A Novel Advancing Front Meshing Algorithm for 3D Parallel FEM

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Abstract

The reduction of calculation time is a very important task for three-dimensional semiconductor process and device simulation. We present a fully parallelization scheme for three-dimensional finite element calculation. That is parallel advancing front meshing algorithm and parallel finite element calculating algorithm using substructure method. The new parallelization algorithm is implemented on CRAY T3E.

1. Introduction

A finite element analysis initially requires the domain under consideration to be discretized into appropriate finite element meshes. It is widely understood that three-dimensional numerical calculation with a large simulation area requires a huge memory size and CPU time for the sequential computer. Today, massively parallel processors, heterogeneous networks of workstations, and shared-memory computers provide users with the hardware capability to outperform traditional vector supercomputers. But in order to efficiently take advantage of these parallel platforms, computational engineers must use message passing libraries, such as PVM and MPI [1]. Therefore, the development of a parallel meshing algorithm may reduce the computational expenses. Although many efforts have been made to implement parallel schemes in FEM, the previous work does not fully utilize the capability of the parallel processors.

Many parallel FEM algorithms are based on domain decomposition with an iterative method. The prior art such as the domain decomposition method still has a disadvantage in that the calculated data should be exchanged between processors and that all of processors are synchronized in every iteration steps [2]. This kind of strong relationship results in lack of flexibility that is necessary to deal with the domain with complicated shape. In addition, if the speed of convergence in decomposed domain is not uniform, workload balance for the processors gets uneven and parallel efficiency would decrease.

In this paper, we applied substructure method [3] for enhancement of parallel efficiency. In substructure method, a domain is decomposed into substructures wherein the number of substructure is determined in accordance with the number of processing elements (PEs). Thereafter, each substructure is meshed by employing the advancing front method. Parallel computation for each substructure could be performed without communication between each processor.

2. Parallel Computation Method

The discretization of a three-dimensional domain is essentially a challenge for the initiation of 3D parallel FEM. Different meshing techniques can be used to achieve finite element meshes. Irrespective of the choice of the method, difficulties are encountered to achieve a fully automatic mesh generation.

We have employed three-dimensional advancing front technique, which is provided with the initial front by advancing front triangulation. The simulation region is decomposed into several domains in proportion to the number of processing elements. The triangulation of a surface is initiated by the general polygonal boundary description of the various parts of the geometry. Firstly, each polygon is triangulated from the boundaries by each process element. Thereafter, tetrahedrization is performed for each domain by each process element as shown in Fig. 1.

The mesh generation process is then followed by a finite element calculation employing a new parallel substructure method. Our substructure method is very efficient because the multiple processors do not have to communicate for their data transfer during parallel computation. The substructure method starts with the formation of the system equation of each substructure as shown in Fig. 2.

By indexing the inside nodes of the domain ahead of the exterior nodes on the boundary, the system equation is formed for later parallel computation. The merits of our indexing scheme are from the fact that the terms of the inside nodes can be eliminated by the manipulation of the stiffness matrix. Finally, the equation becomes a form of $A_{bb}^{*}\, x_b^{*} = b_b^{*}$. By adding A_{bb}^{*} and b_b^{*} across the whole substructures, the global system equation of the boundary nodes can be obtained as shown in Fig. 2: $A_{bb}^{*(global)}\, x_b^{*(global)} = b_b^{*(global)}$. With this global equation, the solution of the inside nodes is obtained from $x_i = A_{ii}^{-1}[b_i - A_{ib}x_b]$. Our new parallel computation method was applied on both CRAY T3E supercomputer and SUN ULTRA 1 workstations linked by LAM/MPI.

In Fig. 3 is shown exemplary structure for demonstrating volume meshing by employing the parallel advancing front method. Figure 4 demonstrates a result of parallel diffusion calculation using 16 process elements. The comparison of the working time with the number of processors is shown in Fig. 5. The total CPU time was reduced approximately by 16 times, which implies good speed-up performance of our parallel algorithm.

3. Conclusion

The presented our fully parallelization scheme using advancing front meshing algorithm and substructure algorithm represents good speed-up performance. Especially, parallel advancing front mesh generation algorithm was employed for the substructure method. Therefore, data communication time was reduced during parallel mesh generation and matrix solving process.

References

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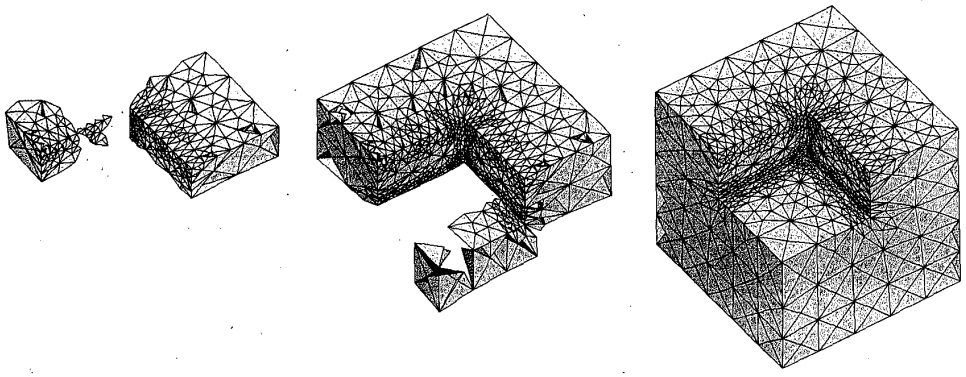

(a) (b) (c)

Figure 1: Plots showing the three-dimensional mesh generation with advancing front algorithm.

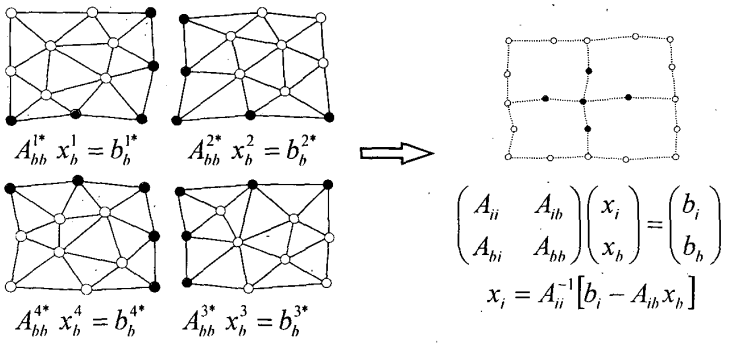

Figure 2: The equation for the boundary nodes of each domain can be obtained by adding up each system equation and then the internal node can be calculated.

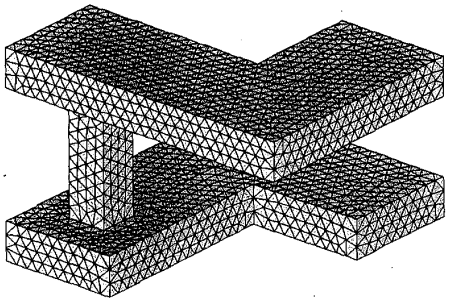

Figure 3: A result of parallel mesh generation for an exemplary structure.

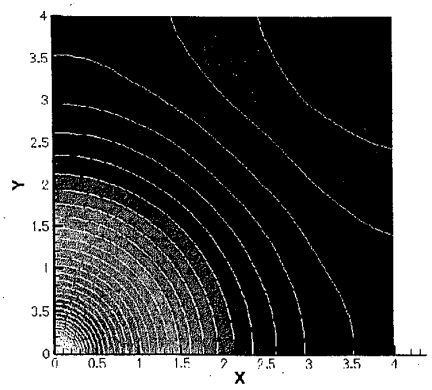

Figure 4: A plot showing the diffusion calculation with substructure method using 16 PEs.

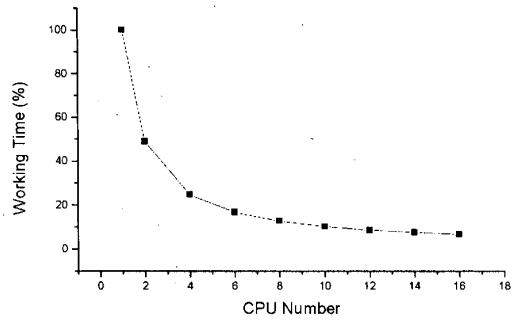

Figure 5: The comparison the working time vs. PEs.