.d.): 19649.