CPIC: a curvilinear Particle-In-Cell code for plasma-material interaction studies

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Plasmas are very often characterized by a wide range of spatial and temporal scales. A typical example can be found in magnetic fusion plasmas, where up to 8 orders of magnitude separation in spatial scales and up to 14 orders of magnitude separation in temporal scales are common. Wide ranges of physical scales also occur in inertial confinement fusion. It follows that, in order to achieve predictive simulation capabilities for these plasmas, sophisticated tools need to be developed to bridge the gap between these disparate scales.

In this context, Particle-In-Cell (PIC) methods are a very popular tool for kinetic simulations of plasmas [1]. The algorithm relies on the interplay between computational particles (each representing a large number of physical particles) and a computational grid where the field equations are solved. The overwhelming majority of existing PIC codes uses uniform, Cartesian grids and explicit time-integration techniques. Since explicit PIC codes must resolve (for stability reasons) the smallest length scale and the fastest time scale in the system, it follows that the application of these codes to some multiscale plasma physics problem can be extremely difficult or even impossible with present computing resources. An example relevant to laboratory and space plasmas can be the interaction of very small (relative to the plasma Debye length) objects with a magnetized plasma.

In order to overcome some of these issues, we present a recently developed PIC code in curvilinear geometry, CPIC (Curvilinear PIC) [2], where the standard PIC algorithm is coupled with a grid generation/adaptation strategy. Through the grid generation strategy (based on Winslow's method [3]), the code can simulate domains of arbitrary complexity, including the interaction of complex objects (with the simulation domain conforming exactly to the objects without any stair-stepping) with a plasma. At present the time-integration is explicit and the code is two-dimensional and electrostatic (only Poisson's equation is solved). It features a hybrid particle mover, where the computational particles are characterized by position in logical space and velocity in physical space. Poisson's equation is solved with preconditioned GMRES. We will present the application of the code to standard test problems such as plasma waves, two-stream instabilities, Landau damping and the charging of a spherical object in a plasma. We will also discuss techniques that can be used to reduce PIC noise, which can be critical when the ratio of the largest to the smallest cell volume becomes large.

[1] Birdsall, C.K., Langdon, A.B., "Plasma Physics Via Computer Simulation." London, New York: Taylor & Francis Group, 2005; Hockney R.W., Eastwood, J.W., "Computer Simulation Using Particles." Bristol, Philadelphia: IOP Publishing, 1994.
[2] Delzanno, G.L, Camporeale, E., "CPIC: a new Particle-in-Cell code for plasma-material interaction studies", *in preparation* (2011).
[3] Winslow, A., "Adaptive mesh zoning by the equipotential method." UCIS-19062, Lawrence Livermore National Laboratory, 1981.