Doctoral School of Information and Biomedical Technologies Polish Academy of Sciences (TIB PAN)

SUBJECT: Resources for quantum computation

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DESCRIPTION: Quantum coherence and entanglement are fundamental features of quantum systems, separating quantum physics from its classical counterpart. In the early days of quantum mechanics entanglement has been considered as a puzzling phenomenon, and Einstein has famously termed it "spooky action at a distance". Over the last decades the situation has changed, with the existence of entanglement being confirmed in numerous experiments. Today, quantum entanglement is considered as a resource for the emerging quantum technologies, allowing us to surpass limitations of classical devices. This has led to the development of the resource theory of entanglement, allowing us to investigate the role of entanglement for technological applications, such as quantum teleportation and quantum cryptography.

The goal of this research is to explore and identify the fundamental quantum resources that are responsible for enabling computational speedup in quantum systems, with a particular focus on mixed-state quantum computation models where noise and decoherence are inherently present. In conventional models of pure-state quantum computing, it is well established that entanglement plays a central role in enabling exponential speedup over classical algorithms. However, this understanding does not readily extend to mixed-state scenarios, where the presence of noise significantly reduces entanglement and other well-studied quantum correlations. As a result, the foundational mechanisms behind speedup in such noisy quantum systems remain poorly understood and are the subject of active investigation.

A central question this research seeks to answer is whether alternative quantum features-such as quantum coherence, quantum discord, or other forms of nonclassical correlations-can account for the computational advantages observed in noisy quantum systems, even in regimes where entanglement is negligible or entirely absent. Understanding which of these resources are necessary or sufficient for achieving quantum speedup is critical not only for theoretical insight but also for the design of practical quantum algorithms that are robust to noise. This includes determining whether certain quantum features can serve as universal indicators of quantum advantage or whether different computational models rely on distinct types of resources. By systematically applying tools from quantum resource theories, we aim to delineate the resource requirements of quantum computation across both pure and mixed-state regimes.

Profile of the candidates: Applicants should have a master's degree in engineering, physics or related areas, and have a good understanding of quantum theory. Candidates are strongly advised to contact Alexander Streltsov before formal submission of the documents: astrel@ippt.pan.pl.