8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Parallel computing for mechanical nuclear analysis

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Key Words: Non-linear computations, parallel strategies, algorithms, large scale problems, load balancing, nuclear industry

ABSTRACT

Complex studies required for conception and safety analysis of nuclear plants lean to extremely expensive numerical simulations. Three costly axes are combined:

Accurate meshes involving a large number of elements
Highly non-linear material behavior, with softening
Complex loadings requiring a small time increment and a large number of time steps

The joint use of parallel computers and powerful algorithms is necessary to strongly reduce the numerical costs of these complex non linear Finite Element simulations [1]. To reach this goal, we have created a parallel environment language that eases the development of parallel algorithms either at the programming level or at the user level. It is based on the development environment of the Finite Element code CAST3M. On the other hand, we use a parallel approach that is well suited to the simulation of a large class of non-linear problems and which allows a good balancing of the workload between the tasks without using dynamic load-balancing. This property is obtained by using two domain decompositions, each using the mechanical properties of the different sub-problems to be solved.

The developed parallel language, which is based on an object-based virtual shared memory system, offers the user the vision of a unique and global address space over the individual memories [2]. It ensures the data coherence and hides data exchanges between processors and a great part of the sequential code can be reused. This system frees the programmer from parallel programming intricacies (management of data, coherence of data, ...) and lets him focus on the program design, the most critical aspect for the application efficiency. The propounded system can be implemented on most parallel computers as it is developed with machine-independent programming techniques and it is important to notice that the different concepts can be used in other object-based parallel languages. Moreover the object-based shared virtual system allows two levels of parallelization: at the programming level and at the user level.

Non-linear problems are usually solved by means of NEWTON methods and lead mainly to compute two types of sub-problems. The proposed parallel strategy uses the mechanical properties of these sub-problems. On one hand, a domain decomposition technique with a direct resolution of the condensed problem is proposed to solve the linear global problems, in order to be compatible with the BFGS type convergence speed-up. One can also use a parallel direct

solver associated to a “nested dissection” ordering approach which limits the fill-in effect in the factorization of the matrix [3]. In fact, this strategy is similar to a decomposition domain technique and gives good numerical results on shared memory computers. On the other hand, it is nearly impossible to predict the space evolution of the CPU time spent to integrate the constitutive laws. Therefore, in order to have a well-balanced load, without communication, we propose the use of a second domain decomposition. An optimization of the communications between the two domain decompositions is necessary to obtain good performances. The implementation of this strategy is carried out starting from the parallel user language of CAST3M.

Numerical examples, in the case of large scale problems (non-linear material behavior, geometrical non-linearities) are presented to validate the propounded parallel approach.

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