

A modified ROM-based parareal method for solving the two-dimensional nonlinear shallow water equations

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In this work, we implement a reduced-order model-based parareal method for solving the two-dimensional nonlinear shallow water equations and we propose a modification of the method for further stability and convergence improvements.

The parareal method was firstly introduced in [1] as an approach for overcoming the trade-off between high-fidelity results and computational costs when performing numerical simulations. This method aims to reduce the computational time necessary to the numerical resolution of an accurate and expensive model, by using alongside a less accurate, but much cheaper coarser one, which allows to parallelize in time the fine simulation, in a predictor-corrector iterative fashion. The parareal method stands out for its simple, generic formulation and its successful application in many problems, mainly parabolic, diffusive ones. However, in the case of hyperbolic or advection-dominated problems, even the simplest ones as the one-dimensional advection equation, the method presents instabilities and slow convergence.

Adaptations allowing to surmount such challenges include the introduction of reduced-order models (ROMs) in the parareal algorithm. In the case of nonlinear hyperbolic problems, the ROMs are formulated using the POD-DEIM (proper orthogonal decomposition - discrete empirical interpolation method) procedure, applied to snapshots of the solutions computed along the parareal iterations [2].

However, the quality of the ROM, and thus the stability and convergence behaviour of the parareal method, depends strongly on how well representative of the fine model are the snapshots sets used as input for the ROM procedure. Misrepresentations may occur if the parareal solutions are not close enough to the fine ones along iterations, and also if there are not enough snapshots to represent the dynamics of the problem. In this work, we present a modification of the POD-DEIM parareal method consisting in the enrichment of the snapshots set with extra snapshots taken at intermediary time steps. This modification does not require any extra computational time for computing the additional snapshots.

Numerical tests consisting on the resolution of the two-dimensional nonlinear shallow water equations are presented, using the classical parareal method, the POD-DEIM-based one and our proposed modification. The objective is to compare the performance of these three variants of the parareal method in terms of computational cost and convergence towards the fine, referential solution. Our proposed method presents improved stability and speed of convergence.

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