

Zhiyuan Li Pen-Chung Yew
Siddharta Chatterjee Chua-Huang Huang
P. Sadayappan David Sehr (Eds.)

Languages and Compilers for Parallel Computing

10th International Workshop, LCPC'97
Minneapolis, Minnesota, USA
August 7-9, 1997
Proceedings



Springer

Volume Editors

Zhiyuan Li

Purdue University, Department of Computer Sciences

1398 Computer Science Building, West Lafayette, IN 47907, USA

E-mail: li@cs.purdue.edu

Pen-Chung Yew

University of Minnesota, Department of Computer Science and Engineering

Minneapolis, MN 55455, USA

E-mail: yew@cs.umn.edu

Siddharta Chatterjee

University of North Carolina, Department of Computer Science

CB#3175, Sitterson Hall 362, Chapel Hill, NC 27599-3175, USA

E-mail: sc@cs.unc.edu

Chua-Huang Huang

P. Sadayappan

The Ohio State University, Department of Computer and Information Sciences

Columbus, OH 43210-1277, USA

E-mail: {chh/saday}@cis.ohio-state.edu

David Sehr

Intel Corporation

2200 Mission College Boulevard, RN6-18, Santa Clara, CA 95052, USA

E-mail: dsehr@gomez.sc.intel.com

Cataloging-in-Publication data applied for

Die Deutsche Bibliothek - CIP-Einheitsaufnahme

Languages and compilers for parallel computing : 10th international workshop ; proceedings / LCPC '97, Minneapolis, Minnesota, USA, August 7 - 9, 1997. Z. Li ... (ed.). - Berlin ; Heidelberg ; New York ; Barcelona ; Budapest ; Hong Kong ; London ; Milan ; Paris ; Santa Clara ; Singapore ; Tokyo : Springer, 1998

(Lecture notes in computer science ; Vol. 1366)

ISBN 3-540-64472-5

CR Subject Classification (1991): D.1.3, D.3.1, D.3.4, F.1.2, B.2.1

ISSN 0302-9743

ISBN 3-540-64472-5 Springer-Verlag Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1998

Printed in Germany

Typesetting: Camera-ready by author

SPIN 10631837 06/3142 - 5 4 3 2 1 0 Printed on acid-free paper

Preface

This year, 1997, is the tenth anniversary of the Annual International Workshop on Languages and Compilers for Parallel Computing (LCPC), a forum for leading research groups to present their current research activities and latest results. The workshop has also been a meeting place to provide intensive interaction and exchanges of ideas about future directions in this dynamic field. Cosponsored by the Minnesota Supercomputing Institute and Cray Research, Inc. (a Silicon Graphics Company), LCPC'97 was hosted by the University of Minnesota from August 7 to August 9, 1997, at the Hubert H. Humphrey Center on the University of Minnesota Twin Cities campus in Minneapolis. Seventy-seven people attended the workshop.

The program committee of LCPC'97, with the help of external reviewers, evaluated the submitted papers. Twenty-eight were selected for formal presentation at the workshop. Each session was followed by an open panel discussion centered on the main topic of the particular session. Many attendees have come to regard the open panels as a very effective format for exchanging views and clarifying research issues. In addition, a poster session was held where several groups, with or without formally presented papers, exhibited and discussed their work. Using feedback provided both during and after the presentations, all of the authors were given an opportunity to improve their papers before submitting the final manuscript contained in this volume. We believe that this collection of papers documents important research activities from the past year in the design and implementation of programming languages and environments for parallel computing.

Recent trends in computer system architecture have been to incorporate multiple levels of parallelism and multiple levels of memory hierarchy. These trends were clearly reflected in the work presented at this year's workshop. Most of the presentations fell into four broad categories: data locality enhancement, parallel programming models and parallel languages, automatic parallelization, and synchronization and communication. In the final editing of these proceedings, we grouped the workshop papers into the above categories.

Two additional events during the workshop gave participants an opportunity to learn about the status of two major research projects in the field. Ken Kennedy, a Noah Harding Professor of Computer Science at Rice University and a member of the National Academy of Engineering, gave a keynote speech titled "High Performance Fortran: A Ten-Year Retrospective View." Professor Kennedy led the effort in making High-Performance Fortran (HPF) an industry standard beginning about ten years ago. His invited speech was part of the celebration for the 10th anniversary of this workshop. A special session titled "SUIF Compiler Infrastructure" was organized by Professor Monica Lam of Stanford University and Professor Martin Rinard of MIT. This special session outlined the goals and the technical details of this ARPA-funded national parallelizing compiler infrastructure project. We thank Professors Kennedy, Lam, and Rinard

for their special contributions to LCPC'97.

We also are grateful to Silicon Graphics/Cray Research, Inc., for their generous financial support of this workshop. We are indebted to the Minnesota Supercomputing Institute (MSI) not only for its generous financial contribution but also for its excellent administrative assistance. We were very fortunate to have Michael Olesen of MSI, assisted by Susan Kalenze, coordinating the innumerable logistical matters before, during, and after the workshop. Their efforts made LCPC'97 a pleasant experience for all of the participants.

Special thanks are due to the LCPC'97 Steering Committee and Program Committee for their many suggestions on the organization of the workshop, and for their time and energy in reviewing the submitted papers. Lastly, but most importantly, we wish to thank all of the authors and participants of LCPC'97. It is their significant research work and their enthusiastic discussions throughout the workshop that made LCPC'97 a tremendous success.

Zhiyuan Li
Pen-Chung Yew
Program Co-Chairs

February 1998

Steering Committee

Utpal Banerjee (Intel Corporation)
David Gelernter (Yale University)
Alex Nicolau (University of California, Irvine)
David Padua (University of Illinois, Urbana-Champaign)

Programming Committee

Sid Chatterjee (University of North Carolina)
Chua-Huang Huang (Ohio State University)
Zhiyuan Li (University of Minnesota, Minneapolis, Co-Chair)
P. Sadayappan (Ohio State University)
David Sehr (Intel Corporation)
Pen-Chung Yew (University of Minnesota, Minneapolis, Co-Chair)

External Referees

Dong-Yuan Chen
William Chen
Junjie Gu
Jian Huang
Peter M. Jensen
Guohua Jin
Knud J. Kirkegaard
Yong-fong Lee
John Ng
Trung N. Nguyen
Matthew O’Keefe
Stephen Skedzielewski
Ernesto Su

Table of Contents

Data Locality

Quantifying the Multi-level Nature of Tiling Interactions	1
<i>N. Mitchell, L. Carter, J. Ferrante, K. Högstedt</i> (University of California, San Diego)	
Reuse-Driven Tiling for Data Locality	16
<i>J. Xue</i> (University of New England, Armidale, Australia)	
<i>C.-H. Huang</i> (Ohio State University)	
Table-Lookup Approach for Compiling Two-Level Data-Processor Mappings in HPF	34
<i>K.-P. Shih, J.-P. Sheu</i> (National Central University, Taiwan)	
<i>C.-H. Huang</i> (Ohio State University)	
Code Generation for Complex Subscripts in Data-Parallel Programs	49
<i>J. Ramanujam, S. Dutta, A. Venkatachar</i> (Louisiana State University, Baton Rouge)	
Automatic Data Decomposition for Message-Passing Machines	64
<i>M. Damian-Iordache, S. V. Pemmaraju</i> (University of Iowa)	
Program Analysis of Overlap Area Usage in Self-Similar Parallel Programs	79
<i>A. Sawdey, M. O'Keefe</i> (University of Minnesota, Minneapolis)	

Program Analysis

Analysis and Optimization of Explicitly Parallel Programs Using the Parallel Program Graph Representation	94
<i>V. Sarkar</i> (Massachusetts Institute of Technology)	
Concurrent Static Single Assignment Form and Constant Propagation for Explicitly Parallel Programs	114
<i>J. Lee</i> (University of Illinois, Urbana)	
<i>S. P. Midkiff</i> (IBM T. J. Watson Research Center, Yorktown Heights, New York)	
<i>D. A. Padua</i> (University of Illinois, Urbana)	
Identifying DEF/USE Information of Statements that Construct and Traverse Dynamic Recursive Data Structures	131
<i>Y.-S. Hwang, J. Saltz</i> (University of Maryland, College Park)	

Automatic Parallelization

Program Optimization for Concurrent Multithreaded Architectures	146
<i>J.-Y. Tsai</i> (University of Illinois, Urbana)	
<i>Z. Jiang, P.-C. Yew</i> (University of Minnesota, Minneapolis)	
Interactive Compilation and Performance Analysis with URSA MINOR	163
<i>I. Park, M. Voss, B. Armstrong, R. Eigenmann</i> (Purdue University)	
The SPNT Test: A New Technology for Run-Time Speculative Parallelization of Loops	177
<i>T.-C. Huang, P.-H. Hsu</i> (National Sun Yat-Sen University, Taiwan)	

HPF Extensions and Compilers

Lowering HPF Procedure Interface to a Canonical Representation	192
<i>J. Borowiec</i> (GMD FIRST Research Institute for Computer Architecture and Software Technology, Berlin, Germany)	
<i>A. Veen</i> (Parallel Computing, Amsterdam, The Netherlands)	
PCRC-based HPF Compilation	204
<i>G. Zhang, B. Carpenter, G. Fox, Xiaoming Li, Xinying Li, Y. Wen</i> (NPAC, Syracuse University)	
Data Parallel Language Extensions for Exploiting Locality in Irregular Problems	218
<i>G. P. Trabado, E. L. Zapata</i> (University of Málaga, Spain)	
Simplifying Control Flow in Compiler-Generated Parallel Code	235
<i>J. Mellor-Crummey, V. Adve</i> (Rice University)	

Synchronization and Communication

Reducing Synchronization Overhead for Compiler-Parallelized Codes on Software DSMs	240
<i>H. Han, C.-W. Tseng, P. Keleher</i> (University of Maryland, College Park)	
An Array Data Flow Analysis Based Communication Optimizer	246
<i>X. Yuan, R. Gupta, R. Melhem</i> (University of Pittsburgh)	
A Compiler Abstraction for Machine Independent Parallel Communication Generation	261
<i>B. L. Chamberlain, S.-E. Choi, L. Snyder</i> (University of Washington)	
The Aggregate Function API: It's Not Just for PAPERS Anymore	277
<i>H. G. Dietz, T. I. Mattox, G. Krishnamurthy</i> (Purdue University)	

Parallel Programming Models and Language Extensions

Definition of the F ⁺⁺ Extension to Fortran 90	292
<i>R. W. Numrich, J. L. Steidel, B. H. Johnson</i> (Cray Research, Eagan, MN)	
<i>B. Dupont de Dinechin</i> (Commissariat a l'Energie Atomique, Centre d'Etudes de Limeil-Valenton, France)	
<i>G. Elsesser, G. Fischer, T. MacDonald</i> (Cray Research, Eagan, MN)	
Exploiting Parallelism Through Directives on the Nano-Threads Programming Model	307
<i>E. Ayguadé, X. Martorell, J. Labarta, M. González, N. Navarro</i> (Polytechnic University of Catalunya, Barcelona, Spain)	
"Optimal" Parallelism through Integration of Data and Control Parallelism: A Case Study in Complete Parallelization	322
<i>D. Banerjee, J. C. Browne</i> (University of Texas, Austin)	
Java as a Language for Scientific Parallel Programming	340
<i>B. Carpenter, Y.-J. Chang, G. Fox, X. Li</i> (NPAC, Syracuse University)	
Experience with Loop Parallelization in <i>javac</i> (A Prototype Restructuring Compiler for Java)	355
<i>A. J.C. Bik, J. E. Villacis, D. B. Gannon</i> (Indiana University)	
NAMD: A Case Study in Multilingual Parallel Programming	367
<i>L. V. Kalé, M. Bhandarkar, R. Brunner, N. Krawetz, J. Phillips, A. Shinozaki</i> (University of Illinois, Urbana)	

Instruction Level Parallelism

A Unified Software Pipeline Construction Scheme for Modulo Scheduled Loops	382
<i>B. Dupont de Dinechin</i> (McGill University)	
A Systematic Approach to Branch Speculation	394
<i>G. Bilardi</i> (Università di Padova, Italy & University of Illinois, Chicago)	
<i>A. Nicolau</i> (University of California, Irvine)	
<i>J. Hummel</i> (University of Illinois, Chicago)	

Poster Papers

Integrating Automatic Data Alignment and Array Operation Synthesis to Optimize Data Parallel Programs	412
<i>G.-H. Hwang, J. K. Lee</i> (National Tsing-Hua University, Taiwan)	
<i>D.-C. R. Ju</i> (Hewlett-Packard Company, Cupertino, CA)	
A Compiler for the IBM Scalable Shared Memory Project Machine	416
<i>M. Gupta, S. P. Midkiff</i> (IBM T. J. Watson Research Center, Yorktown Heights, NY)	

Automatic Data Layout with Read-Only Replication and Memory Constraints	419
<i>U. Kremer</i> (Rutgers University)	
Static Analysis of Recursive Data Structures	423
<i>D. K. Arvind, T. A. Lewis</i> (University of Edinburgh, Scotland)	
Author Index	427