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13. ABSTRACT (Maximum 200 words)

The effort has three major.

(1) Gain algorithm experience in conversion of a suite of Air Force production (CFD) codes to a general format applicable to a variety of such commercial architectures.

(2) Examine the feasibility of using workstation networks for such distributed computation: this involves (a) developing timing models of the communication systems of such networks (b) projecting performance of the above codes on such networks, and (c) implementing one or more codes, as time permits.

(3) Initiate research on CFD-based low-radar crossection analysis on parallel systems: this effort is in association with Dr. Joseph Shang at WRDC.

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Final Technical Report

for Period 10-15-89 to 1-14-94

Grant AF-AFOSR-90-0020

MASSIVELY-PARALLEL COMPUTATIONAL FLUID DYNAMICS

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Ann Arbor, MI

March 10, 1994

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I. Goals

The effort has three major components.

(1) Gain algorithm experience in conversion of a suite of Air Force production CFD codes to a general format applicable to a variety of such commercial architectures.

(2) Examine the feasibility of using workstation networks for such distributed computation; this involves (a) developing timing models of the communication systems of such networks, (b) projecting performance of the above codes on such networks, and (c) implementing one or more codes, as time permits.

(3) Initiate research on CFD-based low-radar crossection analysis on parallel systems; this effort is in association with Dr. Joseph Shang at WRDC.

II. Progress Report

1989-1990 Progress

The following were grant-sponsored accomplishments.

(1) Implicit algorithm development. A full 3-D Navier-Stokes Beam-Warming CFD code was implemented on a 1024-node scalar NCUBE hypercube at SANDIA (Albuquerque).

(2) Distributed-workstation architectures for CFD. The University is providing a cluster of IBM workstations for distributed algorithm study. Critical timing features of such a system are being measured to insert into the overall timing models associated with the completed explicit and implicit AFFDL Navier Stokes codes; their parallel performance will then be predicted.

(3) Generic distributed parallel codes. Commercial operating systems are available which permit algorithm coding toward a distributed parallel environment that includes most current MIMD systems. The EXPRESS system from Parasoft has been adopted and the completed explicit and implicit AFFDL Navier Stokes codes are being adapted to this software environment.

(4) Crossection analysis. Recently-proposed CFD-related numerical procedures by Dr. Shang on new methods of solving Maxwell's equations in real time are being examined for their solvability on parallel systems. This effort will begin in earnest in summer 1991.

1990-1991 progress

The following were grant-sponsored efforts.

(1) Distributed-workstation architectures for CFD. At the time of this grant initiation, the only computing resources in Dr. Shang's group with potentially scalable, parallel features were a collection of graphic workstations. We decided, after completion of the above implicit code conversion, to examine the feasibility of using workstation networks for such distributed computation; this involves (a) developing timing models of the communication systems of such networks, (b) projecting performance of the above codes on such networks, and (c) implementing one or more codes, as time permits.

The University had provided a cluster of IBM workstations for distributed algorithm study. Unfortunately, it was found that, as message-passing architectures, the models provided had long latency times even when connected in a local network and, in the general network environment provided at the University, these latencies would wither any but an embarrassingly parallel

algorithm. It was clear that further research with locally-available network technology would be have no value in demonstrating to Dr. Shang the usefulness of networking his workstations. Also, an effort by the University to implement the EXPRESS distributed system on these IBM units was unsuccessful. For these reasons, this research effort was abandoned.

(2) <u>CFD-based low-radar crossection analysis on parallel systems</u>. Recently-proposed CFD-related numerical procedures by Dr. Shang on new methods of solving Maxwell's equations in real time were examined for their solvability on parallel systems. Dr. Shang forwarded a 2-D code for study. It was found that the algorithm kernel involved a forward-substitution process, which, with little computational complexity, was deemed inappropriate for message-passing architectures. Some investigation was made of the CM-2 because of its NEWS high speed interconnect. However, it was later felt by Dr. Shang that the sample algorithm was not extendable to general 3-D problems, and work was suspended awaiting a new sample serial code.

(3) In June, Dr. Shang informed us that he had received a start-up effort to exploit the DELTA in his work, and that he wished our assistance in the work. Most students familiar with these codes had left our project, so it was decided that
   (a) his staff would, beginning with the above-mentioned NCUBE explicit code, carry out a conversion to the DELTA of a newer explicit code;
   (b) we would evaluate the feasibility of converting his implicit code from the NCUBE[1] to the DELTA.
Regarding the latter, it was understood that the syntactic conversion would be trivial. However, the NCUBE algorithm was converted from the serial form specifically to minimize the number of hops in a *hypercube* interconnect. The price paid was a significant increase in the <u>number</u> of messages in the NCUBE version. The relatively low message latency in the NCUBE hardware had resulted in a 60% parallelization efficiency. It was obvious that the DELTA would be relatively more affected by latency, and an initial evaluation has led us to look elsewhere for efficient implicit kernels which could be interfaced with the FDL code. We visited the Parallel Systems Division at NASA/ARC for discussions with a researcher engaged in similar activities on the INTEL GAMMA. By October 15, the end of this reporting period, we had not obtained access to the DELTA, but we had performed some preliminary generic NCUBE-INTEL conversion on the Argonne GAMMA.

We obtained access to the DELTA in late November and attempted to implement our simpler NCUBE explicit code on the DELTA. We have encountered a number of system problems, as well as I/O programming issues due to the large available local memories on the DELTA, in contrast to the NCUBE.

In summary, we foresee a number of programming and algorithmic issues to achieve a state-of-the-art implementation of the FDL implicit code on the DELTA, and we are now evaluating which would be appropriate for our grant to study or import from ARC.

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[1]This was the version of the NCUBE with 512K bytes/node; it was not the NCUBE2.

1991-1992 progress

The following were grant-sponsored efforts.

(1) **CFD-based Computational Electromagnetcs (CEM) on parallel systems**. Recently-proposed CFD-related numerical procedures by Dr. Shang on new methods of solving Maxwell's equations in real time were examined for their solvability on parallel systems. In previous years of grant effort, Dr. Shang forwarded 2-D and 3-D explicit CEM codes for study. These were found by Dr. Shang to have numerical problems and were put aside before parallelization.

In the summer of 1992, Dr. Shang forwarded a new suite of three CEM codes for parallelization. An attempt to port these to a recently-purchased KSR at the University was put aside when it became clear that the level of KSR compiler support would not permit efficient parallelization. It was agreed with Dr. Shang that remaining effort[2] should be spent on the DELTA, which had achieved a reasonable level of hardware stability and compiler efficiency. Experience on the KSR was useful in giving insight, however. In the process of preparing a code to exploit the KSR's automatic parallelization ("tiling"), a version of the code was developed which could be readily converted to a message-passing machine like the DELTA.

As a result, a two-step algorithm- and code-development procedure was developed. In step (1) Professor Calahan carry out most parallelization on a reliable uniprocessor mainframe with familiar and sophisticated debugging tools; the appropriate DELTA message-passing libraries were emulated where necessary. In step (2), this code was converted to the DELTA, principally a syntactic step, involving Dr. Shang's CEM staff at WRDC. When the grant terminates, these application researchers will then be able to carry on independently. Student assistants at the University are also involved in this final parallelization step. It is expected that these three codes will be completely parallized by 3/31/93 [1]. A paper abstract on this topic, joint with WRDC, has been submitted [2].

(2) **Distributed CFD implicit code**. Based on experience with the above-mentionedtwo-step process, it was felt reasonable to re-institute a project to parallelize a prototype implicit CFD code for the DELTA; a previous parallelization for the NCUBE [1] was deemed inappropriate due to the relatively long message startup of the DELTA. This project had languished due to inability of finding a student sufficiently experienced to carry out the somewhat involved parallelization. It is now felt that the above two-step parallelization process involving Professor Calahan in the emulation step will make parallelization possible with modest student and WRDC help in the final parallelization step. Again, WRDC involvement will have an important educational value.

We now have in hand the most recent implicit N-S production code from WRDC. Successful parallelization will permit DELTA or PARAGON solution within the 3-year period of a DARPA contract with the WRDC CFD group.

1992-1994 progress

In joint work with Dr. Shang at WRDC, the the Fall of 1992 two serial CEM codes were restructured in generic serial formats suitable for easy implementation on distributed parallel architectures; also, performance projections were made based on knowledge of the DELTA

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[2]The grant was scheduled to terminate on 10/14/92. A 1-year no-cost extension has been approved.

architecture. A total of six generic programs were developed, depending on the number geometric directions to be partitioned (i.e., there were 1-D, 2-D, and 3-D versions of each code) t was later decided that the numerical characteristics of one code (the implicit) were nor suitable, so effort was continued only on one code. The 1-D and 2-D versions of this explicit code were then parallelized on the DELTA. and performance data reported in [2]. Another CEM code was then received from Dr. Shang in mid-summer and its parallelization reported in [3].

III. Coupling Activities

1989-1990

Air Force Flight Dynamics Laboratory

The implicit code parallelized by Kominsky (above) was a production CFD obtained from Dr. Joseph Shang, director of the Computational Aerodynamics Group at AFFDL. One visit and monthly contacts were made to his laboratory. This completed a study initiated in a previous AFOSR grant to develop distributed parallel versions of principal production CFD codes in Shang's group.

1990-1991

Air Force Flight Dynamics Laboratory

The implicit code parallelized by Kominsky (above) was a production CFD obtained from Dr. Joseph Shang, director of the Computational Aerodynamics Group at AFFDL. Monthly contacts were made to his laboratory in regard to conversion of the NCUBE explicit code to the DELTA.

1991-1992

Air Force Flight Dynamics Laboratory

Bi-monthly visits are made to WRDC to discuss the above-memtioned CEM and CFD codes.

1992-1994

Air Force Flight Dynamics Laboratory

A number of visits were made to WRDC to discuss parallelization of CEM codes.

Phillips Laboratory, Kirtland AFB

A visit was made to determine the extent to which the interests and experience of the PI might relate to their research in parallel computation.

IV. References

[1]Kominsky, Paul, "Performance Analysis of an Implementation of the Beam and Warming Implicit Factored Scheme on the NCUBE Hypercube," Proc. 3rd Symposium on Massively Parallel Computation, College Park, MD; Oct. 8-10, 1990; pp 119-126.

[2]Shang, J., K. C. Hill, and D. A. Calahan, "Performance of a Characteristically-based, 3D, Time Domain Maxwells Equations Solver on a Massively-Parallel Computer," AIAA Paper 93-3179, AIAA 24th Plasmadynamics and Lasers Conference, July 6-9, 1993, Orlando, FL. Also submitted to the Computing Systems in Engineering.

[3]Shang, J., D. A. Calahan, and B. Vikstrom, "Performance of a Finite Volume CEM Code on Multicomputers," AIAA Paper 94-0236, 32nd Aerospace Sciences Meeting & Exhibit, January 10-13, 1994, Reno, NV. Also accepted for publication in the Advanced Computing Engineering Journal.