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Structure-Preserving Geometric Particle-in-Cell Algorithms

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Particle-in-Cell (PIC) methods are designed to simulate the evolution of particle-field systems, and they have been widely applied in confinement fusion, accelerator and astrophysical researches. In the PIC method, particles are evolved through the Newton's equation and fields are solved using the Maxwell's (or Poisson's) equation. Of course there are also variants of PIC methods such as the gyrokinetic PIC methods or spectrum PIC methods. With the increasing of computing power of large clusters, people can directly simulate larger and larger plasmas. However conventional PIC methods are based on discretizing differential equations directly, and therefore the truncation errors of invariants such as the total energy and total momentum are usually accumulating coherently with time and therefore the long term results are not reliable any more. To solve this serious problem, recently new generation of structure preserving PIC algorithms [1-6] are developed. Based on modern mathematical techniques such as discrete manifolds, interpolating forms, canonical and noncanonical symplectic algorithms, the structure preserving PIC algorithms have the ability to preserve the discrete local charge conservation law and the symplectic two-form associated with the original particle-field system. According to theoretical and numerical investigations, the structure preserving PIC schemes do not suffer from the self-heating problem and invariants such as the total energy can be preserved for all simulation time step. To reduce the porting workload to modern large non-homogeneous such as the CPU-GPU, CPU-MIC, Sunway Manycore clusters, we have also developed a parallel programming framework and use it to implement the relativistic and non-relativistic charge-conserving structure preserving PIC schemes. The goal of this report is to give an overview of the structure preserving algorithm, how to apply it to the particle-fields, and the recent development as well as applications of the structure preserving PIC methods on massive parallel clusters.

References

[1] J. Xiao, J. Liu, H. Qin, and Z. Yu, Physics of Plasmas 20, 102517 (2013).
[2] J. Squire, H. Qin, and W. M. Tang, Physics of Plasmas 19, 084501 (2012).
[3] J. Xiao, H. Qin, J. Liu, Y. He, R. Zhang, and Y. Sun, Physics of Plasmas 22, 112504 (2015).
[4] M. Kraus, K. Kormann, P. J. Morrison, and E. Sonnendrücker, Journal of Plasma Physics 83 (2017).
[5] H. Qin, J. Liu, J. Xiao, R. Zhang, Y. He, Y. Wang, Y. Sun, J. W. Burby, L. Ellison, and Y. Zhou, Nuclear Fusion 56, 014001 (2016).
[6] J. Xiao, H. Qin, and J. Liu, Plasma Science and Technology 20, 110501 (2018).