Massively parallel computing of electromagnetic particle-in-cell model using adaptive mesh and adaptive block: Part II

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Most of dynamical phenomena arising in space plasmas consist of a number of localized processes which involve a variety of physical scales that may be coupled with each other and can have an impact on the global behavior of the phenomena. For instance, magnetic reconnection is highly localized process which facilitates the fast conversion of energy stored in a compressed magnetic field into plasma kinetic energy and is believed to play a key role in magnetospheric substorms and solar flares. In the previous study (Fujimoto and Sydora, Comput. Phys. Commun., 178, p.915, 2008), we have constructed a 3D electromagnetic particle-in-cell (PIC) model with adaptive mesh refinement (AMR). The code has successfully achieved the high-resolution simulations on nonlinear evolution of a current sheet. However, the previous model is parallelized only in a single computational node with shared memory (using OpenMP), so that the total computational resources which can be used for simulations are rigidly restricted within the single computer performance. The present study has extended the previous code to more flexible one which allows us to use a number of computers for a single simulation using the Message Passing Interface (MPI). The new code has successfully realized the highly scalable cluster-type computing of the 3D AMR-PIC model and enables more large-scale simulations of 3D magnetic reconnection.

There are mainly two difficulties to obtain the good scalability in massively parallel computing of the AMR-PIC model. First of them is to establish the difference scheme which consists only of local operations and is compatible with the AMR. The previous model involves Poisson-type equations that require the global operations. However, the model was compatible with the AMR, because it inherently provided weak damping for short-wavelength mode and suppressed the wave reflection at the boundary of the refinement region. In the present study, we employ another scheme on the staggering grid (Morse and Nielson, Phys. Fluids, 14, p.830, 1971) in combination with the charge conservation method. Although this scheme is based on the local operations alone, it gives no damping for all the range of wavelength. Thus the direct use of this scheme results in significant wave reflection at the boundary. We have overcome this difficulty by introducing a smoothing which causes wave damping for short-wavelength mode without violating the local divergence of the electric and magnetic fields.

Second difficulty is to keep the load balance of the computational cost among the processors. In the PIC simulations, this problem is almost equivalent to keeping the number of super particles per decomposition domain ("block") even. In order to adjust the number of particles per block, the present model changes the structure of the blocks dynamically, in accordance with the evolution of the system, so that each block has always the same number of particles as that in other blocks.

In Part II of a series of presentations, we will describe the detailed algorithm which enables the dynamical change of the block structure and keeps the load balance efficiently.