Simulation of high power laser experiments on high performance computer

Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Magurele Romania

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High Power Laser System at ELI-NP

100 TW, 1 PW, 10 PW; Magurele Romania

On 19 August 2020 the first 10 PW laser pulse was shot through the entire ELI-NP laser system (amplifiers, compressor and laser beam transport) as part of the endurance test of the laser beam transport system. *10 PW ~ 10% energy produced by the Sun on Earth

Linear Accelerator (Under construction)

A system producing γ radiation by scattering of light photons on high energy electrons, with tunable energy of the photons up to 19.5 MeV, spectral density above 10^3 ph/s/eV and ~ 0.5 % relative bandwidth.

Preliminary Experiments at E4: looking for spectral broadening materials using 100 TW pulses

Chamber installation
Laser Plasma Interaction

Particle acceleration as a radiation source

- Simulations are needed before performing experiments
- Lower cost!
- Simulation types
  1. Magnetic Hydrodynamic (MHD) code
  2. Particle code
  3. Particle-In-Cell (PIC) code *
Particle-In-Cell (PIC) simulation

**Concept, Lorentz force + Maxwells’ equations**

- Simulation approximation for plasma
- Macroparticles
- Particle shapes

\[ F = eE + ev \times B \]

\[ \nabla \times E = -\frac{\partial B}{\partial t} \]

\[ \nabla \times B = \mu_0 \left( J + \epsilon_0 \frac{\partial E}{\partial t} \right) \]

C.K. Birdsall and A.B. Langdon, Plasma Physics via Computer Simulation

1 particle: 3 positions + 3 momenta + 1 weight

Fields: 3 E-fields + 3 B-fields + 3 currents

Grids: e.g. 128 x 128 x 128

Particle-per-cell: e.g. 2

Memory required: ~400 MB (double precisions)

Higher resolutions ~1-2 GB
Parallelisation

Domain decomposition

Split simulation domain across different processors

Data transfer among processors are performed by Message Passing Interface (MPI)

IntelMPI or OpenMPI (open source), support C++ & FORTRAN

Particle-In-Cell (PIC) simulation

- EPOCH developed in University of Warwick, UK
- Written in FORTRAN90
- Parallelised with MPI
- Open source

EPOCH

2D simulation

3D simulation

Core 0
Core 1
Core 2
Core 3

Data transfer by MPI

Core 0
Core 1
Core 2
Core 3

2 macroparticle/cell

N_{ppc}=2
Particle-In-Cell (PIC) simulation

PROGRAM main
IMPLICIT NONE
INCLUDE "mpif.h"

CALL MPI_INIT(ierr)
CALL MPI_COMM_SIZE(MPI_COMM_WORLD,NPROCS,ierr)
CALL MPI_COMM_RANK(MPI_COMM_WORLD,MYRANK,ierr) !initialize MPI

CALL MPI_BCAST(data_dir,100,MPI_CHARACTER,0,MPI_COMM_WORLD,ierr)

CALL MPI_REDUCE(data,datasummed,128,mpi_real8,mpi_sum,mapi_comm_world,ierr)
CALL other MPI functions

CALL MPI_FINALIZE(ierr)
STOP
END

Introductory manual on MPI

https://www.cs.kent.ac.uk/people/staff/trh/MPI/mpi_ibm.pdf

RS/6000 SP: Practical MPI Programming

https://www.cs.kent.ac.uk/people/staff/trh/MPI/mpi_ibm.pdf
Feasibility studies of an all-optical and compact γ-ray blaster using a 1 PW laser pulse,

Results of simulation with parallelisation
study underlying physics
• compare with experimental data
• cheaper optimisation cost
Thank you