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Large-scale Particle Simulations for Debris Flows using Dynamic Load Balance on a GPU-rich Supercomputer

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Numerical simulations for debris flows including a countless of objects is one of important topics in fluid dynamics and many engineering applications. Particle-based method is a promising approach to carry out the simulations for flows interacting with objects.
In this paper, we propose an efficient method to realize a large-scale simulation for fluid-structure interaction by combining SPH (Smoothed Particle Hydrodynamics) method for fluid with DEM (Discrete Element Method) for objects on a multi-GPU system. By applying space filling curves to decomposition of the computational domain, we are able to contain the same number of particles in each decomposed domain. In our implementation, several techniques for particle counting and data movement have been introduced. Fragmentation of the memory used for particles happens during the time-integration and the frequency of de-fragmentation is examined by taking account for computational load balance and the communication cost between CPU and GPU. A link-list technique of the particle interaction is introduced to save the memory drastically. It is found that the sorting of particle data for the neighboring particle list using linked-list method improves the memory access greatly with a certain interval. The weak and strong scalabilities for a SPH simulation using 111 Million particles was measured from 4 GPUs to 512 GPUs for three types of space filling curves.
A large-scale debris flow simulation of tsunami with 10,368 floating rubbles using 117 Million particles were successfully carried out with 256 GPUs on the TSUBAME 2.5 supercomputer at Tokyo Institute of Technology.