QUANTUM AI

Making AI Better

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WHY QUANTUM?

Quantum Helps AI

Why is quantum computing important to AI (Artificial Intelligence)? To put it simply, quantum computing allows for a **computational advantage** in solving some of the most complex AI problems and allows AI researchers and practitioners to complete more work in less time over more data. It may also allow **deeper neural networks** which will result in **more accurate machine learning models** and allow for more meaningful and practical training.

AI Helps Quantum

Further, classic AI algorithms and methods may also allow us to better utilize quantum computing in this era of noisy quantum computing a.k.a. NISQ which stands for Noisy Intermediate-Scale Quantum. Current quantum computing technologies are flush with errors in need of correction to fully appreciate advantages available through quantum computing. AI may be able to help in error correction allowing quantum computing to be put to use sooner.

CONSIDER THIS

The computational power required by data scientist who are training more accurate models with larger data sets is astounding. Well, some scientists are already attempting to harness quantum computing to lend a hand. Here is a quote from a 2016 article by Michael Copeland that exemplifies the type of computational power needed.

"Andrew Ng, who honed his AI chops at Google and Stanford and is now chief scientist at Baidu's Silicon Valley Lab, says training one of Baidu's Chinese speech recognition models requires not only **four terabytes of training data**, but also **20 exaflops of compute - that's 20 billion billion math operations** - across the entire training cycle. Try getting that to run on a smartphone."

Michael Copeland, "What's the Difference Between Deep Learning Training and Inference?" (nvidia, August 22, 2016), https://blogs.nvidia.com/blog/2016/08/22/difference-deep-learning-training-inference-ai/.

SELECTED PAPERS

The three papers I chose all deal with using quantum computing methods to aid in computer vision problems. The primary point of assistance is in computational speed up.

Paper 01: Quantum Algorithms for Deep Convolutional Neural Networks
Kerenidis, I., Landman, J., Prakash, A. (2019)

Paper 02: A quantum algorithm for training wide and deep classical neural networks
Zlokapa, A., Neven, H., Lloyd, S. (2021)

Paper 03: A quantum deep convolutional neural network for image recognition
Li, Y., Zhou, R., Xu, R., Hu, W. Quantum Science and Technology vol 5, (2020)

In addition, I read the following papers.

Quantum Machine Learning
Biamonte, J., Wittek, P., Pancotti, N., Rebentrost, P., Wiebe, N., Lloyd, S. (2018)

An introduction to quantum machine learning
Schuld, M., Sinayskiy, I., Petruccione, F. (2014).

PAPER 01: QUANTUM ALGORITHMS FOR DEEP CONVOLUTIONAL NEURAL NETWORKS

Paper Introduction: A quantum algorithm that imparts a potential speed up for applying and training deep CNNs. The quantum CNN (QCNN) is a shallow circuit.

Quantum speedups have already been realized in machine learning, but deep learning has been studied, but because of the difficulty of implementing non linearities has created a blocker.

CNNs have wide use in areas like autonomous cars and gravitational wave detection and are used generate or reconstruct images using General Adversarial Networks (GANS) but are computationally expensive.

PAPER 01: QUANTUM ALGORITHMS FOR DEEP CONVOLUTIONAL NEURAL NETWORKS

Problem: It is difficult to implement non linearities with quantum unitaries.

What is a non-linearity? A non-linearity is “Nonlinearity is a term used in statistics to describe a situation where there is not a straight-line or direct relationship between an independent variable and a dependent variable. In a nonlinear relationship, changes in the output do not change in direct proportion to changes in any of the inputs.”

What is a quantum unitary?

Solution: Reproduce a **classical CNN** by **allowing non-linearities** and **pooling operations.**

PAPER 01: QUANTUM ALGORITHMS FOR DEEP CONVOLUTIONAL NEURAL NETWORKS

Content: This paper takes the time to explain a classic CNN and then covers quantum computing basics. It starts by covering tensor representation and CNN architecture, namely Convolution Layer, Activation Function, Pooling Layer and Fully Connected Layer as discussed in our course. It then goes on to discuss Convolution Product as a Tensor Operation. The next section cover basic quantum computing topics such as a qubit, superposition state and amplitudes. Lastly, the paper presents many theorems including theorems for

Theorem 4.1 – Amplitude Estimation

Theorem 4.2 – Median Evaluation

Theorem 4.3 – QRAM Data Structure

Theorem 4.4 – Quantum Linear Algebra

PAPER 01: QUANTUM ALGORITHMS FOR DEEP CONVOLUTIONAL NEURAL NETWORKS

Breakdown: The paper proposes an algorithm using a forward pass for the QCNN.

From what I understand, the writers propose to use quantum computing features to "estimate" inner products during convolution and then to store amplitudes in a quantum register and perform qubit rotations using quantum circuits to amplify correct results and reduce wrong results from appearing in the convolution layer process. Quantum algorithms are also presented for backpropagation and pooling.

A noisy gradient descent rule is also discussed.

Bottom line, the paper presents the first quantum algorithm for computing a convolution product between two tensors with a speedup.

PAPER 02: A QUANTUM ALGORITHM FOR TRAINING WIDE AND DEEP CLASSICAL NEURAL NETWORKS

Introduction of a neural tangent kernels NTK [approximations, sparsing, etc.] algorithm. The paper makes use of sparsified and diagonal kernels, but can apply to any chaotic kernel.

NTK represents an overparameterized neural network as linearized models applied to nonlinear features. This is another attempt to tackle the problem of working with non linearities expressed in the first paper.

Makes use of Quantum Random Access Memory (QRAM).

Makes use of Gradient Descent

The MNIST dataset is used for experiments.

The implementation of the algorithm is presented on GitHub. I read through the code, but I was not able to determine where actual qubits are used. I believe the algorithm presented has not yet been implemented on a quantum computer.

PAPER 03: A QUANTUM DEEP CONVOLUTIONAL NEURAL NETWORK FOR IMAGE RECOGNITION

Paper Introduction: This paper also covers convolutional neural networks but goes further to discuss a quantum deep convolutional neural network (QDCNN).

The paper introduces a quantum deep convolutional neural network (QDCNN). It is analogous to a classical deep convolution neural network (DCNN).

A QDCNN allows for larger convolution kernels and larger or deeper inputs.

This paper discussed QRAM as well.

PAPER 03: A QUANTUM DEEP CONVOLUTIONAL NEURAL NETWORK FOR IMAGE RECOGNITION

What I liked about this paper is that it actually presents a Quantum circuit in a format I am familiar with although the complexity is very high.

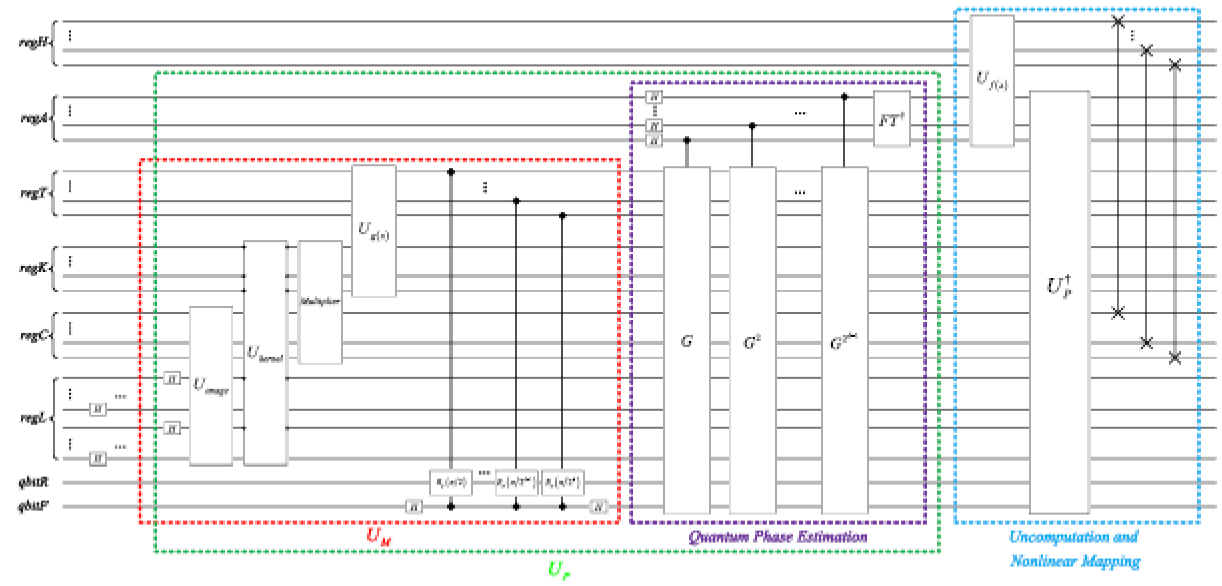

Figure 3. The quantum circuit for the convolutional layer in QDCNN model. (The black points marked in the unitary transformation represent the interaction site.)