Task III: Open task

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1 Task description

Please comment on quantum computing or quantum machine learning. You can also comment on one quantum algorithm or one quantum software you are familiar with. You can also suggest methods you think are good and you would like to work on. Please use your own understanding. Comments copied from the internet will not be considered.

1.1 Comment on quantum computing or quantum machine learning

1.1.1 Potential of Quantum Computing

Interest in Quantum Computing has exponentially grown in recent years, with the potential to become the next technological revolution akin to computers in the 20th-century information era. By harnessing quantum mechanics properties such as superposition, entanglement, interference, and measurement, Quantum Computing offers promising solutions to complex problems. Tasks like factoring large numbers or searching unstructured data can see significant performance improvements, sparking discussions about the quantum advantage.

1.1.2 Quantum Machine Learning (QML)

Quantum computing finds applications in various domains, mainly simulations and optimization algorithms, the latter serving as the foundation of quantum machine learning.

In the last years, many quantum machine learning algorithms have been developed, and, in most cases, when analyzing classical data, QML models generally perform equivalently or less effectively than traditional machine learning models. Additionally, researchers have explored implementing quantum algorithms on different versions of classical machine learning models, resulting in hybrid or fully quantum models.

Developing effective QML models remains challenging. Recent investigations, such as those conducted by Xanadu, aim to assess the effectiveness of QML models and discern whether they offer advantages over classical approaches. Insights from such investigations are crucial for refining QML methodologies and improving their practical applications.[2].

1.1.3 Current state of Quantum Computing

The current state of quantum computation has yet to reach the level of maturity necessary for generating disruptive changes, known as fault-tolerant quantum computers. This is due to the number of qubits that can currently be utilized and hardware limitations, making it challenging to maintain the fidelity of qubit quantum states. Although physical qubits exist, obtaining logical qubits remains challenging. This area is still under development, with many individuals working on it. Hence, the current era is termed Noisy-Intermediate Scale Quantum (NISQ). Nonetheless, several techniques have been proposed to leverage current quantum computing resources known as Near-Term Quantum Computing techniques. These include variational quantum algorithms and error mitigation, among others, which have shown the ability to mitigate errors and implement algorithms with some resistance to noise, enabling real-world applications in various areas. Despite the adversities, these achievements highlight real solutions to diverse problems with a limited number of qubits.[3]

While algorithms like Grover's or Shor's possess a quantum advantage, they are intractable in the NISQ era due to the lack of error correction capability. On the other hand, Variational Quantum Algorithms (VQAs) have shown resilience to this problem.

1.2 Quantum Algorithm and Software Familiarity

I have been studying quantum computing for over six months through various resources, including courses like Google Quantum AI by Qubit by Qubit, Qiskit textbook, and Xanadu Quantum Codebook. Participating in quantum computing communities like Quantum Quipu and events like Qiskit Quantum Experience and the Mexican National Congress of Physics has provided me with practical experience in handling libraries such as Cirq, Qiskit, and Pennylane.

Through practical implementations, I have gained proficiency in fundamental quantum computing concepts, including gates, algorithms like Grover's and Shor's algorithms, Quantum Fourier Transform, variational quantum algorithms, and Quantum neural networks.

A key aspect of current QML is the use of Variational Quantum algorithms (VQA), which have become one of the primary candidates for achieving quantum computational advantage aimed at NISQ devices. This is due to their hybrid quantum-classical approach, which has the potential for noise resistance.

These algorithms involve creating a quantum circuit ansatz that works like a trainable parametrized quantum circuit (PQC) to minimize a cost function and iteratively adjusting parameters using classical optimizers like the Adam optimizer. This approach, resembling classical neural network training, has been adopted in many hybrid models that combine classical and quantum elements.

1.3 Methods Suggestions

The use of equivariant ansatz represents an approach aimed at reducing the number of available gates, thereby simplifying the complexity of the quantum circuit to maintain equivariance with the data's inherent symmetry. For instance, in classical classification models, 2D images exhibit translation symmetry, which convolutional neural networks leverage to enhance performance by detecting patterns across different positions or orientations within an image. [1]

The significance of studying symmetries has surged since Noether established their correlation with conservation laws, offering the scientific community fresh insights, particularly in particle physics. Here, conserved quantities are viewed as symmetries within the system. Embracing group theory is pivotal within this context as it naturally encapsulates symmetries, encompassing both discrete (e.g., spatial parity) and continuous (e.g., rotations) symmetries. Consequently, equivariant quantum neural networks (EQNNs) emerge as promising models for exploring symmetries in particle physics.

Fundamental to the understanding of particle physics is the application of group theory, with the standard model grounded upon it. For instance, special relativity's essential fields find description through the ISO(3,1) group, also known as the Lorentz group. Invariance under Lorentz transformations is a crucial aspect, ensuring the laws of physics remain consistent across all observers. Notably, the Lorentz group forms a subset of the broader Poincaré group, which incorporates transformations entailing both Lorentz transformations and translations.

On a different note, models such as Data Reuploading have exhibited remarkable performance with minimal resources, making them ideal candidates for integration into complex models where applicable.

Lastly, in evaluating quantum model performance, it's interesting to explore the impact of "quantumness" such as entanglement gates.

References

[1] Johannes Jakob Meyer et Al. "Exploiting symmetry in variational quantum machine learning". In: *arXiv preprint arXiv:2205.06217* (May 2022). DOI: `10.48550/arXiv.2205.06217`. arXiv: `2205.06217 [quant-ph]`. URL: `https://doi.org/10.48550/arXiv.2205.06217`.

[2] Joseph Bowles et al. "Better than classical? The subtle art of benchmarking quantum machine learning models". In: *arXiv preprint arXiv:2403.07059* (Mar. 2024). DOI: `10.48550/arXiv.2403.07059`. arXiv: `2403.07059 [quant-ph]`. URL: `https://doi.org/10.48550/arXiv.2403.07059`.

[3] He-Liang Huang et al. "Near-Term Quantum Computing Techniques: Variational Quantum Algorithms, Error Mitigation, Circuit Compilation, Benchmarking and Classical Simulation". In: *Science China Physics, Mechanics & Astronomy* 66.5 (May 2023), p. 250302. DOI: `10.1007/s11433-022-2057-y`. URL: `https://doi.org/10.1007/s11433-022-2057-y`.