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Krylov spaces and algebras for efficient simulation of quantum dynamics

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When we aim to accurately simulate the behaviour of complex dynamical
systems, the problem of finding simpler representations for the model of interest becomes critical. We focus on completely-positive (CP) dynamics, which can be used to describe a wide variety of physically-relevant systems for quantum and classical information, including quantum walks and open quantum systems. For these models, a reduction approach based on Krylov subspaces is derived, by leveraging information on initial conditions and observables of interests. The reduced models obtained by the procedure are provably the smallest linear models that exactly reproduce the target evolution. These can be extended in order to retain a physically admissible evolution, if desired. In doing this, we highlight the minimal memory resources needed to perfectly simulate a given process and thus probe its "quantum-ness". The algebraic tools developed in the process can be used in a variety of settings, including model reduction of quantum trajectories and also approximate model reduction, e.g. by restricting the dynamics onto the slowest evolving modes.

Relevant publications:
[1] Exact Model Reduction for Continuous-Time Open Quantum Dynamics Tommaso Grigoletto, Yukuan Tao, Francesco Ticozzi, Lorenza Viola, Quantum 9, 1814 (2025) [online][arxiv]
[2] Model Reduction for Quantum Systems: Discrete-time Quantum Walks and Open Markov Dynamics, Tommaso Grigoletto, Francesco Ticozzi, IEEE Transactions on Information Theory,2025 [online][arxiv]

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