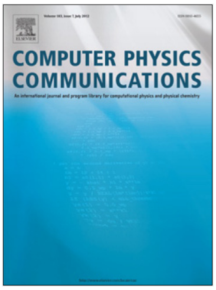

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Iterative load-balancing method with multigrid level relaxation for particle simulation with short-range interactions

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Abstract

We developed dynamic load-balancing algorithms for Particle Simulation Methods (PSM) involving short-range interactions, such as Smoothed Particle Hydrodynamics (SPH), Moving Particle Semi-implicit method (MPS), and Discrete Element method (DEM). These are needed to handle billions of particles modeled in large distributed-memory computer systems. Our method utilizes flexible orthogonal domain decomposition, allowing the sub-domain boundaries in the column to be different for each row. The imbalances in the execution time between parallel logical processes are treated as a nonlinear residual. Load-balancing is achieved by minimizing the residual within the framework of an iterative nonlinear solver, combined with a multigrid technique in the local smoother. Our iterative method is suitable for adjusting the sub-domain frequently by monitoring the performance of each computational process because it is computationally cheaper in terms of communication and memory costs than non-iterative methods. Numerical tests demonstrated the ability of our approach to handle workload imbalances arising from a non-uniform particle distribution, differences in particle types, or heterogeneous computer architecture which was difficult with previously proposed methods. We analyzed the parallel efficiency and scalability of our method using Earth simulator and K-computer supercomputer systems.

Keywords: SPH, DEM, Dynamics load-balancing, Hybrid parallelization

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1. Introduction

Particle Simulation Methods (PSM) involving short-range interactions, such as Smoothed Particle Hydrodynamics (SPH), Moving Particle Semi-implicit (MPS) method, and Discrete Element method (DEM), have been widely used to solve continuum mechanics and granular dynamics [1, 2, 3]. These mesh-free methods are suitable for problems with complex geometry and boundaries. Their Lagrangian nature allows non-diffusive advection, which is useful for tracking history-dependent properties such as rheological, chemical, and thermal evolution. These potential advantages over mesh-based methods offer effective numerical approaches to geodynamical flow systems and engineering processes, for example, the interaction of tsunami run-up with structures

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