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Multi-Agent Reinforcement Learning for Nonlocal Games via Shared VQCs

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Nonlocal games provide a framework for studying cooperative strategies under different resource assumptions. These range from independent agents with no shared resource, through local hidden variable (LHV), to entangled quantum states, allowing one to quantify the advantage of quantum strategies over classical ones. Discovering optimal quantum strategies, however, remains a non-trivial task. We propose a multi-agent reinforcement learning (MARL) approach with shared variational quantum circuits (VQCs) as a general-purpose tool for automated discovery of such strategies. Prior to the game, the agents may agree on a strategy, but once the game begins, each agent receives a question and must provide an answer without communicating. An entangled state is prepared across the agents' respective registers. Each agent then applies local parameterized unitary operations conditioned on their received question, followed by a measurement on their subsystem. The measurement outcomes determine the agents' actions, and the circuit is trained via the REINFORCE algorithm. We evaluate the method on three nonlocal games: the CHSH game, the Magic Square game, and the Rendezvous problem. Our results demonstrate that the proposed approach consistently exceeds LHV bounds and achieves winning probabilities matching quantum optimal limits.

Primary author(s) : MAZUR, Dawid (AGH University of Krakow)

Co-author(s) : GAWRON, Piotr (AstroCeNT / Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences)

Presenter(s) : MAZUR, Dawid (AGH University of Krakow)

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