Quantum Positional Encoding for Neural Radiance Fields

2025 Quantum Machine Learning REU Program

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PROBLEM STATEMENT

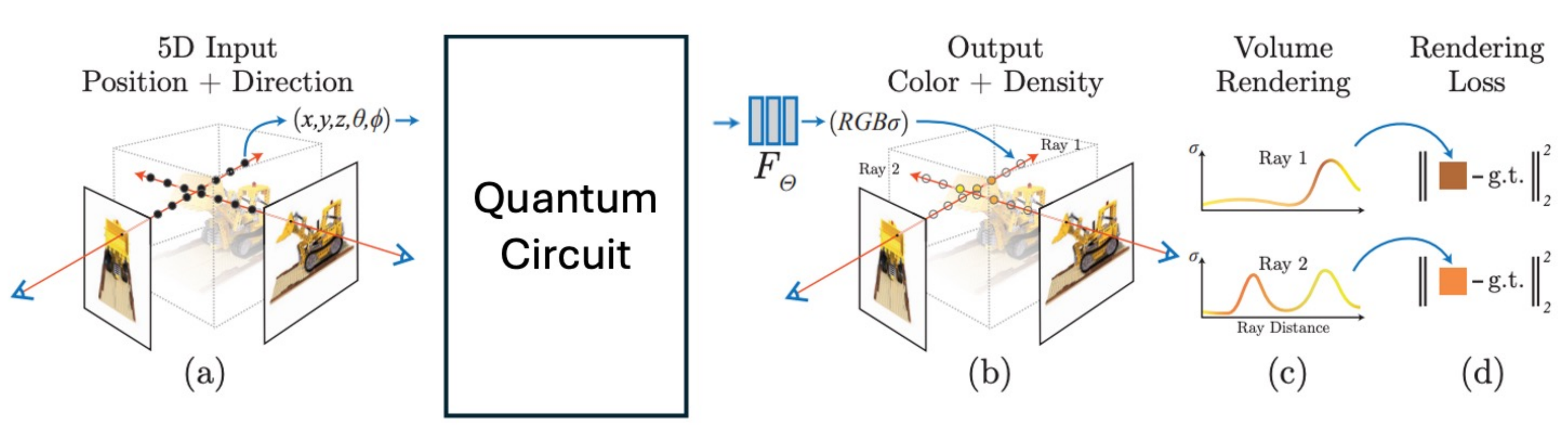
- We want to predict views of a scene from novel angles given a sparse collection of images captured of this scene.
- Neural Radiance Fields (NeRF) [1] use classical neural networks to approach this problem.
- We propose a quantum-classical hybrid model similar to the architecture of NeRF to recreate 3D photorealistic rendering of real-world scenes.

NeRF reconstruction of tomato plant

CLASSICAL ARCHITECTURE

- Multi-Layer Perceptron model trained on multi-frequency encodings of 5D inputs (*x,y,z,ϑ,φ*).
- Encoding equation used on each dimension.
- $\gamma(\rho) = (\sin(2^0\pi\rho), \cos(2^0\pi\rho), \ldots, \sin(2^{L-1}\pi\rho), \cos(2^{L-1}\pi\rho))$
- Loss: Mean-Square Error, measured from both coarse and fine networks.

HYBRID MODEL ARCHITECTURE



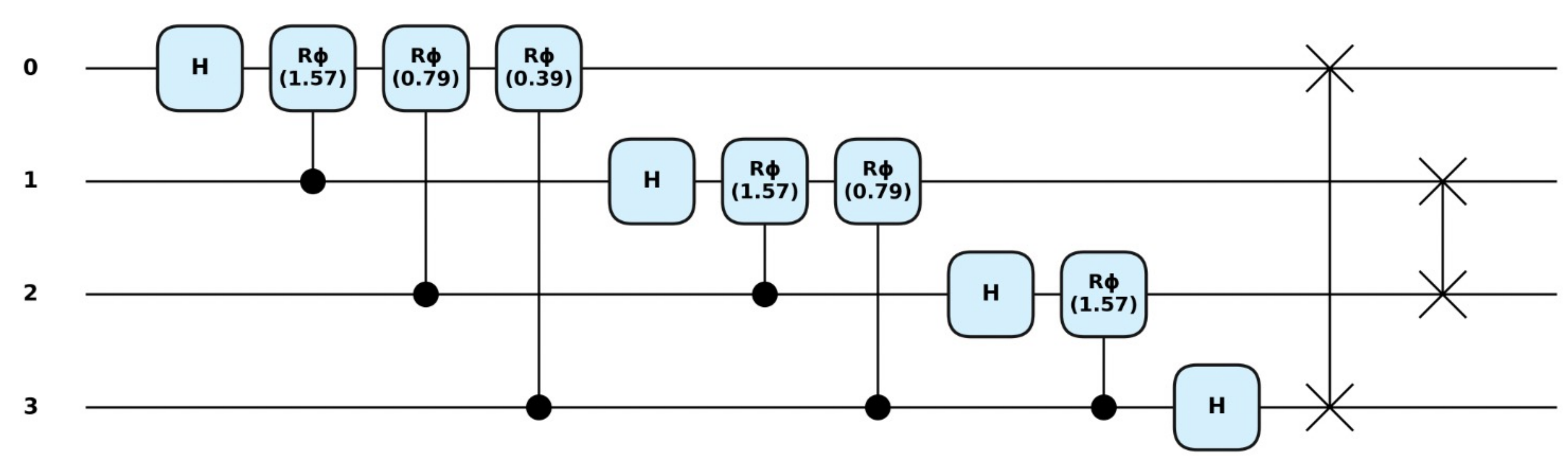
Adaptation of classical NeRF architecture [1] as a hybrid quantum-classical model

METHODOLOGY

- We propose using R_y gates, via quantum computing, to encode information rather than $\gamma(\rho)$.
- Quantum MLP is used to train on encoded data.
- Due to the extensive parallelism of quantum computing, this will provide similar training results with significant improvements on efficiency.

Quantum computer at Google AI [2]

QUANTUM ENCODING CIRCUIT

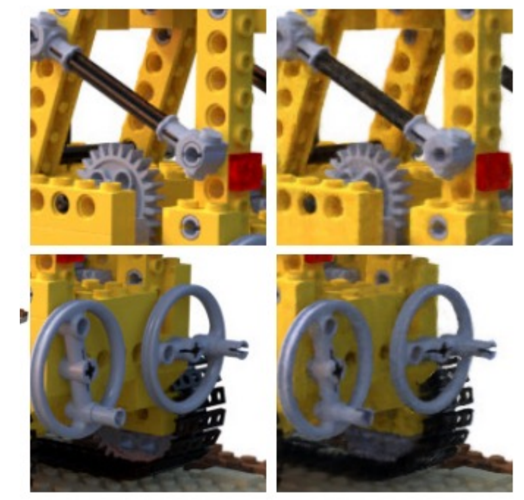


Quantum Fourier Transform for n=4 binary digits [3]

- We perform Quantum Fourier Transform on Pennylane on each coordinate, an O(1) method to produce periodic representations of a binary number.
- Each coordinate ρ is represented as an n-digit binary number; in this case, we choose n=4.
- We use the following equation to define QFT:

$$|\psi\rangle = \frac{1}{\sqrt{2^5}} \sum_{x=0}^{31} \exp\left(\frac{-2\pi i x}{10}\right) |x\rangle$$

EXPERIMENTAL RESULTS

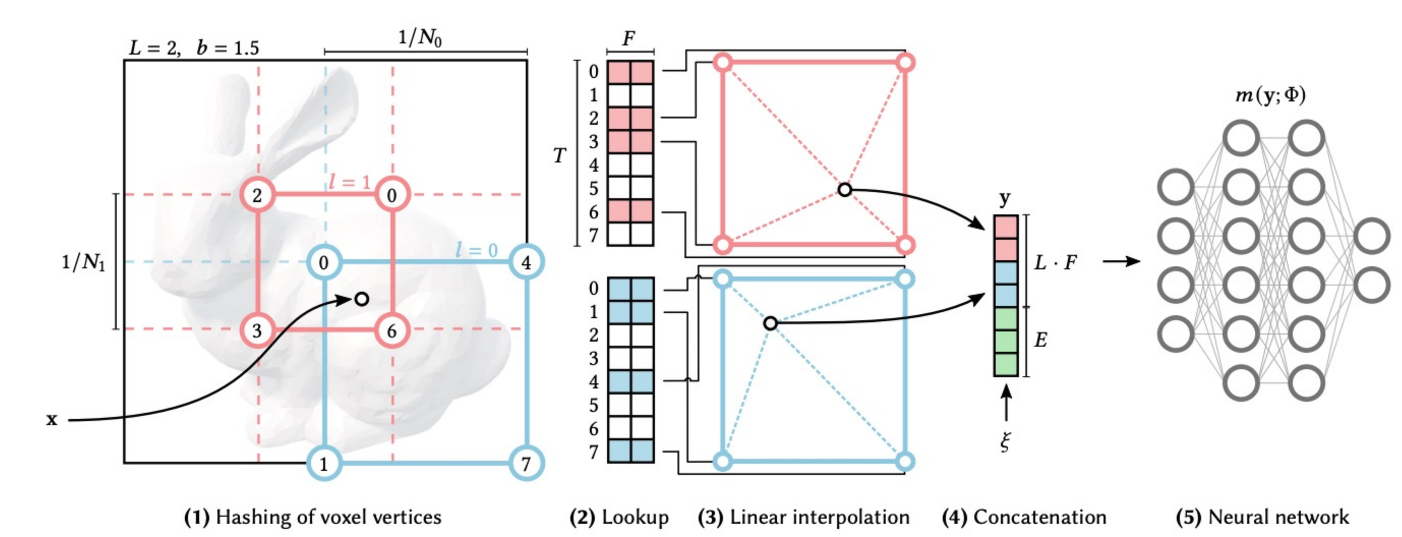


Ground truth (left) vs NeRF reconstruction (right) on Lego sample

- Current results: successful reconstruction only in classical implementation.
- PSNR: 30.87

CONCLUSION & NEXT STEPS

- We conclude that due to the periodic representations provided by QFT and their efficiency proven by their O(1) complexity & parallelism, quantum encoding provides the potential for improved training efficiency without sacrificing accuracy.
- Our next step is to focus on adjusting hyperparameters, such as n.
- We may apply similar encoding to hash function of Instant Neural Graphic Primitives (Instant NGP) [4].



Multiresolution hash encoding of input coordinates [4]

REFERENCES

[1] Mildenhall, B., Srinivasan, P.P., Tancik, M., Barron, J.T., Ramamoorthi, R. and Ng, R., 2021. Nerf: Representing scenes as neural radiance fields for view synthesis. Communications of the ACM, 65(1), pp.99-106.
[2] Google Quantum AI. What is Quantum Computing?.
[3] Alonso, G., 2024. Intro to the Quantum Fourier Transform. Pennylane.
[4] Müller, T., Evans, A., Schied, C. and Keller, A., 2022. Instant neural graphics primitives with a multiresolution hash encoding. ACM transactions on graphics (TOG), 41(4), pp.1-15.

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