Experimental quantification of measuring quantum entanglement and Bell's nonlocality of two-qubit states

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Measuring nontrivial properties of quantum systems, such as entanglement measures and Bell inequality violations, poses significant challenges. The conventional method involves computing these metrics using the fully reconstructed density matrix of the system, necessitating comprehensive knowledge of the quantum system under investigation, whereas nonclasical correlations are invariant with respect to local unitary operations.

To reduce the need to complete system information, one can employ multiple copies of the system and conduct joint measurements. While this approach was once deemed impractical due to the complexities of preparing and controlling quantum-correlated systems, recent advancements have made it viable, albeit with challenges such as nonlinear amplification of experimental noise.

In our study, we successfully measured two-qubit quantum systems for Horodecki and Werner states, utilizing the multicopy approach outlined in [1,2]. We performed measurements, on noiseless simulators as well as on real IBMQ quantum processors [3], to determine the negativity and nonlocality values. Our analysis involved a comparison with the conventional tomography-based method.

To counteract the nonlinear approach's susceptibility to noise, we implemented a maximum likelihood method, leveraging physical constraints on jointly observed multicopy observables. Furthermore, employing SHAP analysis [4], we identified the impact of specific singlet projections on entanglement witnesses. Based on these findings, we showed that it is possible to train a neural network model to quantify nonlocality and negativity.

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References

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