A New Look at the Finite Element Particle-in-Cell Method

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Particle-in-cell methods are an important tool developed for exploring plasma-related phenomena. The most common method utilizes the finite-difference time-domain (FDTD) method to calculate the electric and magnetic fields necessary to push the particles. However, as with codes based on Cartesian stencils, several problems exist. As a result, there has been in a move to develop methods that better represented the geometry, can include higher order representations, and are more adaptable. This has resulted in investigation into unstructured grids using finite element and discontinuous Galerkin methods.

While there have been several attempts to use finite elements to develop PIC codes, some of the most recent may be the most fully developed (H. Moon, F. L. Teixeira, and Y. A. Omelchenko. Computer Physics Communications 194, 2015), and (M.C. Pinto *et al.* Comptes Rendus Mecanique 342, no. 10-11, 2014). In contrast to earlier efforts, these use Maxwell solvers instead of the wave equation, use the proper representation space for charges and derive mappings that preserve charge continuity. They use leap-frog time stepping and have demonstrated effectiveness on a number of two dimensional problems. Likewise, an growing body of literature exists on using discontinuous Galerkin approaches (S. Yan and J. Jin. Journal of Computational Physics 334, 2017). Here, as opposed to developing methods to ensure charge conservation, divergence cleaning is more expedient. This ensures that while errors exist, they propagate at speeds that are higher and do not affect the solution in the domain of interest.

Our interest in this is to examine nuances of finite element based approaches both with regard to function spaces that are used as well as put these methods through systematic three-dimensional test cases that hopefully stress the system. Specifically, we are interested in (a) potentially different spaces that may be better suited to represent both currents and fields, (b) amelioration of cost due to small time step sizes, and (c) rigorous detailed examination of important features of this method, specifically noise characteristics and charge conservation in three dimensional settings. These topics will be discussed at the conference.