IMPLEMENTATION OF A TREE CODE FOR COSMOLOGY

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We have adapted the Barnes-Hut hierarchical N-body method for cosmological applications. A detailed study of the resulting code yielded the following conclusions: it is SIMPLE, FLEXIBLE, ACCURATE, ROBUST, and EFFICIENT.

-SIMPLE: in the hierarchical method the force exerted on a particle by a distant cluster of particles is evaluated using a truncated multipole expansion. In our implementation, only the monopole term is retained. Consider the ratio of the transverse size of a cluster, s, to its distance from a particle, d. If s/d is greater than some fixed value θ, the cluster is divided into subcomponents. This procedure can be performed efficiently if the particles are organized into a nested hierarchy of clusters or cells using a tree data structure. Our code is based on a recursive division of space into cubic cells. The spatial resolution is not limited by a grid.
-FLEXIBLE: apart from the easy accuracy control through the value given to θ, it is also possible to consider various geometries and boundary conditions, *i.e.* freely-expanding, quasi-, and fully-periodic boundaries. (In the quasi-periodic case, the forces are computed as if the box was always centered on the particles, but there are no replicas of the distribution outside of the centered box.)
-ACCURATE: a simple way to estimate the accuracy of the code is to compare the results with those of an N^2 code, in which the forces are computed exactly by summing all the 2-body interactions. We performed detailed comparisons of the evolution of 4096 particles. Visual inspection, computation of 2-point correlation functions, and measurement of the relative differences in the computed forces showed very good agreement between the 2 sets of experiments. We have also tested the code for N up to 32768, $a \leq 30$ (where a is the expansion factor), and a smoothing parameter down to $\lambda/50$, where λ is the mean interparticle separation. In all cases, the energy conservation violation was $\Delta E/\Delta(aU) \sim f(a\theta)/\theta \leq 0.2\%$.
-ROBUST: for sufficiently small values of θ ($\simeq 0.75$), the variations in the dynamical evolution due to the errors in the force computation are negligible compared with variations resulting from statistical fluctuations in the initial conditions.
-EFFICIENT: the computation time scales with the particle number N as $N \log N$ (as a Fourier code), and with θ as θ^{-2}. Finally, and most importantly, the cpu time per step is nearly independent of the level of clustering, unlike a P^3M code.

This method will thus allow simulations with many particles ($N \sim 100,000$), and with a high spatial resolution, deep into the non-linear regime.

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