Abstract

Quantum technologies and protocols yielded an unprecedented boost on communication, computation and information processing. However, optimising performance in tasks with quantum resources requires an ever-increasing knowledge of what the nonclassical features of quantum theory are. Research in quantum foundations in the past decade has identified generalised contextuality as one of the best-motivated notions of nonclassicality available, since it simultaneously provides the quantum advantage in many computation, communication and information processing tasks, subsumes or relates to a wide family of other signatures of nonclassicality, and has a reasonable philosophical motivation from Leibniz's assumption of the identity of indiscernibles.

Assessing generalised noncontextuality however is not straightforward, since it usually relies on the explicit verification of the existence of a noncontextual ontological model for the scenario under investigation. This thesis provides a numerical tool for assessing generalised contextuality in prepare-and-measure scenarios, and applies it to different quantum protocols for which contextuality is known to be a resource to explore how more practical quantities and methods based on contextuality can help assess the resourcefulness of these scenarios for communication tasks.

We start by motivating the adoption of generalised contextuality as a notion of non-classicality by exploring how its device-independent counterpart is not sufficient to draw statements about the realisability of Einstein-Podolsky-Rosen assemblages in Ref. [First Paper]. In particular, we show that if we define a physical principle based on device-independent contextuality, we cannot fully characterise the EPR assemblages that satisfy this principle without making assumptions about the underlying quantum system.

We then shift to the Generalised Probabilistic Theory framework and to the main goal of this thesis in Ref. [Second Paper], where we introduce a linear program for assessing contextuality in prepare-and-measure scenarios. The program estimates the robustness of contextuality to depolarising noise, i.e., how much partial depolarising noise is necessary for a noncontextual ontological model to exist, and provides the ontological model for the depolarised scenario. We also provide an implementation of this program in Mathematica and give some examples of quantum and postquantum scenarios that display or not generalised contextuality.

Finally, we apply this tool to quantum protocols in which contextuality is known to be a resource. In Ref. [Third Paper], we leverage the code to investigate the relation between generalised contextuality and coherence, and show that there are proofs of contextuality that are maximally robust to dephasing noise and that require a vanishing amount of coherence in the states and measurements. We then provide an importation of this linear program to Python in Ref. [Repository]. We employ this new implementation to investigate how well robustness of contextuality to depolarising and to dephasing noise quantify the resourcefulness of scenarios for parity-oblivious multiplexing tasks in Ref. [Preprint]. We conclude that robustness to depolarising noise, as well as robustness to dephasing minimised over key axes, are good quantifiers of the quantum advantage in this task.