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13. ABSTRACT (Maximum 200 words)

In this report we describe our efforts to design and construct tools for parallel software for highly parallel computers. Applications include gas dynamics and ocean circulation on computers such as the CM-5 and Cray T3D.

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Final Report

Translation Tools for High Performance Computing

ONR Grant No. N00014-93-1-0426-P00001
Program Director: Dr. Gary Koob

Principal Investigator: Dr. Matthew T. O'Keefe

Overview

The goal of this research was three-fold: to refine a programming model that allowed serial codes to be translated to highly parallel form, to construct translators to perform this conversion, and to measure and understand the performance achieved when executing these codes on highly parallel machines. We succeeded in all three goals and applied our techniques to three different codes to validate our approach. In this report we summarize these results and describe the papers published, students graduated and research products produced.

Results and Transitions

In this research we validated the Fortran-P programming paradigm, applied it to three different computer codes (PPM, MICOM, and ARPS), and measured the performance achieved on massively parallel computers including the CM-5 and the Cray T3D. Good performance and high efficiency was achieved with these codes but we did learn that data parallel Fortran's like HPF and CM-Fortran are harder to optimize than message-passing programs, though the former are perhaps easier for the programmer to use.

Though successful, economic and technical problems have made MPPs less viable today and we have improved the Fortran-P model (with further ONR support) so that it may be used to develop codes for clusters of multiprocessors machines often referred to as SMP clusters.

A variety of students have been supported under this grant: they are listed below. Aaron Sawdey has been the primary researcher on this project, and he is how supported on another ONR grant pursuing his Ph.D. and contuing his highly successful efforts from this grant. In addition, a total of 11 publications and 3 technical reports resulted from this work.

Products from this research include the following:

- *Parallel Ocean Model:* we parallelized the Miami ocean model and have made it available to other researchers on the WWW. Approximately 3-4 sites are using this code, including several in Europe.
- *Fortran-P translator:* we wrote a translator that converts Fortran-P codes to data parallel form and used it to convert the PPM gas dynamics code for execution on the CM-5 parallel computer. Though useful, this code is not robust enough for general release and interest in the CM-5 is declining with the demise of TMC.
- *Miami Ocean Model Calculations and Movies:* using our parallel ocean model we computed a high resolution North Atlantic simulation which achieved good fidelity

to observed Gulf Stream currents, something which had hitherto not been seen in ocean models. This increased resolution and speed afforded by the parallel model was thought to have provided this improved fidelity. We created several scientific animations from this calculation, some of which can be seen on the WWW at *http://www-mount.ee.umn.edu/~dereklee/micom_movies/micom_movies.html.*

Graduate Theses Supported (University of Minnesota)

Note: Some of the students received only partial support from this ONR grant while completing their graduate studies.

Student's Name	Date	Degree	Thesis Title
Peter Dahl	Nov. 1994	Ph.D.	Compiler and Architecture Issues for CRegs. *Dr. Dahl is now in the Compilers Group at Silicon Graphics Inc., Mountain View, CA.*
Peter Bergner	Dec. 1993	Masters	Minimizing Spill Code in Graph Coloring Register Allocators via Arc Spilling.
John Page	July 1993	Masters	Instruction Scheduling and Optimization for Superscalar Microprocessors.
Olivier Meiraghe	April 1994	Masters	Software Testing for a FORTRAN Compiler
Aaron Sawdey	Dec. 1994	Masters	A Cray T3D Emulation Package.
Derek Lee	Feb 1995	Masters	Scientific Animation

Software Developed

[1] *Parallel Ocean Circulation Model* : a parallel version of the Miami ocean model developed for the Cray T3D massively parallel processor and SGI Challenge multiprocessor now used at Caltech and the University of Miami. This parallel ocean model and related pre- and post-processing software is available on the Web at URL address: "*http://www-mount.ee.umn.edu/~sawdey/micom.html*". As of July 1996 there have been 2800 accesses to this Web page.

[2] *The Fortran-P Translator* (beta) : translates Fortran 77 codes to CM Fortran for execution on the CM-5. Developed under ONR, ARO and NSF support.

[3] *Fortran-P Translation Tool Kit* : set of tools for developing all kinds of translation systems; used to date to construct the Fortran-P translator and other translation systems.

Papers Published

Journal Publications

[1] Matthew O'Keefe, Terence Parr, B Kedgar, Steve Anderson, Paul Woodward and Henry Dietz, "The Fortran-P Translator:Towards Automatic Translation of Fortran 77 Programs for Massively Parallel Processors," *The Journal of Scientific Programming*, vol. 4, no. 1, pp. 1-22, Spring 1995.

[2] Allan Knies, Matthew T. O'Keefe, and Tom MacDonald, "High Performance Fortran: A Practical Analysis," *The Journal of Scientific Programming,* vol. 3, no. 3,pp. 187-199, Fall 1994.

[3] Rainer Bleck, Sumner Dean, Matthew O'Keefe and Aaron Sawdey, "A Comparison of Data-Parallel and Message-Passing Versions of the Miami Isopycnic Coordinate Ocean Model," *Parallel Computing*, vol. 4, no. 1, 1995.

[4] Aaron C. Sawdey and Matthew T. O'Keefe, "A Software-level Cray T3D Emulation Package for SGI Shared-memory Multiprocessor Systems," submitted to *Software: Practice and Experience*, June 1995, *under revision.*

Book Publications

[5] Kelvin K. Droegemeier, Ming Xue, Kenneth Johnson, Matthew T. O'Keefe, Aaron C. Sawdey, Gary W. Sabot, Skef Wholey, Kim Mills, and Neng-Tan Lin, *Weather Prediction: A Scalable Storm-Scale Model,* published in **High Performance Computing**, Addison-Wesley Publishers, ed. by G. Sabot, 1995.

[6] Matthew T. O'Keefe and Aaron C. Sawdey, "Translation Tools for High Performance Computing," *Proceedings of the Les Houches Workshop on High Performance Computing in the Geosciences*, Les Houches, France, June 1993. Proceedings published by *Kluwer Academic Publishers* in **High Performance Computing in the Geosciences**, ed. by Francois X. Le Dimet, 1995.

[7] Aaron C. Sawdey, Matthew T. O'Keefe, Rainer Bleck, and Robert W. Numrich, "The Design, Implementation, and Performance of a Parallel Ocean Circulation Model," *Proceedings of the Sixth ECMWF Workshop on the Use of Parallel Processors in Meteorology,* Reading, England, November 1994. Proceedings published by *World Scientific Publishers* (Singapore) in **Coming of Age**, edited by G-R. Hoffman and N. Kreitz, 1995.

[8] David Dent, Lars Isaksen, George Mozdzynski, Matthew T. O'Keefe, Guy Robinson and Fritz Wollenweber, "Performance Measurements of the ECMWF Integrated Forecast System," *Proceedings of the Sixth ECMWF Workshop on the Use of Parallel Processors in Meteorology*, Reading, England, November 1994. Proceedings published by *World Scientific Publishers* (Singapore) in **Coming of Age**, edited by G-R. Hoffman and N. Kreitz, 1995.

[9] Kelvin Droegemeier, Ming Xue, Kenneth Johnson, Kim Mills, and Matthew O'Keefe, "Experiences with the Scalable-Parallel ARPS Cloud/Mesoscale Prediction Model on Massively Parallel and Workstation Cluster Architectures," *Proc. Fifth Workshop on the Use of Parallel Processors in Meteorology,* Reading, England, November 1992. Proceedings published by *World Scientific Publishers* in **Parallel Supercomputing in Atmospheric Science**, edited by G-R. Hoffmann and T. Kauranne, 1993.

Conference Publications

[10] Peter Dahl, Peter Bergner, John Mejia, and Matthew O'Keefe, "Prototyping Compiler and Simulation Tools with PCCTS," *First Annual Purdue Compiler Construction Toolset (PCCTS) Workshop,* Redwood City, CA, July 24-25, 1994. In cooperation with SIGPLAN and NeXT Inc.

[11] Aaron Sawdey, Derek Lee, Thomas Ruwart, Paul Woodward, Matthew O'Keefe, and Rainer Bleck, "Interactive Smooth-Motion Animation of High Resolution Ocean Circulation Calculations," *OCEANS '95 MTS/IEEE Conference,* San Diego, October 1995.

Research Products

Digital Movies: MPEG movies from the calculation described in journal reference [11] are available on the WWW at URL address: "*http://www-mount.ee.umn.edu/~dereklee/micom_movies/micom_movies.html*". These movies were recently reference by Semtner in his article on computer simulations of ocean circulation which appeared in the September issue of *Science.* As of July 1996, there have been 2755 accesses to this Web page. Actual data from our runs is also available at the Web site.

Technical Reports

[1] Terence Parr, Aaron Sawdey, Will Cohen, and Matthew O'Keefe, The Fortran-P Intermediate Representation, Army High Performance Computing Research Center Preprint 94-006, University of Minnesota, Minneapolis, MN, January 1994.

[2] John Page, Peter Dahl, David Engebretsen, Paul Woodward, and Matthew O'Keefe, Code Scheduling for High Performance Computing, Army High Performance Computing Research Center Preprint 93-101, U. of Minnesota, Minneapolis, MN, October 1993.

[3] A. Sawdey, M. O'Keefe, and T. Parr, Implementing a Fortran 77 to CM Fortran translator using the SORCERER source-to-source translator generator, Army High Performance Computing Research Center Preprint 93-102, U. of Minnesota, Minneapolis, MN, October 1993.