Classification of Quantum Correlations via Quantum inspired Machine Learning

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A well-known problem in quantum theory is identifying quantum correlations between states, such as discriminating between entangled states and separable states. Additionally, there is the concept of non-locality, whose discrimination remains less studied. While there are optimal discrimination strategies for systems of small size, the problem becomes increasingly difficult to handle as the number of qubits grows. In the recent past, several approaches of quantum machine learning have been introduced to classify entangled and separable states. Quantum information theory, and in particular, the theory of quantum state discrimination, has enabled the development of a supervised multi-class classification algorithm. Inspired by the *Pretty Good Measurement* (PGM), it has been possible to design a quantum-inspired classifier named the PGM Classifier [1,2], capable of classifying among multiple classes without resorting to the One versus One or One versus Rest strategy.

In this article, we apply the PGM Classifier to discriminate between factorized states, separable states, and entangled states. We analyze from the simplest case (**2** qubits) up to a system of **5** qubits and offer a comparison between our quantum-inspired classifier and other classical classifiers. In addition to state classification, we explore the PGM Classifier's application in detecting nonlocality. Our experiments reveal its high accuracy in identifying violations of Bell-type inequalities for 2 and 3-qubit systems, underscoring its strength in revealing genuine quantum correlations.

The obtained results highlight some fundamental elements. The first consideration involves the comparison with other classification algorithms. The PGM clearly demonstrates superiority over all other classifiers as shown in Fig. 1. This superiority is consistently observed across all explored cases, from 2 to 5 qubits. As a further experimental evidence, it is confirmed that, while the classification between factorized and entangled states is relatively straightforward for the PGM, the classification of separable states proves to be more contentious. In the case of two qubits, the PGM classification between entangled and factorized states yields a balanced accuracy exceeding 80% for the PGM. As the number of qubits increases, the accuracy gradually decreases. Observing the confusion matrices for each case, it becomes evident that the percentage of true positive instances remains consistently high within the factorized and entangled state classes, while it is proportionally much lower for each subclass of the separable states. Additionally, it is noted that increasing the dataset's cardinality generally results in improved performance; however, this improvement predominantly benefits the entangled and factorized classes, with only partial gains for the separable class. The aforementioned considerations lead us to conclude that the PGM is a highly suitable classifier for the classification of quantum correlations. Furthermore, although the classification of separable states remains particularly challenging, classification via quantum-inspired machine learning is confirmed as a promising strategy for further investigation.

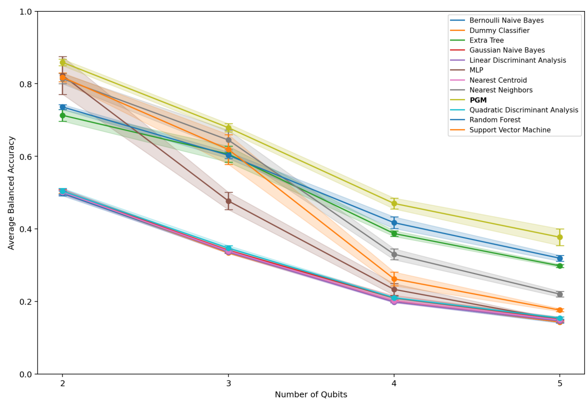

Figure 1: Comparison of classifier performance for different numbers of qubits.

References

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