§40. Development of a Portable AMR Module Applicable to Fluid/particle Simulation Codes

Miura, H., Nunami, M., Usui, H. (Kobe Univ.),
Moritaka, T. (Kobe Univ.), Matsui, T. (Kobe Univ.),
Goto, R. (Grad. Univ. Advanced Studies)

Enabling a high-resolution simulation is a prerequisite subject to study complex and dynamic behaviors of hot plasma and understand detailed physics of small-scale events such as saturations of short-wave instabilities, micro-turbulence and magnetic reconnections. It is also necessary to construct a macro-scale model to predict long-time behaviors of the plasma because small-scale events often affect the long-time behaviors through changing local pressure gradients and/or magnetic configurations. Such a requirement is considered to become much more salient if we are going to carry out self-consistent simulations of fusion plasmas over multiple length and time scales simulations.

For the purpose of carrying out numerical simulations with a high resolution efficiently, we develop an adaptive mesh refinement (AMR) module which is easily transplanted to various numerical codes, especially for the Numerical Simulation Research Project (NSRP) of NIFS. It is aimed to enable resolving the ion skin depth, the ion Larmor radius and some other scales locally in a fluid/particle simulation code by introducing the AMR module while macroscopic behaviors are also simulated simultaneously. (See Fig.1 for a concept image of the AMR in a torus simulation.) As the first year of this subject, we have decided a basic specification of the AMR module. The module is based on the block-based domain decomposition approach and the self-similar refinement. The module is also designed so that it is applicable to a particle simulation code by changing the block-size. The computational domains generated as a consequence of the refinement are distributed on the computational nodes according to the Morton method[1], being connected to each other by the use of the Fully-Threaded Tree (FTT) structure.

As the first step, we developed the FTT data samples and the Morton load balancing part of the module. In Fig.2, results of the numerical check of the local refinement by the use of these parts are shown. We have solved the one-dimensional advection equation

$$\frac{\partial u}{\partial t}+c\frac{\partial u}{\partial x}=0\,. \qquad (1)$$

In the left two panels, the equation is solved by the use of the first-order Upwind Difference Scheme (UDS). In the right panels, the equations are solved by the Lax-Wendroff scheme. In the upper two panels, the wave forms solved by the UDS (left) and the Lax-Wendroff (right) schemes with the local refinement are shown. The lower two panes are numerical results without local refinements. The results show that the simulations with local refinements resolve wave forms more sharply than the simulations without the refinement, whether the numerical scheme is UDS or Lax-Wendroff. We have also checked the computational costs of the simulations and verified that the computational cost should become smaller by the AMR approach when a finer numerical resolution is required. These results are presented at the ITC-21 conference [2].

Based on these results, we are going to develop data-packing/unpacking parts of the module so that the AMR approach can be transplanted to many simulation codes which have been used for various numerical studies of the NSRP and other plasma physics studies.

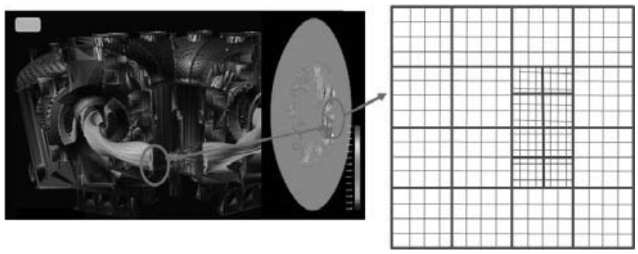

Fig.1. Concept image of the adaptive mesh refinement in a torus simulation. The mesh is refined when the numerical resolution should be improved because of growth of ballooning modes, for example.

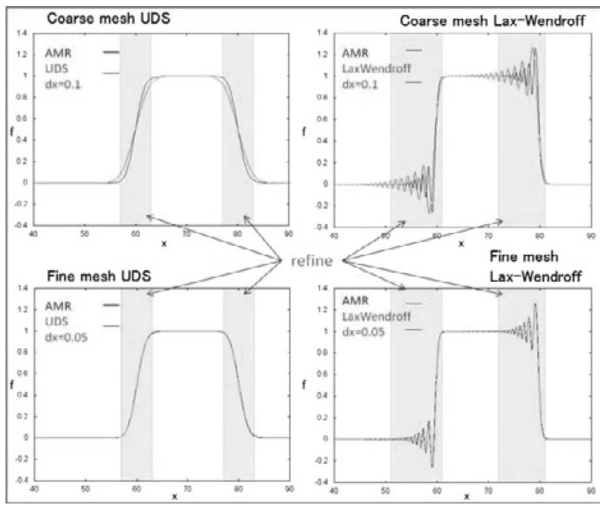

Fig.2 Numerical check of the local refinement by the use of the module.

1) Warren, M.S. and Salmon, J.K.: Proc. Supercomputing, IEEE, **12** (1993) 21.
2) Miura et al.: 21st International Toki Conference (Nov.28-Dec.1 2011, Toki, Japan).