

Random layers for quantum optimal control with exponential expressivity

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A long-standing problem in quantum optimal control is finding an optimal pulse structure that leads to an efficient exploration of the unitary space with a minimal number of optimization parameters. We solve this problem by constructing parametrized pulse sequences from random-amplitude pulses grouped in layers with one optimization parameter per layer. We show that, when increasing the number of pulses, the resulting random unitaries converge exponentially fast to the uniform Haar-random ensemble, thus providing for an efficient exploration of the unitary space. Grouping the pulses into layers allows for lowering the total number of optimization parameters. We focus on two random-layer (RALLY) methods: In RALLY_T, time durations of the layers are optimized while the pulse amplitudes are randomly chosen beforehand, possibly even from a few discrete values. RALLY_A optimizes a joint scaling factor of the random pulse amplitudes in each layer. We numerically validate the two methods by applying them to problems of unitary synthesis, ground-state preparation and state transfer in different quantum systems. For all problems considered, both methods approach an information-theoretic lower bound on the number of optimization parameters and outperform other commonly used algorithms. In gradient-free optimization, the RALLY methods are orders of magnitude more accurate with fewer figure-of-merit evaluations. The RALLY methods are promising for advancing quantum machine learning and variational quantum algorithms.