Massively Parallel Solution for FEA

by

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ABSTRACT

The past few years have seen the development of Parallel Processing computer hardware systems utilizing both minor and massive parallelism. Massive parallelism utilizing distributed memory processors, such as the INMOSS Transputers, offers a tremendous potential reduction in computation time for FEA applications. This paper outlines the differences between minor and massive parallelism and the special issues involved in massive parallelism.

This paper also describes the results of software research performed by FEGS, Limited regarding the use of massive parallelism for Finite Element Analysis and Finite Element Modeling as well as the current availability of Massively Parallel hardware and Software for Finite Element applications.

Introduction

The hardware computing technology has made major advances regarding computational power in both serial and parallel processing environments. The most promising of which are in the area of minor and massively parallel processing. This increase in computing capacity has occurred in a time of rapidly increasing computing demand for Finite Element applications due to increasing mesh density, increasing acceptance of non-linear analyses, adaptive mesh refinement, and design optimization requirements.

Parallel Processing

The advent of RISC (Reduced Instruction Set Computers) have recently provided a significant improvement in computation speeds, however, parallel processing is widely acknowledged to promise an even more dramtic increase in computing capacity beyond RISC architecture. The race is on for the major computer hardware manufacturers (IBM, Digital, Convex, etc.) to implement and/or broaden their use of multiple parallel processors.

Parallel processing allows several processors to act on various parts of the computational problem simultaneously, thereby reducing the time to solve the problem. The computational benefit is a function of the number of processors employed, intercommunication between processors, and the parallel nature of the problem being solved.

Minor Parallelism

There are two (2) different approaches currently being employed in the application of parallel processing known as Minor Parallelism and Massive Parallelism. The first method (Minor Parallelism) is currently being employed in a range of computers known as "mini-supercomputers", or "super-minicomputers" (ie. Convex, Stardent, etc...).

Minor Parallelism is based on multiple processors communicating through a communications bus to a block of memory shared by all the processors. This is referred to as a shared memory approach to computing. The communication bus is proprietary and dependent on particular machine architecture. Communication between processors and memory is achieved through the bus shared memory and is typically limited to 4 to 16 processors running in parallel, with some available as high as 64 processors. The relationship of processors, communications bus, and memory is illustrated in Figure 1.

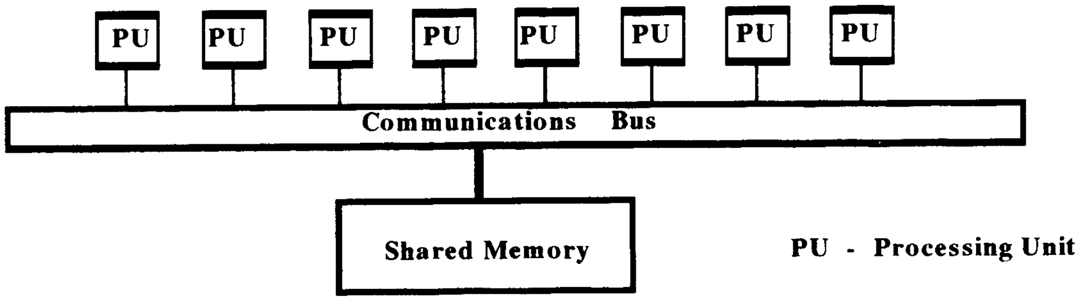

Figure 1: Minor Parallelism Architecture

The processing speed improvement from minor parallelism is limited to the number of processors (typically 1-16) , machine architecture, and the effectiveness of "parallelising" compilers. This speed improvement is rarely greater than one (1) order of magnitude greater than single-processor systems.

Massive Parallelism

Massive Parallelism is based on using a large number of independent processors with distributed memory on each processor and direct inter-processor communication. The INMOS transputer developed in the UK provides this distributed memory and inter-processor communication as shown in Figure 2.

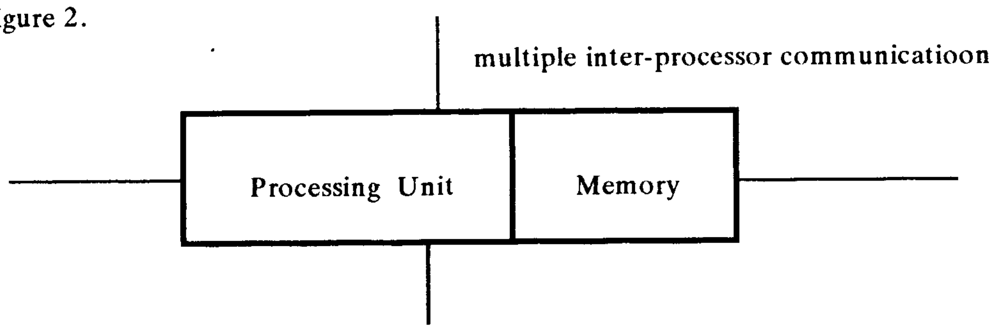

Figure 2: INMOS transputer (simplified)

These INMOS transputers are then configured together in arrays of varying size (16 to 1,000's) to provide massively parallel computing architecture. This configuration of processing units provides the flexibility required to implement a large number of processors in a parrallel computing environment. An illustration of the INMOS transputer based massively parallel architecture is illustrated in Figure 3.

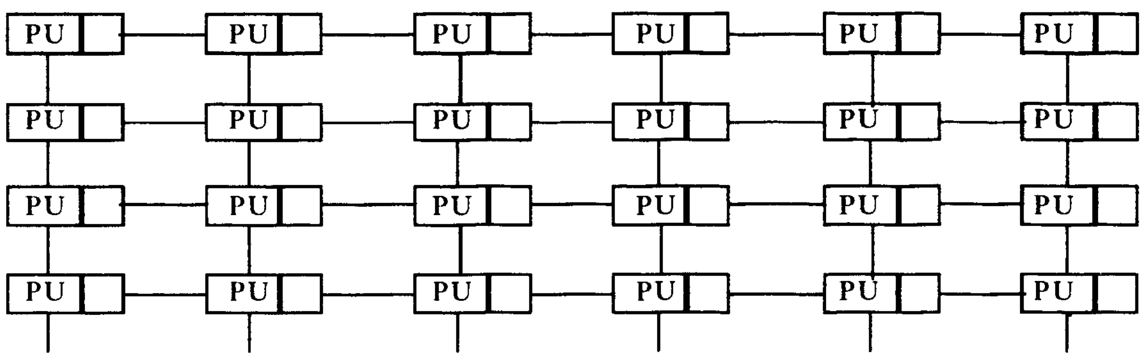

Figure 3: Massive Parallelism

Massive Parallelism offers almost unlimited computing potential in an affordable environment, but also brings with it a new set of technological problems not present in serial processing or minor parallelism.

The first such technological difficulty is the current, and projected long term, lack of a FORTRAN compiler which will automatically make existing sequential code exploit massive parallelism. Portions and/or all of the application needs to be rewritten in a language specifically designed for a massively parallel architecture in order to take full advantage of the parallel computing environment. INMOS provides the OCCAM language for transputer based systems which is callable from either C or FORTRAN.

The next technological difficulty is the increased difficulty in parallel programming and debugging.

Finite Element Applications

Several different aspects of Finite Element analysis are excellent candidates for the application of massive parallelism. The major areas of interest are equation solution (factorization), element stiffness formulation, stress recovery, mesh generation, and loading.

FEGS Limited based in Cambridge, UK has recently completed extensive research in the area of Massively Parallel Finite Element solutions resulting in a solution algorithm for solving linear differential equations which produces a 90% utilization rate of available processors for problem with sufficient bandwidth. Figure 4 illustrates comparative results for a range of models and processor configurations based on providing a massively parrallel solution algorithm.

Model	Degrees of Freedom	Sequential	Massive Parallelism			
			32 PU	40 PU	48 PU	64 PU
Piston (1)	11,792	>24 hours VAX 11/750	<10 min	-------	<8 min	<6 min
Carriage(2)	12,401	4,749 sec SUN 4/110	935 sec	835 sec	771 sec	699 sec
Carriage(3)	12,401	------------	477 sec	382 sec	320 sec	247 sec

Notes: (1) indicates Total Elapsed Time using a banded solver
(2) indicates Total Solution Time using a banded solver
(3) indicates Factorization Time (Factorization is the only massively parrallel activity in this benchmark)

Figure 4: Massively Parallel Equation Solution

FEGS Limited is currently working on parallelizing the element stiffness formulation and stress recovery as well as reviewing the entire solution process in the context of a massively parallel computing environment.

Conclusion

Massive Parallelism offers the growth in computional facilities necessary to meet the current and future needs of Finite Element applications. FEGS Limited of Cambridge, England is actively involved in the research on massively parallel Finite Element applications and has developed a linear static equation solver which runs on the PARSYS Super Node 1000 transputer based system. Hardware and Software technologies are available to start taking advantage of massive parallelism in equation solution but continued research is also necessary to fully utilize massively parallel processing for Finite Element Analyses.

The solution algorithm developed by FEGS Limited for linear differential equations (ie. linear statics for FEM) was developed and tested on a PARSYS Super Node 1000. This massively parallel solution algorithm is written such that a "heart transplant" may be performed within Finite Element codes replacing the existing linear statics equation solver, as illustrated in figure 6.

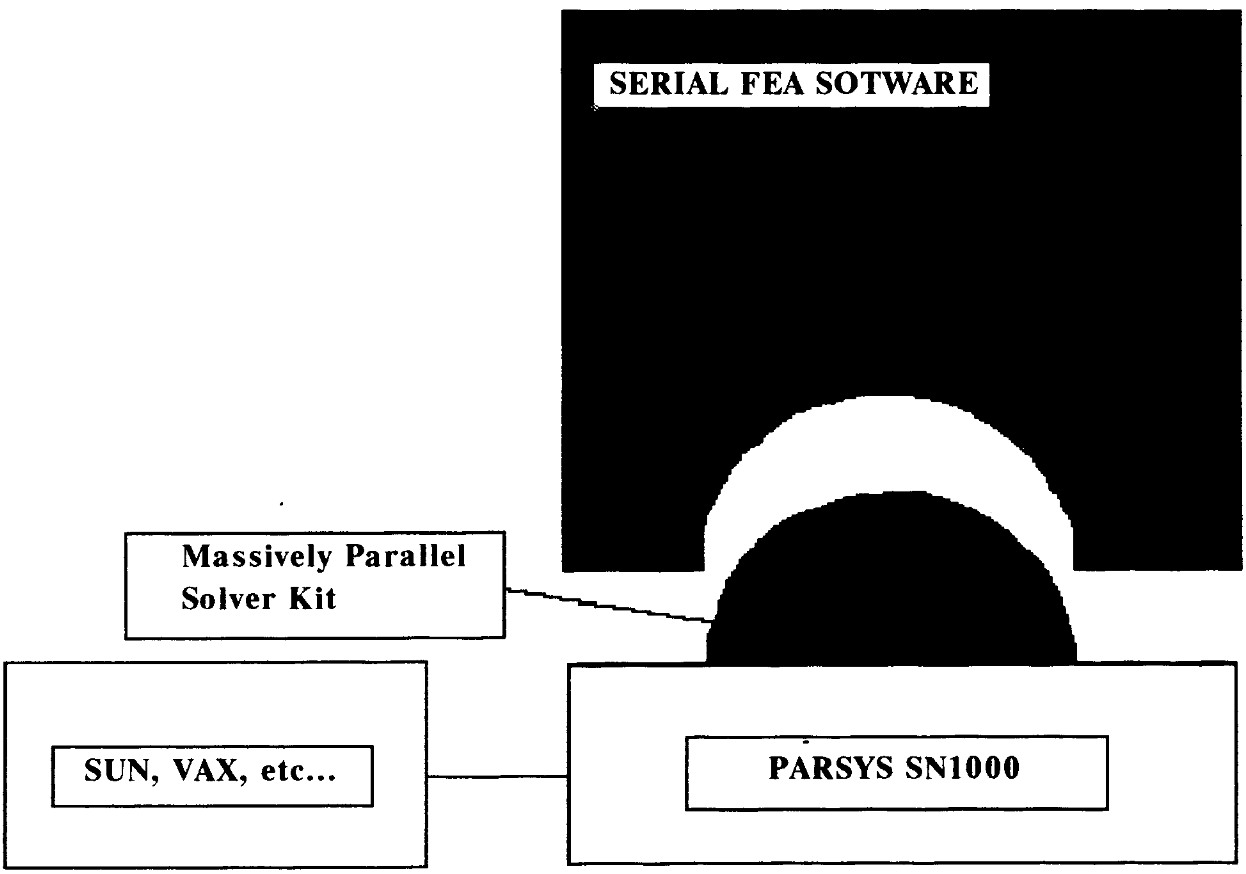

Figure 6: Massively Parallel "Heart Transplant"

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