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High-Performance Computing in Radiative Hydrodynamics Simulation

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ABSTRACT

Modern problems in pulsed-power energetics issue a real challenge to the computer simulation theory and practice. High-performance computing is a promising technology for modeling complex multiscale nonlinear processes such as transient flows of strongly radiative multicharged plasmas. An essential part of such numerical investigation is devoted to the computer simulation of pinches resulted from electric explosion of cold matter, such as gas-puff jets, foam strings, or metallic wire arrays. The goal of numerical research in pulsed-power is to study the evolution of very intensive transient electric discharges and to perform a multiparametric optimization of future experimental schemes. These problems are known to be computationally very hard, so using high-performance computing is of great demand in the field. In this work the use of different approaches in parallel computing is considered in relation to radiative hydrodynamics simulation problems.

Among the most common parallel techniques for gasdynamics, hydrodynamics, and MHD in particular, numerical modeling on spatial meshes is the traditional geometric domain decomposition. At this, certain specificity of introducing parallelism into a complete program complex in our case relates to the object-oriented nature of MARPLE code, developed in IMM RAS and designed for numerical radiative magnetohydrodynamics simulation, which essentially employs C++ language facilities, such as polymorphism, encapsulation, inheritance, and parametric programming. Special data structures based on the concept of topological complex have been elaborated to provide problem statement in an arbitrary domain, and for handling unstructured meshes, including dynamic mesh changes. Some of these structures have to be adapted to allow for parallel computations and data exchanges, taking into account the requirement of keeping interprocessor communication adequately small.

Another basic approach is dividing a problem into sub-problems with different sets of governing parameters. Highly accurate simulation of radiative energy transfer, including detailed reproducing of the radiation spectrum, is among the most important requirements to the developed code. Thereto, the entire spectrum is divided into a number of frequency ranges (from several tens to several hundreds), and it is necessary to reconstruct the radiation field with respect to its angular distribution for each frequency range, that makes the radiation transport computation one of the most laborious steps in radiative hydrodynamics simulations. The frequency ranges model requires repeating large volumes of uniform computation with different sets of opacity and emissivity values for each range. So we decided to carry

out these computations concurrently on several processors, and then to collect the results by simple summation, using the fact that all wavebands produce a uniform and independent contribution to the total radiative energy fluxes.

Finally, we consider the other level of problem splitting corresponding to different physical processes taken into account by modeling. Thus we expect to also make use of setting different dedicated groups of processors for different processes computations, which might utilize different methods, numerical schemes, parallelizing techniques, and sequences of iterations. Actually a kind of physical splitting is already performed in sequential codes when equations corresponding to different processes are calculated in turn inside an iteration or a time step. We think of extending this concept to doing these computations in parallel as well.

Parallel computing technology applied to the radiative energy transfer calculation helped us to reduce the total processing time by factor of 2-4 on moderate budget clusters with 10-20 processors, and with yet non-complete parallelization. This is already a significant achievement, since for the experiment scheme optimization a big series of similar numerical simulations is actually needed. The concurrent practical advantage is that the number of ranges in a spectrum can be greatly increased, that gives immediate effect on the accuracy and quality of numerical solutions.

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