Parallelization of a Tree-Code for the Simulation of Self–Gravitating Astrophysical Systems.

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Abstract

We have preliminary results on the parallelization of a Tree-Code for evaluating gravitational forces in N-body astrophysical systems. Our HPF/CRAFT implementation on a CRAY T3E machine attained an encouraging speed-up behavior, reaching a value of 75 with 128 processor elements (PEs). The speed-up tests regarded the evaluation of the forces among $N = 130,369$ particles distributed scaling the actual distribution of a sample of galaxies.

1 The scientific aim

In Astrophysics large $N$–body systems are generally self–gravitating, that is the dynamics of the bodies is strongly influenced by the gravitational field produced by the bodies themselves. This ‘self–influence’ makes the exact evaluation of the interactions a particularly heavy task, since the number of operations needed scales like $N^2$. To overcome this problem various techniques have been proposed. Among them, the tree–code algorithm proposed by Barnes & Hut (see [1], [2]) is now widely used in Astrophysics because it does not require any spatial fixed grid (like, for example, the ‘Poisson solver’ methods). This makes it suitable to follow very inhomogeneous and variable (in time) situations, typical of self-gravitating systems out of equilibrium. Furthermore its CPU–time scales like $N \log N$.

2 The HPF/CRAFT tree–code parallelization

Tree–codes are difficult to parallelize mainly because gravitation is a long–range force and the evaluation of all the interactions among bodies is not completely separable into a set of independent tasks (inter-processor communications are inevitable). Moreover, astrophysical non-uniform distributions imply great differences in the amount of contributions to the force on each particle, thus a good load balancing is hard to be achieved.
In the tree–code we distinguish substantially two parts: i) a *tree–setting* phase where the logical tree structure is built and the various multipolar coefficients of the cells in which the space is subdivided are placed in the corresponding locations; ii) a *tree–walking* phase in which the force on each particle is evaluated “walking” the tree and considering all the cells.

Our parallelization was based on a *work and data sharing* approach (using the directives of the HPF/CRAFT language) and we found that the greatest difficulties in getting good performances are in the tree–setting phase, in which is not easy to avoid *load unbalancing* among the PEs, due mainly to *synchronization* points. After various attempts, we adopted a sophisticated scheme whose details can be found in [3].

To test the speed-up of our parallelized code on realistic distributions, we located \( N = 130,329 \) particles scaling the quite clumped density distribution of a sample of galaxies in the Northern galactic hemisphere (see [3]).

In Fig.1 we show the speed-up results obtained on a CRAY T3E\(^1\) for both phases i) and ii) as well as the total speed-up. The tree–setting is confirmed as the most difficult part of the algorithm to be well parallelized, while the tree–walking speed-up has a quite good behavior in spite of that it uses intensively remote reading. In Fig.2 the work load distribution is shown for the run with 8 processors, for both phases. Note how load balancing is very good for the tree–walking phase, while for the tree–setting there are differences among PEs work load which, in any case, do not exceed the 20% of the average.

To conclude, the results are rather good: the total speed-up is high enough and it does not show any flattening, at least for \( p \leq 128 \). One has to consider also that for \( p > 16 \) the amount of particles per processor is not that high (less than 5,000). We think that using more particles we would get even better results.

References

[1] Barnes J., Hut P., *Nature*, vol. 324, p. 446 (1986).

[2] Miocchi, P., Graduation Thesis, Univ. of L’Aquila, Italy (1994).

[3] Miocchi, P., PhD thesis, in prep. (Univ. of Rome “La Sapienza”, Italy) (1998)

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Figure 1: Measured speed-up for the tree-setting phase, the tree-walking phase and total.

Figure 2: Normalized work load distribution over 8 processors in both phases.