Generative AI in the era Quantum Computing: Learning with Density Operators

Probabilistic Latent variable models are at the heart of Generative AI.
Developing algorithms for latent variable models for quantum computers is in a nascent stage of research. Learning Quantum Boltzmann Machines (QBM), a prominent quantum latent learning model, rarely scale beyond 10 qubit systems, severely prohibiting their applicability. This is because learning density operators, the generalization of probability distributions, pose formidable computational challenges that require the development of new formalisms. Inspired by the EM algorithm, we propose an iterative Minorant-Maximization algorithm called Density Operator Expectation Maximization (DO-EM) for learning density matrices. Using the Petz recovery map, we develop models that provably improve log-likelihood, analogous to classical EM. We introduce Classical-Quantum LVMs (ClassiQ) that can train on high-dimensional data, including Quantum Interleaved Deep Boltzmann Machines (QiDBM), a novel DBM with quantum layers interleaved among classical layers. QiDBM, when trained with DO-EM under Contrastive Divergence, outperform DBMs on image generation for the MNIST dataset with a 40-60% reduction in the Fréchet Inception Distance.