# PhD Thesis Defense FLORIAN CURCHOD 'Nonlocal Resources for Quantum Information Tasks'

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Thursday, October 11, 11:00. ICFO Auditorium

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Quantum Information Theory

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This thesis focusses on the essential features of Quantum Theory that are systems in an entangled state and Bell nonlocal correlations. Here, we take the angle of a resource theory and are interested in understanding better how entanglement and nonlocality, first, relate to one another. Indeed, if entangled systems are necessary for the generation of nonlocal correlations, there nevertheless exist entangled systems that seem

unable to do so. Quantitatively, it is also unclear whether "more" entanglement leads to "more" nonlocality and, related to that, which measures should be used as quantifiers. Second, entangled systems and nonlocal correlations have been identified as resources for information tasks with no classical equivalent such as the generation of true random numbers. It is then important to understand how the two quantum resources relate to other quantities generated in information tasks. First, we show that entangled quantum systems are unbounded resources for the
generation of certified random numbers by making sequences of measurements on them. This certification is achieved through the successive near maximal violation of a particular Bell inequality for each measurement in the sequence. Moreover,
even the simplest two-qubit systems in an almost separable (pure) state achieve this unbounded randomness certification.
Second, we show that entanglement and nonlocality are seemingly put in a quantitative equivalence when using the nonlocal volume as measure. This measure is defined as the probability that a system in a given state generates nonlocal correlations
when random measurements are performed on it. We prove that this measure satisfies natural properties for an operational measure of nonlocality. Then we show that, in all situations that we could explore, the most nonlocal state -- as measured
by the nonlocal volume -- is always the maximally entangled state. Third, we consider multipartite scenarios in which quantum systems are distributed to numerous parties. Note that it is in general harder to generate a system that is entangled between many parties rather than more systems entangled between fewer parties. In that spirit, we develop a framework and tools for the study of correlation depth, i.e. the minimal size of the resource -- such as entangled systems -- that is needed for the (re)production of the correlations. Fourth, we study the equivalence between the multipartite notions of entanglement and of nonlocality. From an operational understanding of multipartite entanglement, we develop simple families of Bell inequalities that are very efficient for the detection of multipartite nonlocality of pure states. Last, we study the utility of multipartite quantum correlations for the design of information protocols. We also identify novel features characteristic of these correlations.

The results of this thesis shed light on the interrelations in the triangle entanglementnonlocality- randomness in Quantum Theory. By going beyond the standard approaches -- by considering sequences of measurements on the systems or by considering a novel measure of nonlocality -- we obtain insight on the quantitative relations between these three essential quantities. Our study of the multipartite scenario also helps in characterising and identifying multipartite correlations in a simple way. Finally, we also deepened our understanding of how entangled systems and nonlocal correlations, in particular multipartite ones, serve as resources for the design of information tasks with no classical equivalent.

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