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Time-Convolutionless Master Equation Applied to Adiabatic Elimination

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In Open Quantum Systems (OQS) theory, where the effective dynamics of a subsystem are described by tracing out environmental degrees of freedom, model reduction techniques become crucial for both conceptual understanding and practical efficiency. In this work, we study the connection between two model reduction methods for systems described by a Lindblad equation. The first is the Time Convolutionless (TCL) master equation, a standard tool in OQS theory used to compute the projected time-evolution. The second is the geometric formulation of Adiabatic Elimination (AE), based on the timescale separation of the dynamics of those quantum systems that exhibit a rapid relaxation to an invariant subspace, followed by a slower relaxation in it.

We provide a unified perspective on the two approaches, showing that the TCL master equation offers an alternative formulation to AE. We do so by introducing a conjecture and proving it up to third order of the timescale separation parameter in perturbative calculations. Additionally, we provide practical demonstrations of the TCL projective approach to AE.

Our findings have twofold implications: the geometric perspective of AE gives a novel understanding to the TCL master equations, while the latter provides robust solutions to challenges within AE computations.

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