Abstract

Quantum information theory is a rapidly growing field that harnesses the power of microscopic physical systems in information theoretical tasks. Some of its predictions could have a tremendous impact on near-term information technology, such as exponential speedup in computational tasks or unconditionally secure cryptographic protocols. These perspectives are highly promising, however, they call for verification schemes: one must be able to certify the correctness of quantum computations, as well as to verify the security of cryptographic devices.

While such verification schemes already exist, and are thoroughly studied, there are still a few drawbacks associated with them. The most rigorous certification scheme of "self-testing" is rather difficult to implement in the laboratory, and results in the high-dimensional setting are lacking, despite the apparent advantage of high-dimensional systems. Moreover, most verification methods focus on certifying the exact physical setup rather than some relevant properties thereof, which is impractical in some cases.

In the current thesis, I address the above shortcomings by devising experimentally friendly certification schemes of relevant properties in the high-dimensional setting. Specifically, I focus on the experimentally less demanding task of "prepare-and-measure" scenarios, in which, together with my collaborators, I introduce two methods of certifying quantum states and measurements. The first method concentrates on verifying the genuine high-dimensional nature of quantum states and measurements, a property that we refer to as 'irreducible high-dimensional systems'. Together with my collaborators, we demonstrate the applicability of our methods in a photonic experiment in dimension 1024, proving the irreducibility of the implemented quantum optical setup.

My second method uses the same prepare-and-measure protocol, however, this time I concentrate on certifying a class of measurements that has proven to be immensely useful in quantum information theory, mutually unbiased bases. Together with my collaborator, we show that these measurements can be certified in the prepare-and-measure scenario in an experimentally feasible manner. Moreover, using our results, we are able to certify two additional properties of the measurements, namely their capability of generating randomness, and their incompatibility robustness.

Finally, I focus on the above mentioned relevant property of measurements, incompatibility robustness, which measures to what extent a pair of quantum measurements is not jointly measurable. Incompatible measurements turn out to be a useful resource in various quantum information theoretic protocols, and therefore it is an important task to

quantify the extent to which a pair of measurements is incompatible. Together with my collaborators, we analyse a wide class of incompatibility robustness measures, corresponding to generic noise models. We show that some of the measures that are often used in the literature do not satisfy certain natural properties. Moreover, we show that according to one of the measures, mutually unbiased bases are among the most incompatible pairs of measurements in every dimension, but also that this is not the case for some other measures. Our results highlight that despite the significant effort dedicated to this topic, a thorough understanding of incompatibility robustness measures is still lacking in the quantum information community.