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Boris-type particle solvers in particle-in-cell (PIC) simulation

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Particle-in-cell (PIC) simulation has long been used in theoretical plasma physics. In PIC simulation, the Boris solver is a de facto standard to advance charged particles, and it has been used for nearly 50 years. Meanwhile, there is a growing demand for better particle solvers, because scientists are carrying out longer simulations than ever, and because small errors will be accumulated in such long-time simulations.

In this contribution, we will introduce two particle solvers to advance charged particles in PIC simulation. First, we propose a particle solver that takes advantage of two exact solutions for the Coulomb-force part and for the Lorentz-force part [1]. It provides a second-order accuracy, and it gives much more accurate results than a popular form of the Boris solver. Second, we propose a family of approximate Boris-type solvers [2]. They virtually repeat the popular form of Boris solver multiple times (n times), and their one-step forms are provided by using Chebyshev polynomials.

We compare accuracy and computation time of Boris-type solvers, including our new solvers, by means of test-particle simulations. For example, Figure 1 presents numerical errors by various solvers as a function of the timestep Δt. One can see that our exact-type (Zenitani=Umeda) solver is as good as the Boris solver with gyrophase correction. We also evaluate particle solvers in a magnetized flow at a relativistic speed [3].

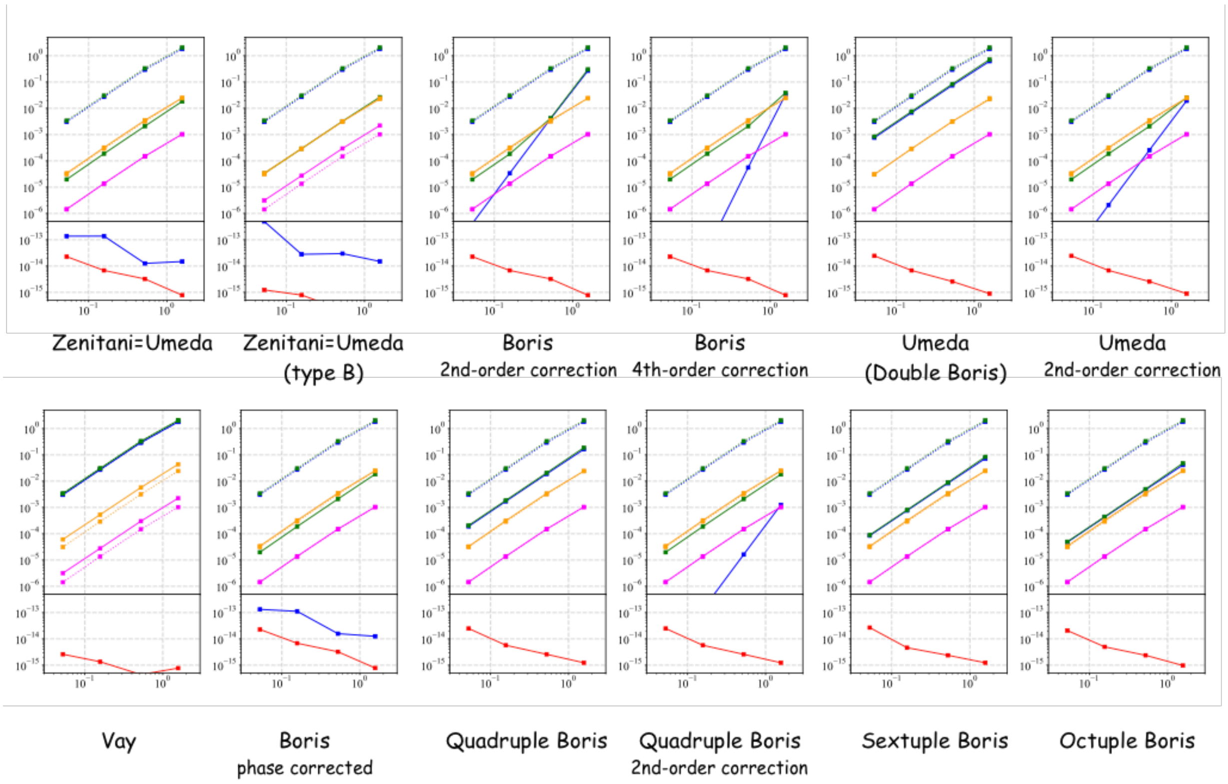

Figure 1. Numerical errors in test-particle simulations by various particle solvers. The vertical axis shows normalized numerical errors, the horizontal axis shows the timestep Δt, and the color indicates field configurations in the same format as in Figure 2 in Ref. [1]. The solid lines indicate the results by each solver, while the dotted lines indicate the results by the popular form of the Boris solver.

References

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3. S. Zenitani & T. N. Kato, *Numerical methods for charged particles in relativistic particle-in-cell simulation*, Sustainable Humanosphere **14**, 62, http://hdl.handle.net/2433/235378 (2018) (in Japanese language)