Improving virtual distillation with stochastic transpilation

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Abstract

Error mitigation is a vital part of quantum computing for near intermediate noisy quantum (NISQ) devices by improving their performance. While many proposals, such as zero noise interpolation or probabilistic error cancellation, concentrate on compensating coherent errors, we will focus on mitigating incoherent errors using purification techniques based on virtual distillation. Virtual distillation aims to reduce the noise's effect by creating copies of the target state and should reduce it exponentially fast in the number of copies. However, virtual distillation suffers from high demand in connectivity and is therefore not the best suited for certain architecture, such as the one developed by IBM. Therefore, we will emulate the two copy preparation with a single register by inverting the evolution and postselection Moreover, state tomography on the ancilla can be performed to further enhance the results. This work emphasizes adding extra error mitigation layers to this framework and quantifying the change in performance. For instance, twirling and dynamical decoupling are transpilation techniques that transform coherent errors into incoherent ones that can be handled more efficiently by virtual distillation. We aim to benchmark different twirling and dynamical decoupling sequences for computing the time evolution of an Heisenberg chain.

To be more practical, we choose to simulate the time evolution of the magnetisation on the first site of a Heisenberg spin chain of size 10, with uniform strength between the different axis and closed boundary condition

$$H = J \sum_{j=1}^{9} X_j X_{j+1} + Y_j Y_{j+1} + Z_j Z_{j+1}, \tag{1}$$

where $J = \tan 1/2$ and X, Y, Z the corresponding Pauli matrices. We perform a benchmarking experiment on the superconducting ibmq_mumbai chip, using 100k shots, across different dynamical decoupling sequences. We observe that dynamical decoupling does not have a particular effect on the raw circuits, however, the XY8 sequences does improve in the virtual distillation cases. Twirling also seems to improve the situation, as shown by the purity of the ancilla. Using all of those techniques combined, we can perform five Trotter steps near maximal fidelity.

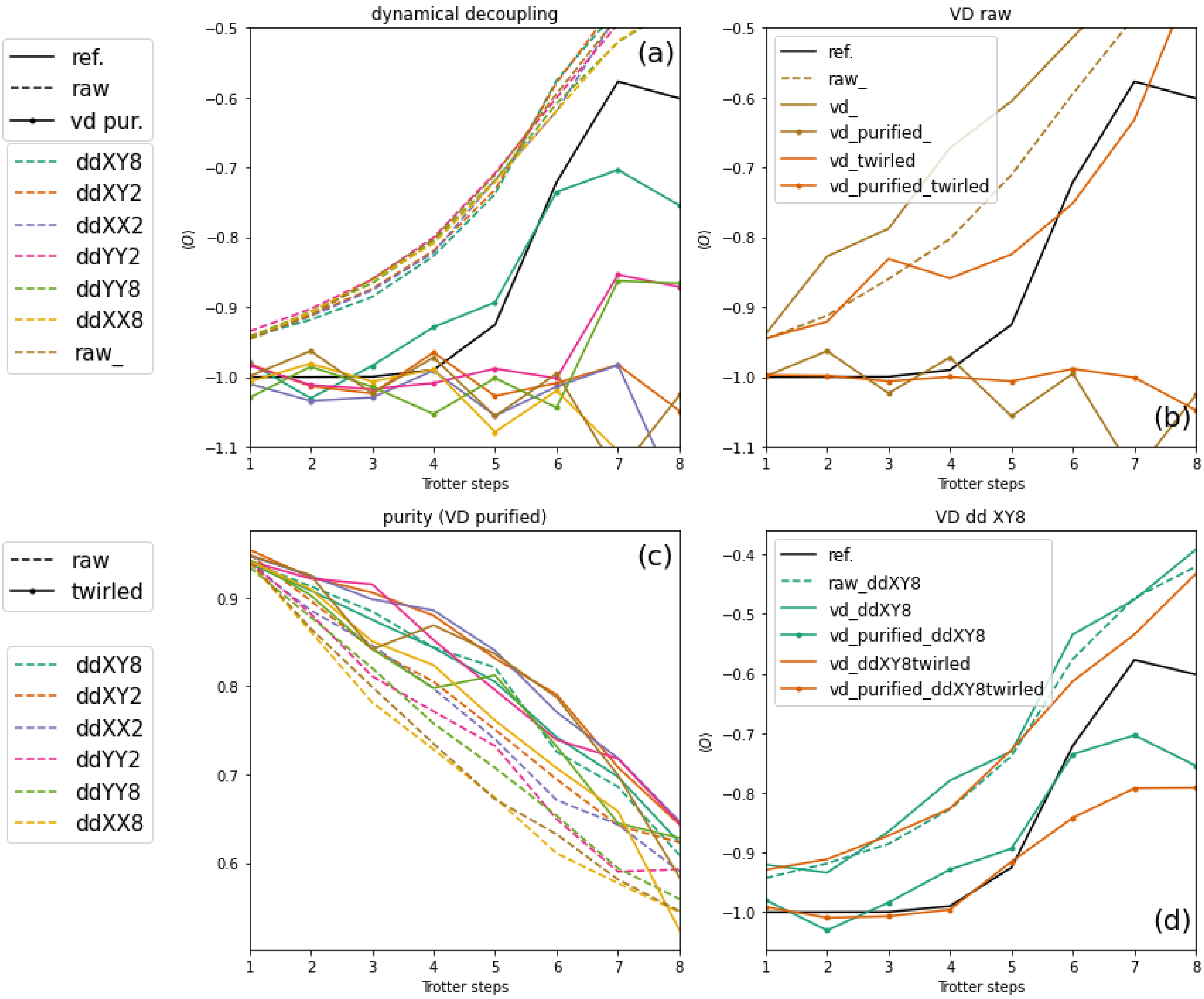

Figure 1: [a] Effect of dynamical decoupling (sequences are denoted by the colors) on the raw circuit (dashed) and virtual distillation with ancilla purification (dotted line). [b] Effect of twirling (10 samples) and purification on the raw virtual distillation. [c] Effect of twirling (line) and dynamical decoupling (colors) on the purity of the ancilla in the virtual distillation scheme. [d] Effect of virtual distillation, twirling and purification with the best dynamical decoupling sequence.