Parallelization issues of PIC in NIMROD

Charlson C. Kim
and the NIMROD Team

PSI Center
U. Washington

APS-DPP Dallas, Texas
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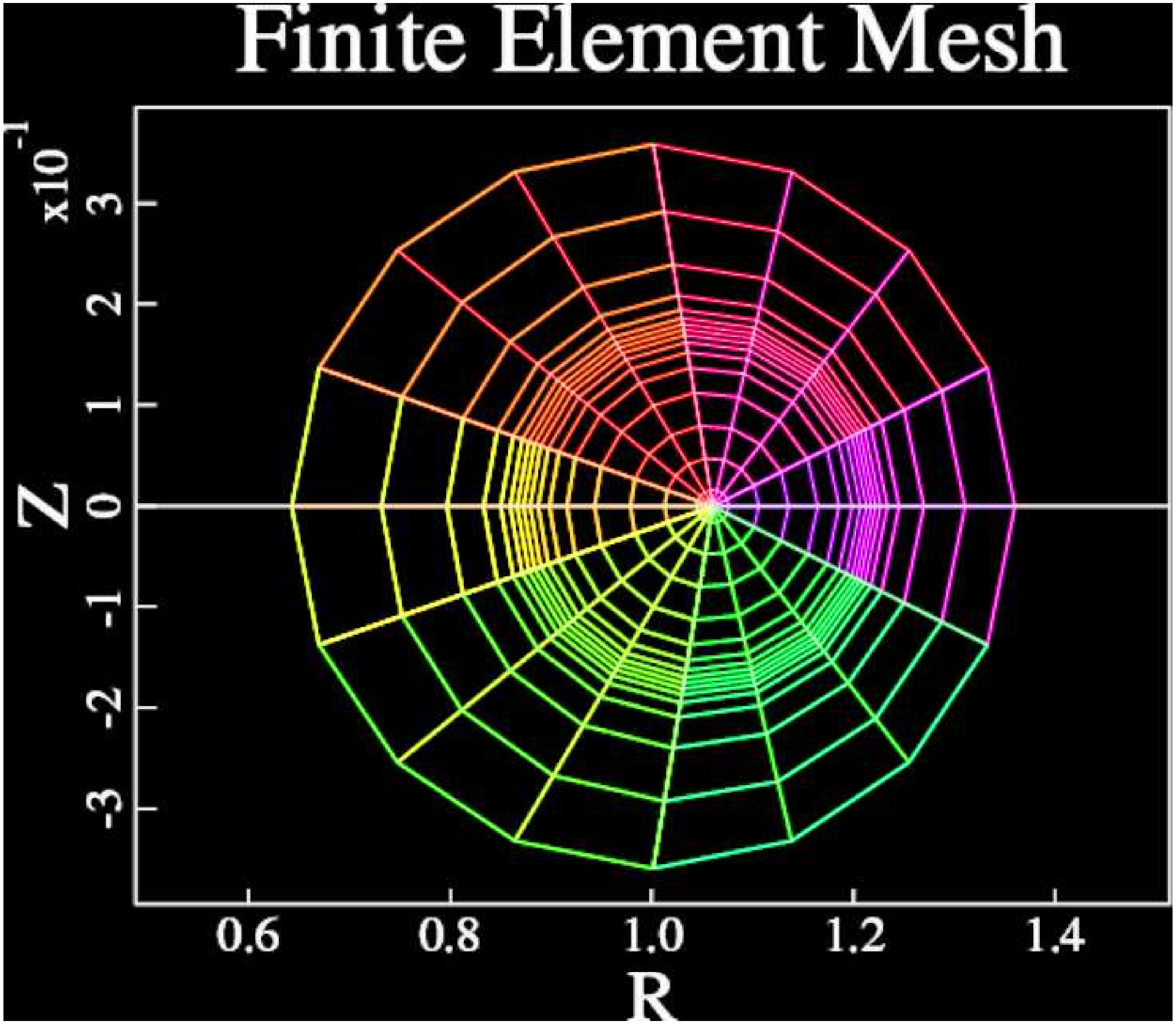
The δf PIC method [a] [b]

- PIC is a Lagrangian simulation of phase space $f(\mathbf{x}, \mathbf{v})$
- PIC uses 'particle' to represent 'clump' of phase space
- usually want uniform sized 'clump's
- in principle, $f(\mathbf{x}(\mathbf{t}), \mathbf{v}(\mathbf{t}))$ contains everything
- typically PIC is noisy, can't beat $1/\sqrt{N}$
- δf PIC reduces the discrete particle noise associated with conventional PIC
- always helps to have more particles

[a] S. E. Parker and W. W. Lee, 'A fully nonlinear characteristic method for gyro-kinetic simulation', *Physics of Fluids B*, **5**, 1993

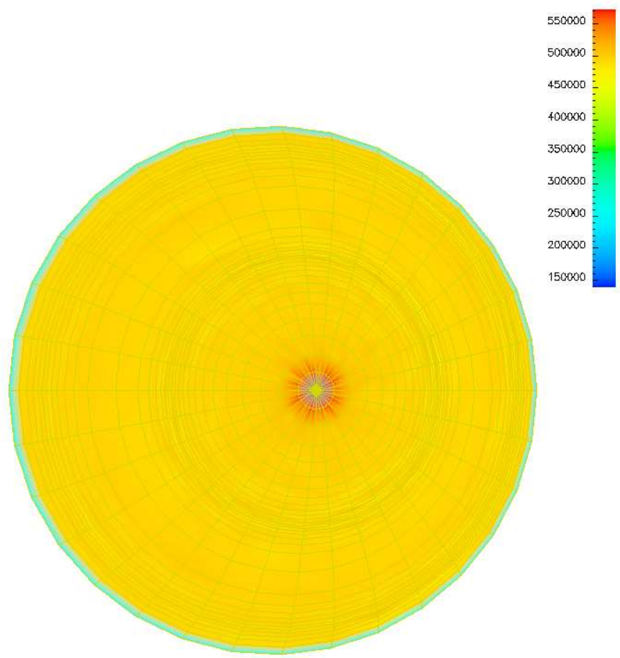
[b] G. Hu and J. A. Krommes, "Generalized weighting scheme for δf particle simulation method", *Physics of Plasmas*, **1**, 1994

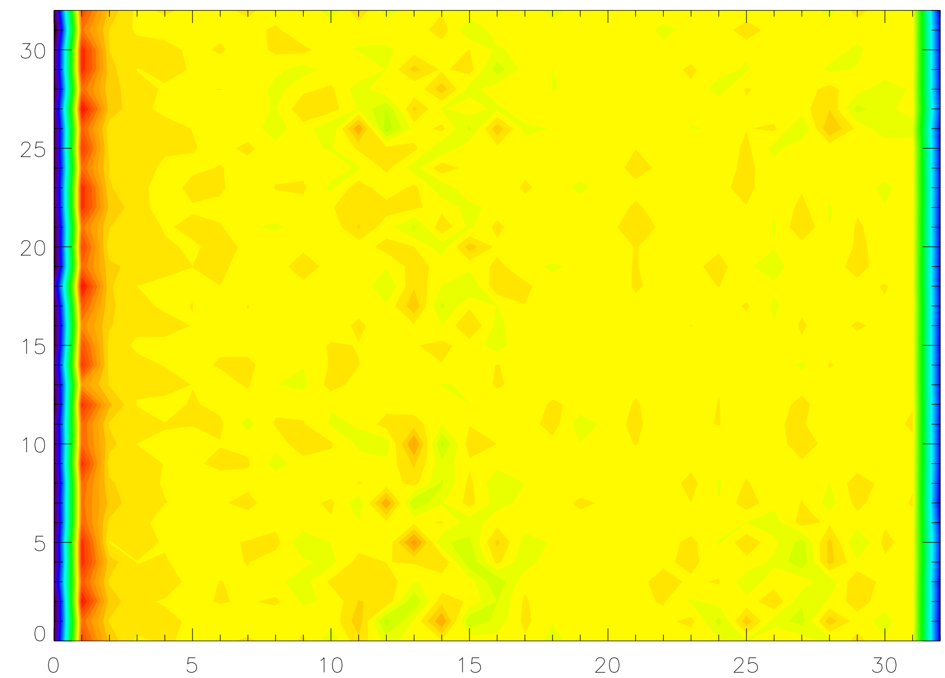
Example NIMROD Grid



PIC deposited uniform density

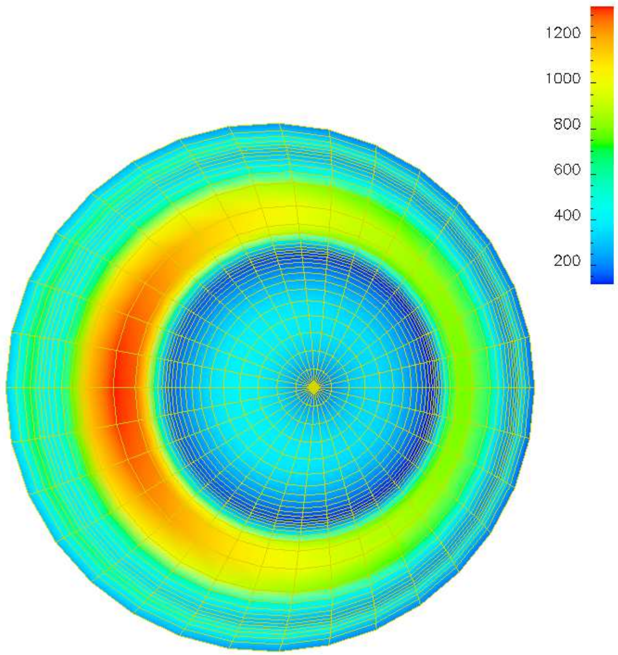
- ‘trivial’ uniform density loading

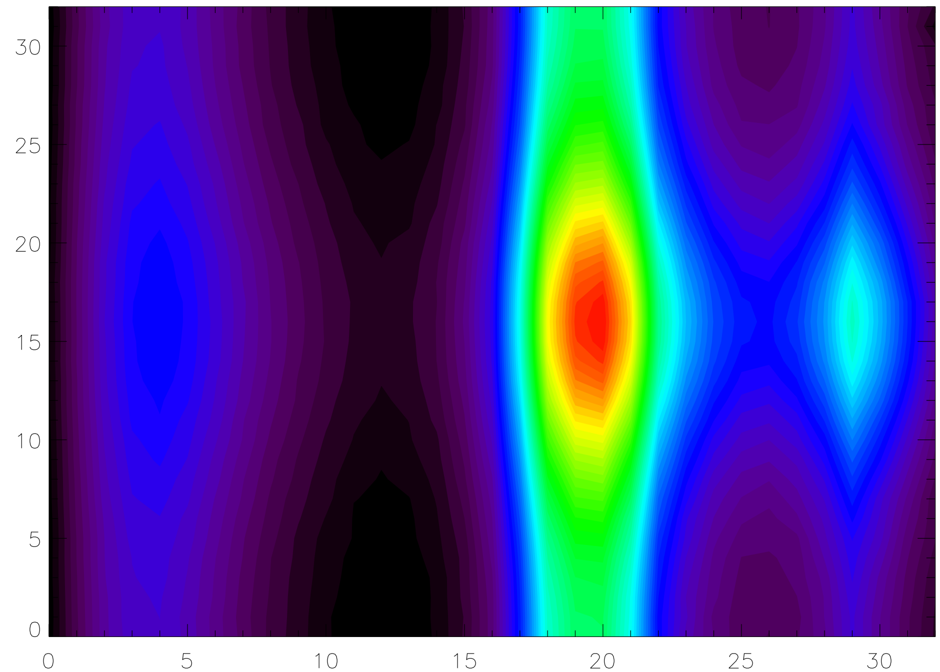




- axis suffers lack of statistics
- boundary suffers limit of statistical deposition

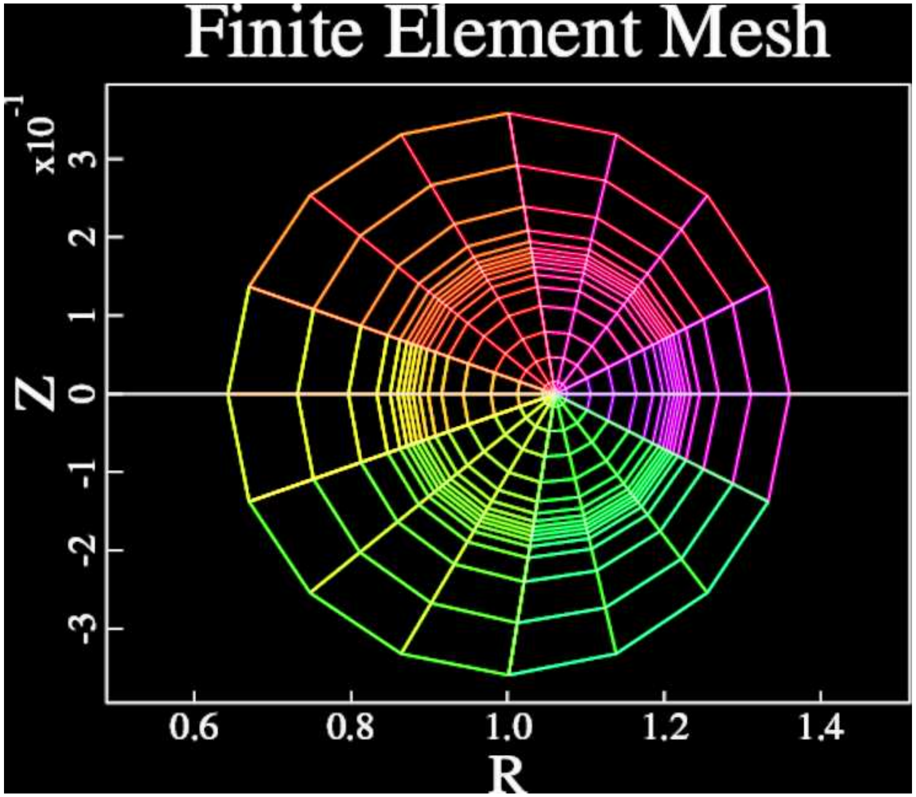
Competing Resolution Requirements of FEM and PIC

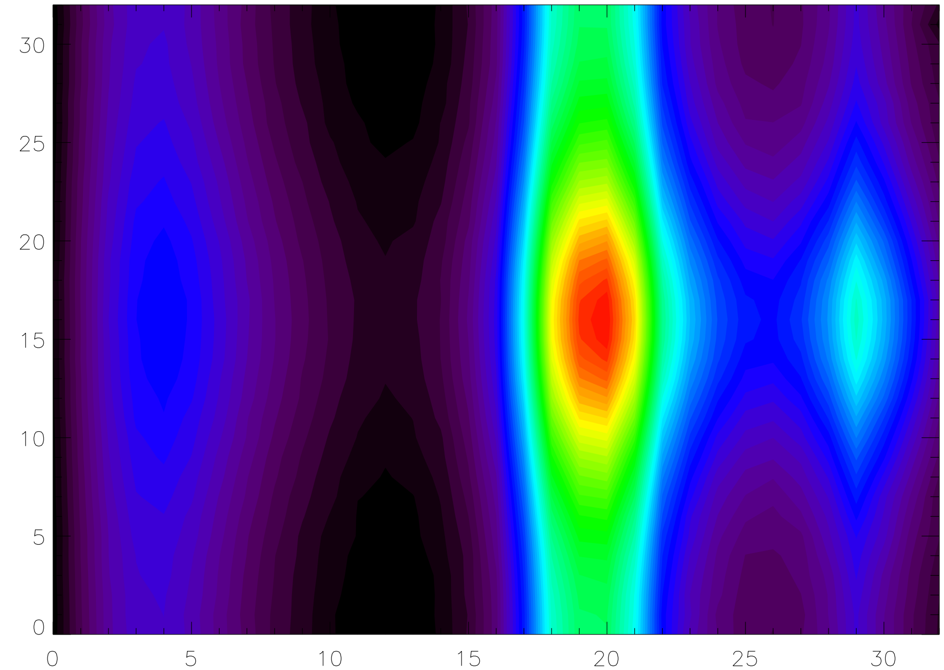




- large number of particles in large grids where the 'action' is low
- higher resolution regions result in lower number of marker particles - susceptible to particle noise
- not as bad as it looks because particles move

Typical Domain Decomposition





- native NIMROD domain decomposition not amenable with PIC

Survey of the Literature

- dynamic domain decomposition or dynamic load balancing
  - J.S. Wu et al. CPC **177** (2007)
  - Othmer and Schule CPC **147** (2002)
  - Liewe and Decyk JCP **85** (1989)
  - useful for inhomogeneous distribution of particles
  - relies on assumption that PIC is dominant
- hybrid ordered particles
  - D.V. Anderson and D.E. Shumaker CPC **87** (1995)
  - advocates sorting particles for better memory efficiency
  - also studied by K. Bowers (2001 Plasma Disseration Prize)
  - already there but not fully leveraged
- particle decomposition or domain cloning
  - B. DiMartino et al. Parallel Computing **27** (2001)
  - C. C. Kim back in the gyrokinetic days

– clone domains with separate particles
– also relies on assumption that PIC is dominant
– limited parallelizability - quickly diminishing return
– works well as a supplemental decomposition

- variable particle number
  – G. Lapenta and J.U. Brackbill CPC **87** (1995)
  – add particles as needed
  – not a parallelization technique
  – but very interesting

Where is this going?

- shake down the implemented domain decomposition
- leverage the sorted particles
- implement domain cloning ideas
- look into the variable particle number