Contribution ID: **111** Type: **Oral**

Full Quantum GAN Model for High Energy Physics Simulations

Thursday, 27 October 2022 14:50 (20 minutes)

The prospect of possibly exponential speed-up of quantum computing compared to classical computing marks it as a promising method when searching for alternative future High Energy Physics (HEP) simulation approaches. HEP simulations like at the LHC at CERN are extraordinarily complex and, therefore, require immense amounts of computing hardware resources and computing time. For some HEP simulations classical machine learning models are already successfully tested leading to speed-ups in the order of magnitudes. In this research we proceed to the next step and test if quantum computing can further improve HEP machine learning simulations.

With a small prototype model we showcase a full quantum Generative Adversarial Network (GAN) model for successfully generating real calorimeter shower images with high precision. The advantage compared to previous other quantum models is, that with employing angle encoding the pixel to qubit ratio scales linear and the model generates real images with pixel energy values instead of simple probability distributions. The model is constructed and evaluated for images with eight pixels and requires only eight qubits for the generator and discriminator quantum circuit. The quantum circuits make use of the properties of entanglement and superposition to learn and reproduce the correlations in the images.

To complete the picture, the results of the full quantum GAN model are compared to other quantum and hybrid quantum-classical models.

Significance

Exploring future ideas of employing quantum computing to a HEP use case. We are the first ones who test a full quantum generative adversarial network (qGAN) model for generating calorimeter detector images. Furthermore, we employ a different encoding strategy than in a previous research which allows us to generate real images with pixel energies instead of only probability distributions. With quantum computing we hope to combat computing hardware restraints for future HEP experiments and start, therefore, already with initial tests. Lastly, we compare our results to other state of the art quantum models.

References

We were working already on a hybrid qGAN which, however, only was able to generate probability distributions in those two papers:
- http://ceur-ws.org/Vol-3041/363-368-paper-67.pdf
- https://arxiv.org/abs/2203.01007

The new model is full quantum (compared to the previous hybrid model) and uses another encoding allowing to generate real images.

Experiment context, if any

Study is carried out general for HEP detectors at CERN, no specific experiment.

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Session Classification: Track 2: Data Analysis - Algorithms and Tools

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