

# Nonadiabatic Self-Healing of Trotter Errors in Digitized Counterdiabatic Dynamics

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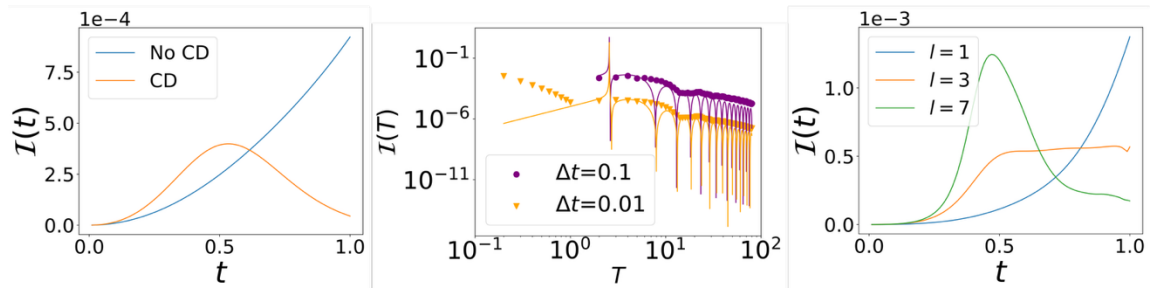
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**Abstract:** Trotter errors in digital quantum dynamics can exhibit a self-healing behavior. Using counterdiabatic driving, we isolate discretization effects and derive finite-time error bounds, regardless of the evolution duration.

Trotter errors in digitized quantum dynamics (defined by  $I(t)$ , where  $t$  is the time) arise from approximating time-ordered evolution under noncommuting Hamiltonian terms with a product formula. In the adiabatic regime, such errors are known to exhibit long-time self-healing [1], where discretization effects are effectively suppressed. Here we show that self-healing persists at finite evolution times once nonadiabatic errors induced by finite-speed ramps are compensated. Using counterdiabatic driving to cancel diabatic transitions and isolate discretization effects, we study both noninteracting and interacting spin models and characterize the finite-time scaling with the Trotter steps and the total evolution time. In the instantaneous eigenbasis of the driven Hamiltonian, the leading digital error maps to an effective harmonic perturbation whose dominant Fourier component yields an analytic upper bound on the finite-time Trotter error and reveals the phase-cancellation mechanism underlying self-healing. Our results establish finite-time self-healing as a generic feature of digitized counterdiabatic protocols, clarify its mechanism beyond the long-time adiabatic limit, and provide practical guidance for high-fidelity state preparation on gate-based quantum processors. We study these phenomena using both exact and approximate counterdiabatic driving. For the exact case, the role of the correction is clear; when using approximations [3], its nature progressively emerges as the protocol approaches the exact counterdiabatic form. This abstract is based on the work presented in Ref. [2]



**Fig. 1** On the left: the error  $I(t)$  vs during the dynamics  $t$  for a non-interacting model. Final time of evolution is  $T=1$ . The blue curve shows nonadiabatic dynamics (without counterdiabatic driving), while the orange curve corresponds to adiabatic dynamics (with counterdiabatic driving). The decrease of the orange curve illustrates the *self-healing* of the error. On the center: the error  $I(T)$  vs final time of evolution  $T$  for an interacting model evolved with the exact counterdiabatic driving. Different colors correspond to different Trotterization steps. Points represent computational data and continuous curves the analytical ansatz found in the paper. We see how the predicted ansatz match with the computational data. On the right: the error  $I(t)$  vs during the dynamics  $t$  for an interacting model evolved with the approximated counterdiabatic driving. The Trotterization steps is fixed and final time of evolution is  $T=1$ . and different curves correspond to the different orders of the approximation of the counterdiabatic potential: blue curve for order  $l=1$ , orange curve for order  $l=3$  and green curve for order  $l=7$ . We see that as the order increases (i.e. the approximate counterdiabatic driving gets to close to the real one), the error decreases, starting to have a self-healing behavior.

## Example References

- [1] Kovalsky, L. K., Calderon-Vargas, F. A., Grace, M. D., Magann, A. B., Larsen, J. B., Baczewski, A. D., & Sarovar, M. (2023). Self-healing of trotter error in digital adiabatic state preparation. *Physical Review Letters*, 131(6), 060602.
- [2] Vizzuso, M., Passarelli, G., Cantele, G., Lucignano, P., Chen, X., & Paul, K. (2025). Nonadiabatic Self-Healing of Trotter Errors in Digitized Counterdiabatic Dynamics. *arXiv preprint arXiv:2512.22636*.
- [3] Passarelli, G., Cataudella, V., Fazio, R., & Lucignano, P. (2020). Counterdiabatic driving in the quantum annealing of the p-spin model: A variational approach. *Physical Review Research*, 2(1), 013283.