Model Reduction for Nonlinear Dynamical Systems

Beckett Y. Zhou

Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

Abstract: In many applications in science and engineering, it is necessary to numerically solve systems of nonlinear partial differential equations (PDEs) to make predictions. In multi-query contexts such as uncertainty quantification and optimization, it is often a computationally intractable task due to the cost of each evaluation. Reduced-order models (ROMs) based on the proper orthogonal decomposition (POD) provide a means to alleviate this issue by projecting the large system of equations onto a reduced subspace. When used in conjunction with the discrete empirical interpolation method (DEIM), an approximation to the nonlinearities of the governing PDE, this approach permits the construction of reduced-order models whose computational cost is significantly lower than that of the original problem. In multi-physics problems where vastly different scales can potentially be present in the unknowns, the traditional DEIM approximation results in large error in the unknowns of smaller scales. In unsteady simulations, such error can quickly accumulate over time and significantly reduce the quality of the ROM solution. The interpolative nature of this approximation method also limits its accuracy in the cases where the nonlinear terms are noisy and non-smooth. In this research, we propose a modification to the existing formulation whereby unknowns with different scales are treated using separate DEIM approximations and the interpolation at sample points are also replaced by least squares regression. Results indicate that the reduced-order model thus constructed leads to substantial computational cost savings while maintaining desired accuracy.