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HETEROGENEOUS MULTISCALE METHODS FOR ORBITAL DYNAMICS

Abstract

Multiscale problems pose several challenges to mathematical computations, typically either by the large number of degrees of freedom that they contain or their highly oscillatory components. Beside mathematical complications, the main difficulty in applications lies in the frequent need of long-time simulations (prototypical examples and illustrations may be found in molecular dynamics, celestial or spatial mechanics). In order to integrate the equations of motion the solver has to resolve the fastest mode which is a tedious and expansive task.

The Heterogeneous Multiscale Methods (HMM) is a general framework to deal with dynamical models (deterministic or stochastic) containing different spatio, temporal or spatiotemporal scales (Weinan and Engquist, Comm. Math. Sci., 1, 1, 2003). The denomination reflects the use of diverse entities (e.g physical models or numerical methods) throughout the computational domain. The framework provides strategies and approaches to gain computational efficiency during the numerical simulation of the physical system of interest. The numerical savings relie on the very components of any HMM scheme: an effective coupling between a microscopic and a macroscopic solver. The fine and resolved microscopic solver solves the finest scale but only in small parts of the computational domain. The solution and datas are then supplied, on the fly, to a coarser (macroscopic) solver. The swap between the micro and macro solver is repeated as needed throughout the computational domain (Engquist and Tsai, Mathematics of Computation, 74, 252, 1707–1742, 2005; Abdulle et al., Acta Numerica, 21, 1-87, 2012).

The aim of the present work is to present and discuss the HMM in the context of the deterministic equations of motion of artificial satellites and space debris. Even if several techniques have been proven to be fruitful in approaching the problem (classical averaging approaches in semi-analytical satellites theories, symplectic or regularised schemes), we believe that the generality of the HMM framework would be appreciable for Space Situational Awareness (SSA) efforts. Indeed, the HMM framework seems to open the possibility of a monolithic and efficient numerical integrator, suited for short terms and very accurate purposes (e.g for orbit determination problems), medium term (e.g conjunction assessment screening) or even for long-term studies where typical integration length exceeds centuries (chaos detection). This monolithic model is made possible by the existence of a parameter that can control the call of the two micro/macro solvers and their respective mesh spacing. When the mesh spacing is collapsed to zero, the full numerical solution is recovered.