Quantum Implementations of Generative Adversarial Networks (GANs) and a Comparative Analysis with the Classical Counterpart

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Abstract

Generative Adversarial Networks (GANs) are effective deep learning techniques where two neural networks compete in order to generate effective data that resemble the original data. Quantum GANs, GANs implemented on quantum systems, are theoretically suggested to maybe provide an exponential advantage over its classical counterpart. In this project, it is demonstrated how well the Quantum GAN models can generate fake images from the MNIST dataset and how the output compares with the classical GAN implementation with extensive comparative analysis. The Patch Method, State Based QuGAN methods are implemented to generate synthetic images for handwritten digits.

Introduction

GANs have been proven to have usages beyond generating synthetic images, with applications extending even to domains such as image enhancement techniques, generating higher resolution images. Quantum Machine Learning is predicted to be one of the first tangible real life applications for quantum devices. One of the models used in the project were the Patch Method, This method uses several quantum generators, with each sub-generator responsible for constructing a small patch of the final image. The final image is contructed by concatenting all of the patches together. The other model, QuGAN operates broadly by the iterated upon operation of a classical computer passing a parameterizedquantum circuit to a quantum computer, which then passes back a measured quantum state fidelity.

Methodology

At first, we implemented the classical GAN on the MNIST dataset, We constructed two quantum versions of the Generative Adversarial Network in this work: a Patch Method based QGAN and a Quantum State Based QuGAN. Since working with high resolution images for quantum implementations becomes complicated and demands high end machines, we utilized the MNIST dataset, which has an image resolution of 28 x 28. The dimensionality is still high for the available quantum simulators. In order to reduce the dimensionality, we adopted two different approaches: the Patch Method, shown in Figure 2, and the PCA algorithm for QuGAN, shown in Figure 1. QuGAN is implemented based on Python 3.8 with IBM Qiskit, an open-source framework for quantum computing. The generated quantum circuits are trained on GPU-enabled servers on the Google Cloud Platform.

Diagrams

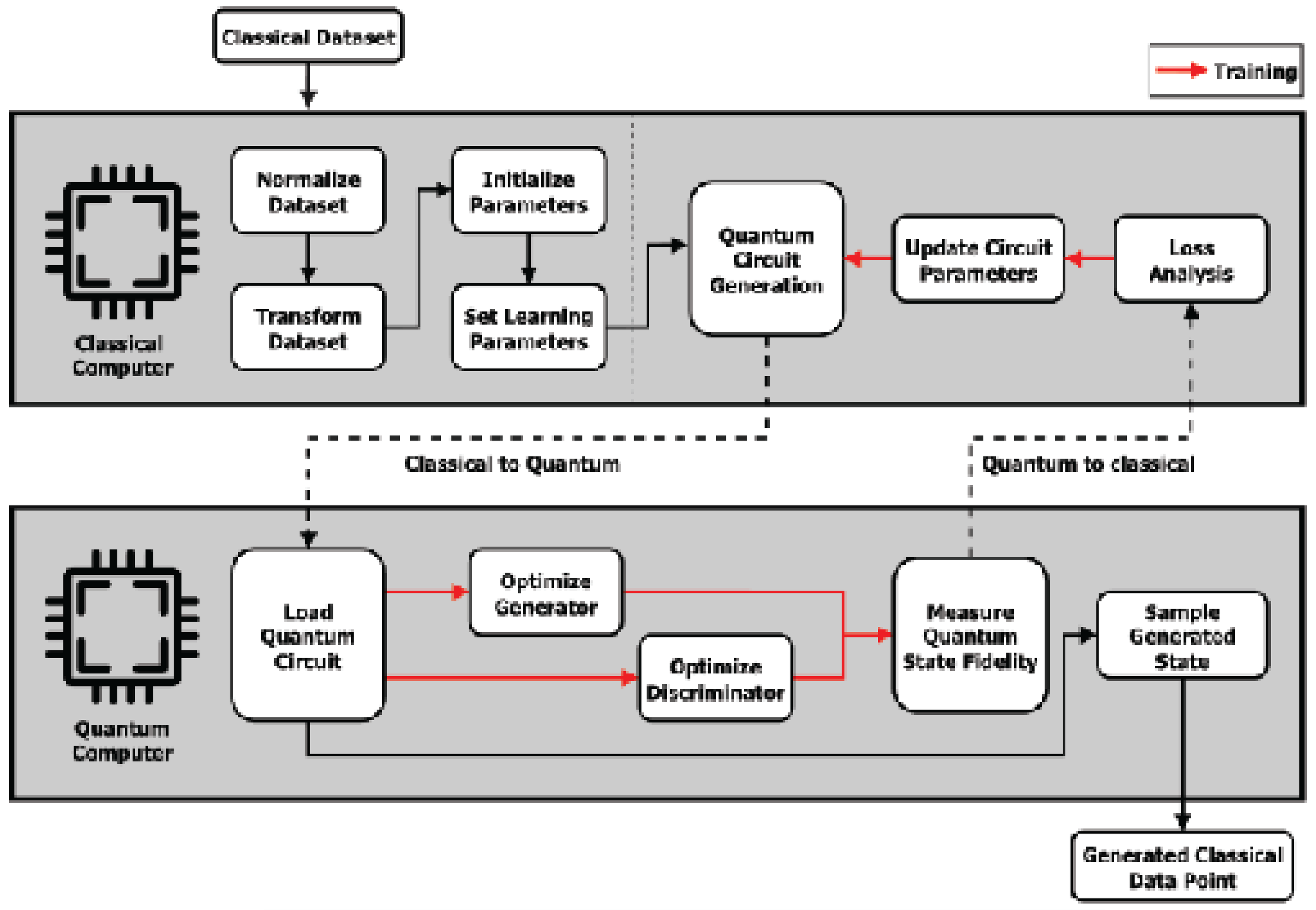


Figure 1: Diagram for the State Based QuGan

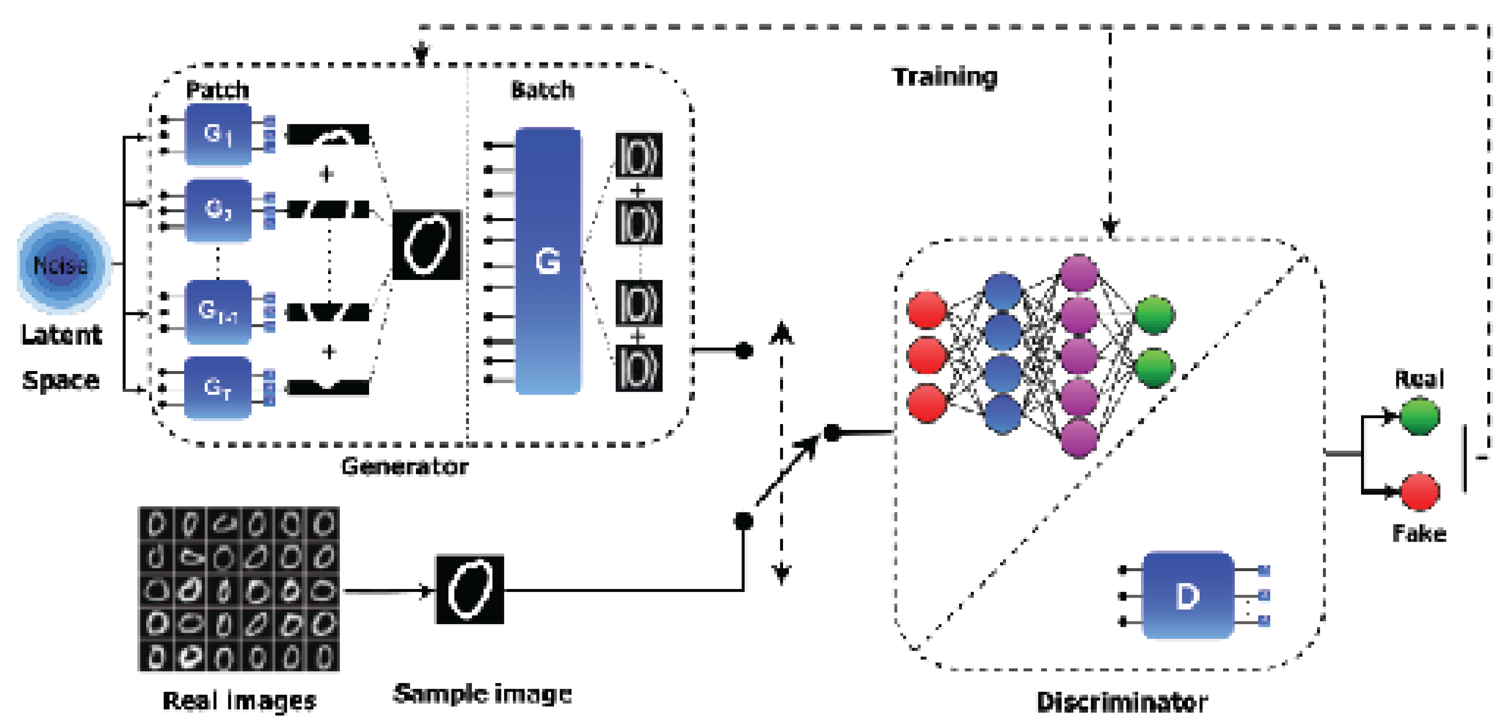
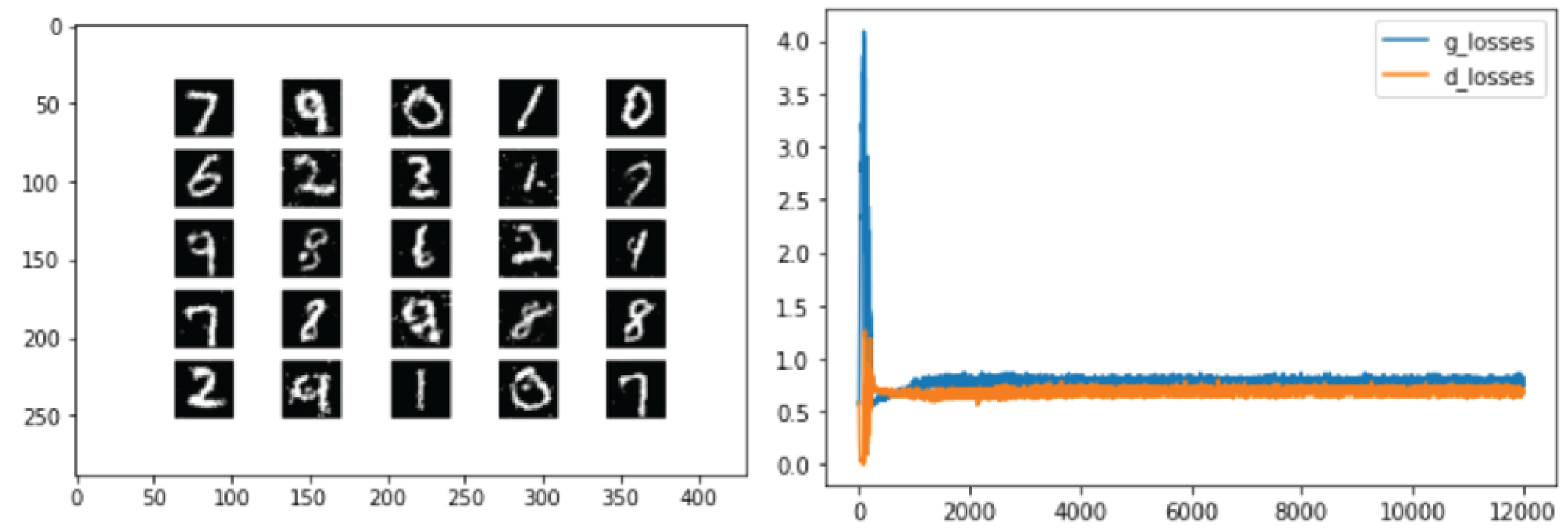
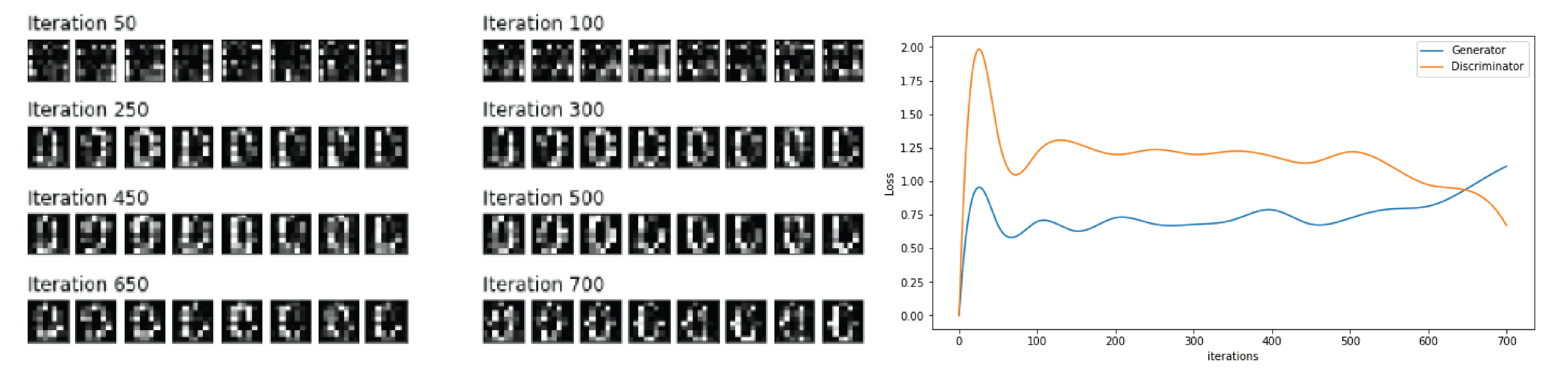


Figure 2: Diagram for the Patch QGAN Method

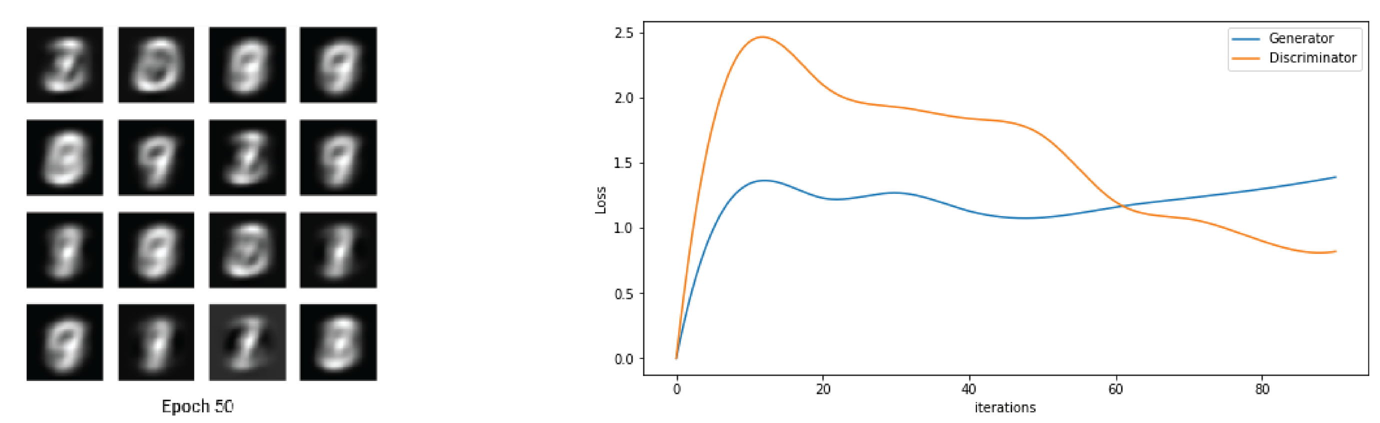
Results and Analyses



Approach 1 Classical GAN: It generated excellent quality synthetic images from the dataset. As we can see, the losses almost converge each other from about 4000 epochs onwards.



Approach 2 Quantum Patch GAN: For 0s, the patch method was applied to reconstruct fake 0s for 700 epochs. The Discriminator Loss started to fall from the 700th epoch onwards and the results started to deteriorate.



Approach 3 Quantum State-Based GAN: The target was to generate 3s, 6s, 9s from the the MNIST dataset. We successfully generated decent quality 9s, and mildly recognizable 3s and was trained with those images.

Conclusion

To conclude and reiterate, we observed two different quantum GAN models being implemented and compared with the classical GAN. A rigorous comparison between them were conducted. We found the generated 9s to be better than the ones implemented in the QuGAN paper. For future works, we can work on further improving these models or take inspiration and implement quantum implementations for other classical GAN based models. For instance, a quantum CycleGAN.

References

[1] H.-L. Huang et al., 'Experimental Quantum Generative Adversarial Networks for Image Generation', Physical Review Applied, vol. 16, no. 2, Aug. 2021.

[2] S. A. Stein et al., 'QuGAN: A Quantum State Fidelity based Generative Adversarial Network', in 2021 IEEE International Conference on Quantum Computing and Engineering