Macroscopic non-contextuality as a principle for Almost Quantum Correlations

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Foundational aspects of Quantum Mechanics continues to be a subject of intense research, looking for physically grounded rather than purely mathematical and abstract axioms for quantum theory, in particular for its predictions in correlation experiments. Even though many information-theoretic principles have been proposed, none of them proved to single out the set of quantum correlations. In addition, there is a larger set of correlations called "almost quantum" that has raised interest in the past years. One of the reasons is that this set, which includes supra-quantum correlations, seems to satisfy all the principles proposed so far. In this paper, we present a principle called Macroscopic Non-Contextuality and prove that it fully characterises the Almost Quantum set.

It is a well accepted fact that the predictions of quantum theory are incompatible with those of classical physics. Nonlocality and Contextuality are phenomena which cannot be explained in the classical world, although they arise naturally in quantum mechanics. In the past decades, nonlocality and contextuality have become a fruitful topic of research, where new discoveries have revealed their intrinsic interdisciplinarity and striking applications in a wide range of topics far from the setting in which they were originally discovered.

In spite of the new insights on these phenomena, little is known about the structure of quantum nonlocality and contextuality, which is still a fundamental open problem. Indeed, no concise operational characterisation of these quantum predictions has been found so far, and it is unclear whether such a characterisation even exists. From the physical perspective, such a question has its root in Bell's theorem [2] and the Kochen-Specker theorem [5].

Characterising the set of quantum correlations is hence an active area of research and an interesting problem on its own. Indeed, several candidate axioms for quantum correlations have been proposed, such as non-trivial communication complexity [3], information causality (IC) [8], local orthogonality [4] and macroscopic locality [7]. The problem of characterising quantum correlations in Bell scenarios from basic principles is however far from being solved. All the principles proposed so far, except IC, have been shown to be satisfied by some supra-quantum correlations (and the same is suspected to be true of IC) [6]. Indeed, there exists a set of correlations called "almost quantum" that is slightly larger than the quantum set and yet satisfies these principles, presenting a curious barrier to a full characterisation of the quantum set [6]. However, even a characterisation of the almost quantum set from basic principles is still missing.

Here we focus on the macroscopic locality (ML) principle [7]. Essentially ML states that, for a certain macroscopic extension of a Bell experiment, Bell's local causality will hold, or in other words quantum nonlocality will no longer be detectable in this macroscopic limit. ML however is formulated for bipartite Bell scenarios only and is satisfied by an even larger set than that of almost quantum correlations.

In this work we propose a generalisation of ML to arbitrary contextuality scenarios, which we call macroscopic non-contextuality (MNC). We use the hypergraph based formalism [1] to represent such

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scenarios, and find that MNC characterises the particular set Q_1 of probabilistic models, which includes supraquantum models. For Bell scenarios, this strengthens the original ML principle, because the set Q_1 is equivalent to the set of almost quantum correlations [1, 6] and moreover because it may be applied to an arbitrary n-partite Bell scenario. Thus, we provide the first characterisation of almost quantum correlations from basic physical principles.

One key ingredient in the formulation of the principle relies on considering correlated measurements as operationally allowed measurements in Bell scenarios. Such measurements have also played an important role when defining correlations in the hypergraph approach to contextuality [1] since they enforce the no-signalling principle from within the description of the scenario alone. This highlights the importance of correlated measurements, whose full significance is still under debate.

Our result allows for important future lines of research. In particular, now that a characterisation of almost quantum models is provided, the attention can be focused on distinguishing this set from the quantum one. We believe that this will shed light on the possible characterisation of quantum probabilistic models.

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