Case Study: On Performing Efficient Highly Parallel Three-Dimensional PIC based Simulations in Constantly Changing Computing Environments

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Particle-In-Cell, PIC, modeling techniques have been proven to be an effective mechanism to study a number of complex nonlinear plasma dynamics problems. PIC code is used to empirically track the influence of ions and electrons as they move under a self-consistent electromagnetic field. It requires that the field equations be solved at discrete points in space which reside along an imaginary grid point mesh while the particles (ions and electrons) reside at arbitrary points in the simulation domain. After the initialization period, the computation is cyclical with each iteration being composed of two basic phases. One phase is concerned with updating the field values at the grid points by employing an appropriate subset of Maxwell's Equations. This is performed after the grid point charges and current densities have been calculated by incorporating the electromagnetic effects of particles in adjacent cells using standard interpolation techniques. In the second phase, the new positions and velocities of the particles are calculated by applying forces which are obtained by interpolating the effects of the fields at the grid points which border the cell in which each particle resides.

A number of domain decomposition strategies exist to parallelize PIC (particle-mesh) applications for execution in Multiple Instruction Single Program, MISP, computing environments. These include variants of *spacial partitioning*, where each plasma particle is placed in an area of distributed memory based upon that particle's positional coordinates within the simulation space. In this configuration, each distributed memory module is assumed to have an affinity for a particular processor, and each processor is responsible for performing the particle computation for all particles which reside in its memory.

During the past seven years, we have been using highly parallel three-dimensional PIC code to study the effects of space weather and solar activity by simulating plasmas which occur in the Auroral region of the Earth's ionosphere. These simulations have been used to investigate the nonlinear evolution of lower hybrid waves. The spacial decomposition technique employed fully exploited the data parallelism that was present within these simulations and produced parallel representations which were then executed on a wide variety of parallel and distributed processing environments which include a traditional multicomputer (i.e. an nCube 2, hypercube), homogeneous and heterogeneous clusters of workstations, and highly parallel distributed shared memory super computers (i.e. a Cray T3D, an HP Exemplar, and a SGI Origin). The simulations utilized up to 256 processors. They were created by partitioning the rectanguliod region of plasma space, which was assumed to be periodic, along its elongated Z dimension while keeping the X and Y dimension completely contained within the local memory associated with each of the processors.

The focus of this paper will be to summarize the major findings from this research from a simulationist point of view as new variations of this simulation problem have been implemented on each of these machines. Such issues as the performance, scalability, portability and maintainability of the program code will be discussed. The paper will also describe possible obstacles to future highly parallel PIC simulation performance, fidelity and portability as these simulations continue to expand in scope and size and continue to be implemented on newer parallel platforms.