ELMIS
a fully parallel Fourier-based multi-dimensional PIC code for laser-plasma interaction simulations

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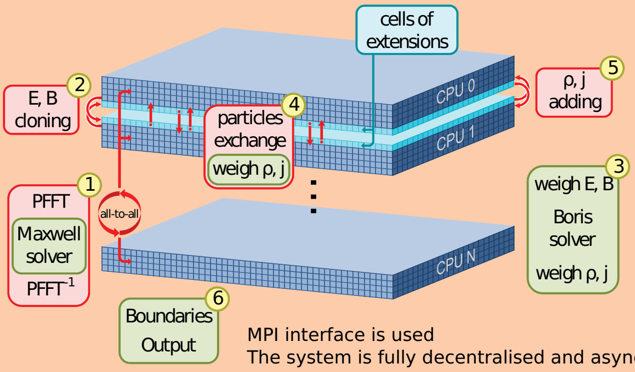
The science of superintense laser-plasma interactions relies heavily on high-perfomance computational resources. The main tool for simulations in this field are fully electromagnetic multidimensional Particle-In-Cell (PIC) codes. As these codes are resource-demanding, they are usually parallelized and adapted for use on super-computers. Moreover, in such codes, because of its straightforward and effective parallelization, the Finite Dierence-Time Domain (FDTD) scheme is commonly applied in calculations of the electromagnetic fields. The known drawback of the FDTD scheme is an artificial dispersion introducing by the numerical grid. There are a plenty of the workarounds developed to reduce the influence of this problem and some of them are quite effective. On the other hand, Fourier-based electromagnetic codes have the property that they imply exact fullfilment of the vacuum dispersion relation. Unfortunately, the fast Fourier transform (FFT) cannot be effectively parallelized in a straightforward way, and this technique is therefore commonly considered as non-parallelizable.

Her we present the Extreme Laser-Matter Interaction Simulator (ELMIS), a new fully parallel multi-dimensional PIC code developed by our SimLight group (http://ipfran.ru/english/structure/lab334/simlight.html). The main feature of this code is that the electromagnetic fields are calculated by the parallel Fourier method. The main idea behind the parallelization of the fast Fourier transform is the parallel execution of calculations and data transfer between the nodes. The parallel program is shown to be considerably faster in comparison to the serial analogue, both for two- and three-dimensional cases.

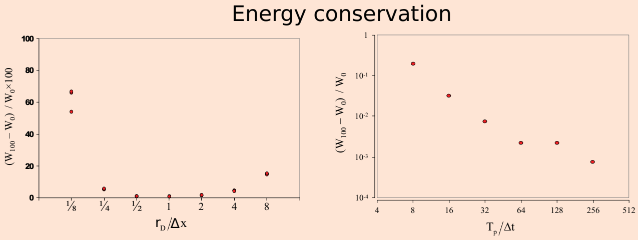
The main advantage of the ELMIS is an absence of the artificial dispersion. It is especially important for long-term simulations. Such simulations are crucial in, for example, the investigation of laser-electron acceleration in underdense plasmas. We have compared the ELMIS and a PIC code based on the simple FDTD scheme for this particular example. It is shown that their execution times are almost the same when the same parameters are used in the simulations. However, the results obtained by the codes can be both quantitatively and qualitatively different.

General scheme of data processing and transfering

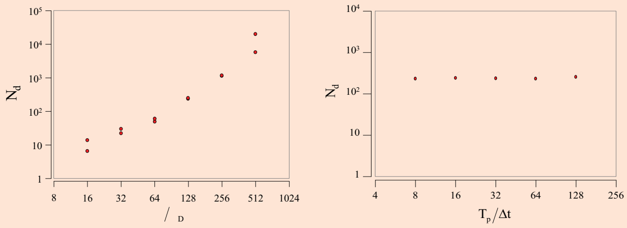


MPI interface is used
The system is fully decentralised and asynchronous

Energy conservation



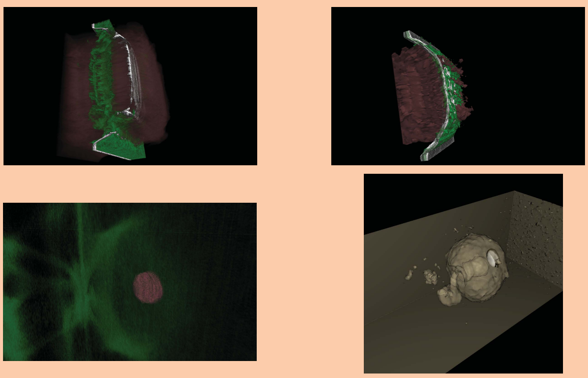
Artificial damping of plasma oscillations



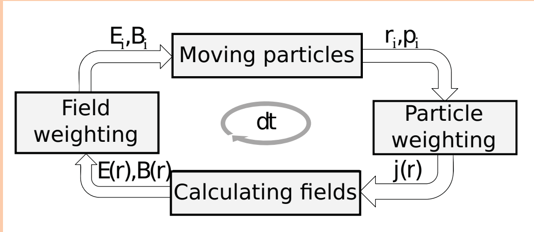
N_d is the number of the oscillations after which the amplitude drops by the factor e

Visualisation

For visualisation a special program has been developed. It is suited for effective 3d visualisation of matrices based on the ray tracing technique. It is implemented using both OpenGL and DirectX frameworks. The program is also able to use Nvidia 3d vision technology for creation of stereo-images.

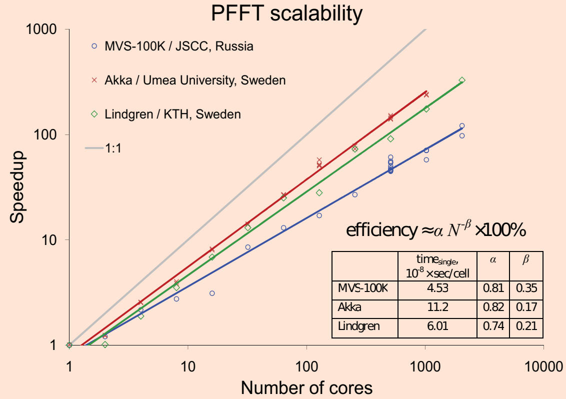


General scheme



We use:
1. Boris scheme to integrate equations of the motion
2. Cubic form-factors for particle weighting
3. Parallel Fast Fourier Transform (PFFT) to calculate fields

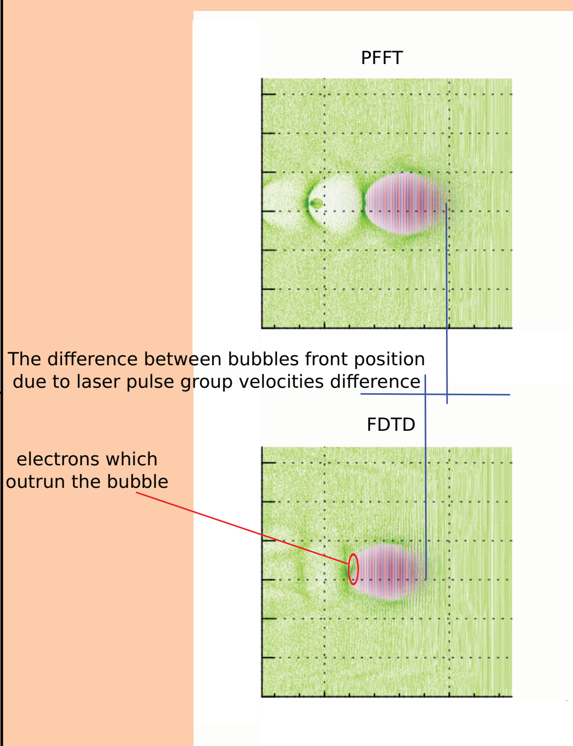
PFFT scalability



	time$_{single}$, $10^{-8}\times$sec/cell	α	β
MVS-100K	4.53	0.81	0.35
Akka	11.2	0.82	0.17
Lindgren	6.01	0.74	0.21

The tests were performed on the following supercomputers:
1. MVS-100K (Joint Supercomputer Center of the Russian Academy of Sciences, Moscow, Russia)
2. Akka (Umea University, Umea, Sweden)
3. Lindgren (KTH - Royal Institute of Technology, Stockholm, Sweden)

Comparison with a basic FDTD scheme



We studied laser electron acceleration in the so-called blowout or "bubble" regime.

The dynamics of the acceleration process strongly depends on the dispersion error.

The result of simulations after 600 fs is shown on the left.