2025

Universal, Unambiguous Concentration and Distillation of Bell pairs. — The ability of preparing perfect Bell pairs with a practical scheme is of great relevance for quantum communication as well as distributed quantum computing. We proposed a scheme which probabilistically, but universally and unambiguously produces the $|\phi_+\rangle$ Bell pair from four copies of qubit pairs initially in the same unknown pure quantum state. The same scheme, extended to eight qubit pairs initially in the same, moderately mixed quantum state, unambiguously produces the $|\phi_+\rangle$ Bell pair with quadratically suppressed noise. The core step of the proposed scheme consists of a pair of local two-qubit operations applied at each of the two distant locations, followed by a partial projective measurement and postselection at each party, with results communicated classically (see Fig.1). While the scheme resembles standard entanglement distillation protocols, it achieves success within just three iterations, making it attractive for real-world applications [1].

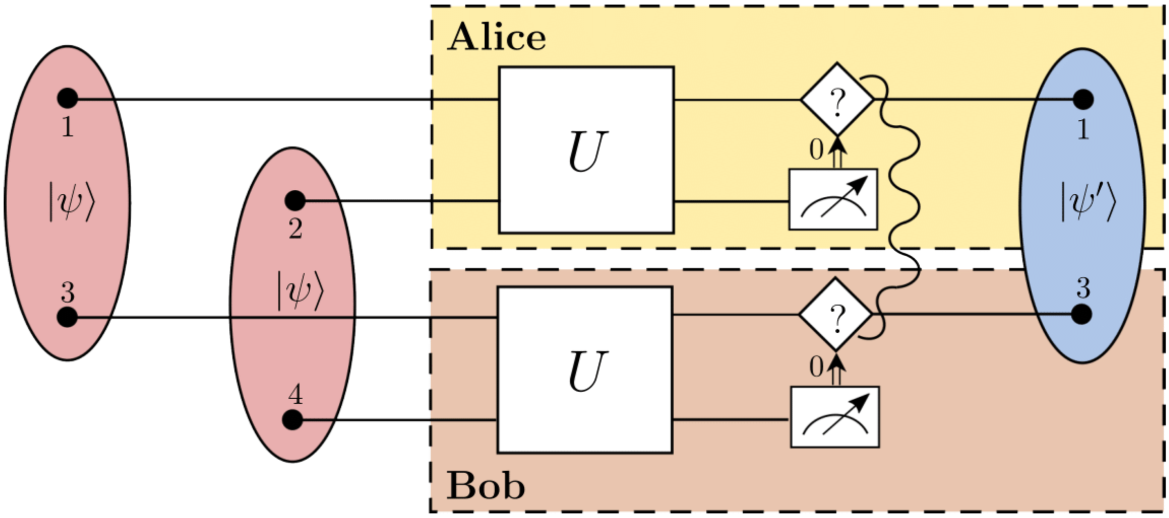

Figure 1. The schematic representation of the core step of the protocol. A and B denote two distant parties, Alice and Bob, who apply a local two-qubit unitary U, and a subsequent measurement on qubits 2 and 4, respectively, after which they only keep qubits 1 and 3 if the measurements resulted 0, which they can communicate classically.

Hybrid quantum-classical reinforcement learning in latent observation spaces. — Recent progress in quantum machine learning has sparked interest in using quantum methods to tackle classical control problems via quantum reinforcement learning. However, the classical reinforcement learning environments often scale to high dimensional problem spaces, which represents a challenge for the limited and costly resources available for quantum agent implementations. We propose to solve this dimensionality challenge by a classical autoencoder and a quantum agent together, where a compressed representation of observations is jointly learned in a hybrid training loop (see Fig.2). The latent representation of such an autoencoder serves as a tailored observation space best suited for both the control problem and the QPU architecture, aligning with the agent's requirements. We designed a series of numerical experiments for a performance analysis of the latent-space learning method for different control problems and for both photonic (continuous-variable) and qubit-based agents, to show how the QNN learning process is improved by the joint training [2].

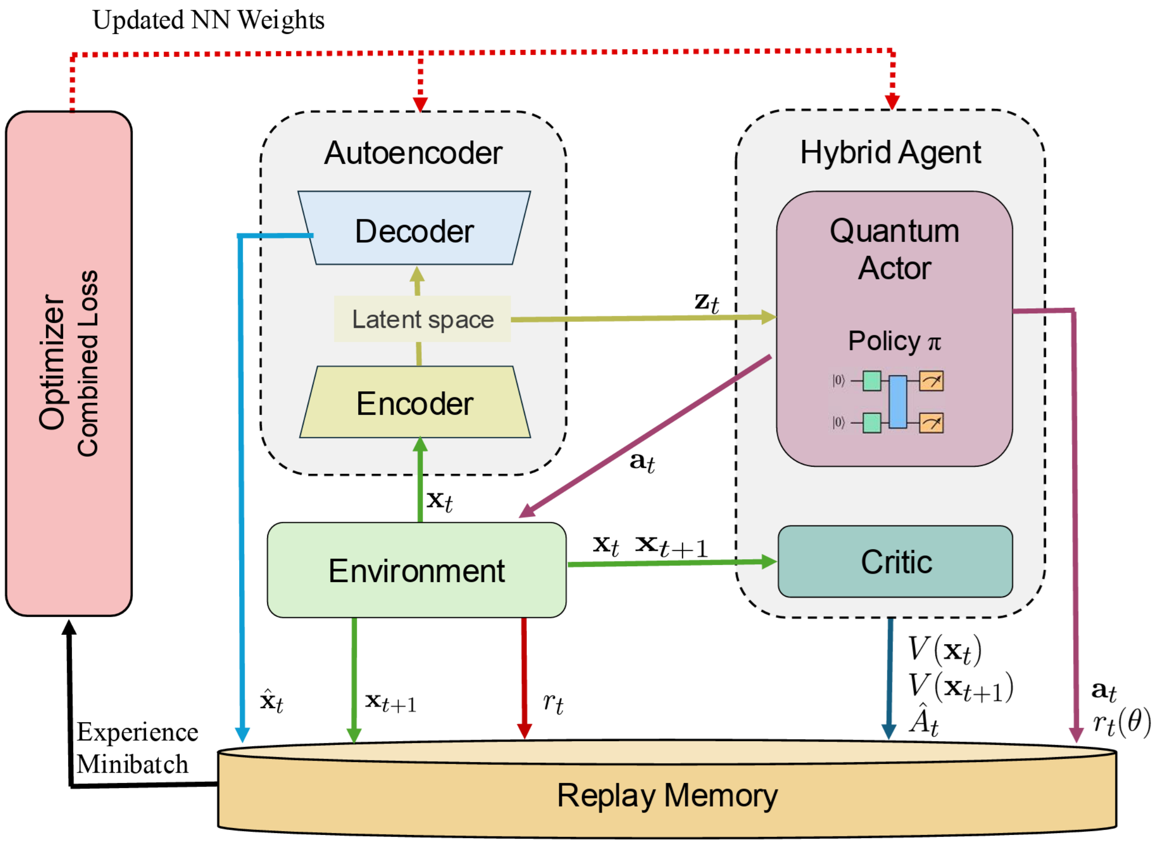

Figure 2. Hybrid quantum-classical QRL training via the PPO algorithm in latent observation space. An Autoencoder is introduced to learn latent state representation of a Classical Environment for optimal performance of a hybrid QRL PPO agent with quantum policy network. At each timestep, a Classical Optimizer updates the parameters for the Autoencoder and Quantum Policy networks based on a joint loss function.

References:

[1] O. Kálmán, A. Gábris, I. Jex, and T. Kiss, *Universal, Unambiguous Concentration and Distillation of Bell pairs*, Physical Review Letters **135**, 260202 (2025). https://doi.org/10.1103/rcx1-w6j7

[2] D. T. R. Nagy, C. Czabán, B. Bakó, P. Hága, Z. Kallus, and Z. Zimborás, *Hybrid Quantum-Classical Reinforcement Learning in Latent Observation Spaces,* Quantum Machine Intelligence **7**, 88 (2025). https://doi.org/10.1007/s42484-025-00306-z