Scalable quantum dynamics compilation with quantum machine learning

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Simulation of real-time quantum dynamics is among the most promising applications of quantum computers. Classical algorithms face challenges in accurately replicating quantum dynamics due to the exponentially large Hilbert space, the substantial amount of entanglement generated during evolution, the sign problem, etc. Quantum computers avoid these issues and provide an efficient framework for simulating quantum systems. The standard approach to deriving circuits for implementing dynamics involves Trotterization. This method divides the evolution into small time steps and decomposes each step into unitary gates. While this approach enables straightforward theoretical analysis, it typically leads to deep circuits that are difficult to implement, especially on near-term devices. We use out-of-distribution generalization in quantum machine learning (QML) to efficiently find shallow circuits that implement the dynamics much more accurately. This QML property allows us to use tensor network simulation methods for training data construction and circuit optimization. We demonstrate our approach on a variety of one-dimensional (1D) and quasi-1D quantum spin systems, shortening the circuit depth by a factor larger than 6 and reducing the error by several orders of magnitude.