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A matrix DEIM technique for model reduction of nonlinear parametrized problems in cardiac mechanics

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Abstract

When relying on Newton iterations to solve nonlinear problems in the context of Reduced Basis (RB) methods, the assembling of the RB arrays during the online stage depends on the dimension of the underlying high-fidelity approximation. This is more of an issue when dealing with fully nonlinear problems, for which the global Jacobian matrix has to be entirely reassembled at each Newton step. In this paper the Discrete Empirical Interpolation Method (DEIM) and its matrix version (MDEIM) are combined to evaluate both the residual vector and the Jacobian matrix very efficiently in the case of complex parametrized nonlinear mechanical problems. We compare this strategy with the classical DEIM approach and we derive a posteriori error estimates on the solution accounting for the contribution of DEIM/MDEIM errors. The effectiveness of the proposed framework is assessed on quasi-static nonlinear problems. In particular, we consider a nonlinear elasticity problem defined on a cube and a mechanical model describing heart contraction, for an idealized left ventricle geometry. The latter is a coupled problem, in which the activation of the heart contraction is given by the solution of an electrophysiology model. Our numerical results show that MDEIM is preferable to the classical DEIM, both in terms of efficiency and accuracy.

Keywords: reduced basis method; discrete empirical interpolation; nonlinear mechanics; cardiac mechanics; a posteriori error estimation

1. Introduction

Reducing the computational time for the numerical solution of complex parametrized mechanical problems is crucial in many engineering applications, e.g. in biomechanics, where parameters may be related to initial and/or boundary conditions, physical coefficients or forcing terms. Being able to rapidly approximate the solution of such problems allows to investigate the parameter-to-solution map and, ultimately, the impact of significant parameters on the modeled system; this is e.g. required when dealing with sensitivity analysis, uncertainty quantification, and parameter estimation. Reduced order modeling (ROM) techniques are suitable to achieve this goal, as they provide accurate solutions at a greatly reduced computational cost. This is usually achieved by seeking the solution in a subspace of much smaller dimension N than the one, N_h, of the original finite dimensional space employed by a full order model (FOM). The ability of a ROM to provide

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