Quantum Walks Search as a Solution for Barren Plateaus in Quantum Machine Learning

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The Barren Plateaus (BPs) phenomenon is a significant obstacle in the implementation of quantum variational algorithms, which are among the most widely used algorithms in quantum machine learning (QML) [1]. BPs have been extensively studied, their primary causes and characteristics have been identified. The two main explanations for BPs are: a classical optimizer executing a local search guided by an evaluation function that suffers from loss concentration, and data sparsity due to the curse of dimensionality. However, these are not the only factors contributing to BPs. In this work, we propose an alternative approach to quantum variational algorithms, a technique based on Quantum Walks (QWs), which can effectively avoid BPs in the field of QML.

Quantum variational algorithms conceptualize a problem as an optimization task that can be addressed as an optimization problem, solved through a classical search process. Quantum walks can be utilized similarly, as demonstrated in Quantum Metropolis Solver (QMS) algorithm [2], with the crucial distinction that the search is quantum-based and occurs over a superposition of states. Unlike the local landscape search in variational algorithms, quantum walks evaluate the entire state space in superposition, thereby avoiding issues related to flat landscapes or loss concentration. In this work, this state space is seen as a hypothesis space, similar to what a machine learning algorithm does. In this context, techniques based on quantum walks have been shown to avoid the BPs phenomenon in various use cases related with optimization problem and Bayesian inference [2–5].

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The strength of the QMS technique [2] is to be able to characterize the state space with high precision and low number of repetitions of the main operator. This operator is known as W derived from the QW notation and is composed by a Grover reflection and a set of swap gates. For small problems like 2^4 states, 3-4 Ws sample with high precision the hidden function $f(x)$ of the state space as shown in figure 1. QMS (colour lines) perfectly reconstructs the distribution of the problem (black line). These good results during the sampling process can be used to perform a good search process to find a maximum or minimum.

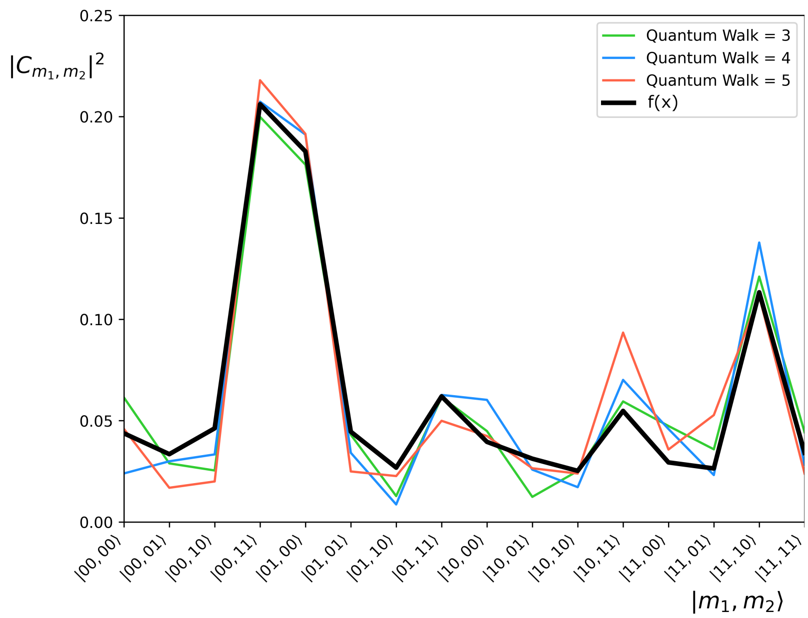

FIG. 1. $f(x)$ is the hidden function to guess by the QMS algorithm. Black line ($f(x)$) represents probabilities for 16 combinations of 2 variables using 2 discretization qubits (total 4 qubits). The colored lines show the probability of measuring the state register for different numbers of applications of the quantum walk operator W. It is shown the high precision of the algorithm to reconstruct the hidden distribution. This state space is equivalent to the hypothesis space of an ML algorithm.

In this work, we extend previous research that employed QWs to conduct quantum searches and Bayesian inference for addressing optimization problems. We introduce an algorithm that leverages QWs as its core component and apply it to a QML task. This QML task is an inference problem where it is necessary to identify the hypothesis that best explains the input data according to an evaluation or loss function $f(x)$. While classical algorithms would typically require an exhaustive search, a quantum walk can exploit the superposition of the state/hypothesis space. We propose this new QML algorithm as a promising approach to develop QML algorithms that circumvent the BPs phenomenon.

It is important to note that QWs are not inherently NISQ techniques. The circuit depth required to execute any of the potential implementations of a QW is typically closer to what is feasible on a Fault-Tolerant Quantum Computer rather than on NISQ devices. However, as demonstrated in [5], we developed a depth circuit reduction technique known as "Renormalization & Downsampling" for hybrid computation. This technique brings the execution of depth circuits closer to the capabilities of NISQ devices. Detailed insights into this technique are provided in the proposed talk for QTML24, titled "Renormalization & Downsampling as a Classical Subroutine for Amplitude Amplification of Quantum States" by Gabriel Escrig.

This algorithm based on QWs can be applied to the field of Quantum Machine Learning (QML), particularly in problems that can be framed as optimization tasks. The key advantage of using QWs is their ability to circumvent BPs phenomenon. This QWs-core algorithm has been successfully tested in other use cases and is naturally adapted to QML problems.

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