

*Commenced Publication in 1973*

Founding and Former Series Editors:

Gerhard Goos, Juris Hartmanis, and Jan van Leeuwen

## Editorial Board

David Hutchison

*Lancaster University, UK*

Takeo Kanade

*Carnegie Mellon University, Pittsburgh, PA, USA*

Josef Kittler

*University of Surrey, Guildford, UK*

Jon M. Kleinberg

*Cornell University, Ithaca, NY, USA*

Alfred Kobsa

*University of California, Irvine, CA, USA*

Friedemann Mattern

*ETH Zurich, Switzerland*

John C. Mitchell

*Stanford University, CA, USA*

Moni Naor

*Weizmann Institute of Science, Rehovot, Israel*

Oscar Nierstrasz

*University of Bern, Switzerland*

C. Pandu Rangan

*Indian Institute of Technology, Madras, India*

Bernhard Steffen

*TU Dortmund University, Germany*

Madhu Sudan

*Microsoft Research, Cambridge, MA, USA*

Demetri Terzopoulos

*University of California, Los Angeles, CA, USA*

Doug Tygar

*University of California, Berkeley, CA, USA*

Gerhard Weikum

*Max Planck Institute for Informatics, Saarbruecken, Germany*

Barbara M. Chapman William D. Gropp  
Kalyan Kumaran Matthias S. Müller (Eds.)

# OpenMP in the Petascale Era

7th International Workshop on OpenMP, IWOMP 2011  
Chicago, IL, USA, June 13-15, 2011  
Proceedings

## Volume Editors

Barbara M. Chapman

University of Houston, Dept. of Computer Science  
4800 Calhoun Rd, Houston, TX, 77204-3010, USA  
E-mail: chapman@cs.uh.edu

William D. Gropp

University of Illinois at Urbana-Champaign, Dept. of Computer Science  
201 N Goodwin Ave, Urbana, IL 61801, USA  
E-mail: wgropp@illinois.edu

Kalyan Kumaran

Argonne National Laboratory  
TCS, Bldg 240, Rm 1125, 9700 S. Cass Avenue, Argonne, IL 60439, USA  
E-mail: kumaran@alcf.anl.gov

Matthias S. Müller

University of Technology Dresden  
Center for Information Services and High Performance Computing (ZIH)  
Zellescher Weg 12, 01062 Dresden, Germany  
E-mail: matthias.mueller@tu-dresden.de

ISSN 0302-9743

e-ISSN 1611-3349

ISBN 978-3-642-21486-8

e-ISBN 978-3-642-21487-5

DOI 10.1007/978-3-642-21487-5

Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2011928504

CR Subject Classification (1998): C.1, D.2, F.2, D.4, C.3, C.4

LNCS Sublibrary: SL 2 – Programming and Software Engineering

© Springer-Verlag Berlin Heidelberg 2011

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. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

*Typesetting:* Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India

Printed on acid-free paper

Springer is part of Springer Science+Business Media ([www.springer.com](http://www.springer.com))

# Preface

OpenMP is a widely accepted, standard application programming interface (API) for high-level shared-memory parallel programming in Fortran, C, and C++. Since its introduction in 1997, OpenMP has gained support from most high-performance compiler and hardware vendors. Under the direction of the OpenMP Architecture Review Board (ARB), the OpenMP specification has evolved, including the recent release of the draft of Specification 3.1 for public comment. Active research in OpenMP compilers, runtime systems, tools, and environments drives its evolution, including new features such as tasking. OpenMP is both an important programming model for single multicore processors and as part of a hybrid programming model for massively parallel, distributed memory systems built from multicore or manycore processors. In fact, OpenMP offers important features that can improve the scalability of applications on the petascale systems now being installed (both the current “Peak” petascale systems and the sustained petascale systems, two of which are being installed in Illinois). This year’s conference took its title from the important role that OpenMP has to play in the new era of petascale computing systems. The papers, each of which was rigorously reviewed by at least three experts in the field, cover everything from using OpenMP with applications, tools for more effective use of OpenMP, and extensions and implementation of OpenMP.

The community of OpenMP researchers and developers in academia and industry is united under cOMPunity ([www.compunity.org](http://www.compunity.org)). This organization has held workshops on OpenMP around the world since 1999: the European Workshop on OpenMP (EWOMP), the North American Workshop on OpenMP Applications and Tools (WOMPAT), and the Asian Workshop on OpenMP Experiences and Implementation (WOMPEI) attracted annual audiences from academia and industry. The International Workshop on OpenMP (IWOMP) consolidated these three workshop series into a single annual international event that rotates across the previous workshop sites. The first IWOMP meeting was held in 2005, in Eugene, Oregon, USA. Since then, meetings have been held each year, in Reims, France, Beijing, China, West Lafayette, USA, Dresden, Germany, and Tsukuba, Japan. Each workshop has drawn participants from research and industry throughout the world. IWOMP 2011 continued the series with technical papers, tutorials, and OpenMP status reports. In addition, IWOMP 2011 was colocated with the meetings of the OpenMP Architecture Review Board and Language Committee, providing a close connection between researchers and OpenMP standard. The first IWOMP workshop was organized under the auspices of cOMPunity. Since that workshop, the IWOMP Steering Committee has organized these events and guided development of the series. The IWOMP meetings have been successful in large part due to the generous support from numerous sponsors.

The cOMPunity website ([www.compunity.org](http://www.compunity.org)) provides access to many of the activities and resources of the OpenMP community. The IWOMP website ([www.iwomp.org](http://www.iwomp.org)) provides information on the latest event. This book contains proceedings of IWOMP 2011. The workshop program included 13 technical papers, 2 keynote talks, and a tutorial on OpenMP.

March 2011

Barbara M. Chapman  
William D. Gropp  
Kalyan Kumaran  
Matthias S. Müller

# Conference Organization

## Organizing Co-chairs

William Gropp	University of Illinois, USA
Kalyan Kumaran	Argonne National Laboratory, USA

## Sponsors Contact Chair

Barbara Chapman	University of Houston, USA
-----------------	----------------------------

## Tutorials Chair

Ruud van der Pas	Oracle America, USA
------------------	---------------------

## Local Coordination Chair

David Martin	Argonne National Laboratory, USA
--------------	----------------------------------

## Program Committee

William Gropp (Co-chair)	University of Illinois, USA
Kalyan Kumaran (Co-chair)	Argonne National Laboratory, USA
Dieter an Mey	RWTH Aachen University, Germany
Eduard Ayguade	Barcelona Supercomputing Center, Spain
Mark Bull	EPCC, UK
Rudi Eigenmann	Purdue University, USA
Maria Garzaran	University of Illinois, USA
Guang R. Gao	University of Delaware, USA
Lei Huang	University of Houston, USA
Ricky Kendall	Oak Ridge National Laboratory, USA
Rick Kufrin	National Center for Supercomputing Applications/University of Illinois, USA
Raymond Loy	Argonne National Laboratory, USA
Larry Meadows	Intel, USA
Matthias Müller	ZIH, TU Dresden, Germany
Bronis R. de Supinski	NNSA ASC, LLNL, USA
Mitsuhsa Sato	University of Tsukuba, Japan
Ruud van der Pas	Oracle America, USA
Michael Wong	IBM, Canada

## IWOMP Steering Committee

<b>Chair</b>	Matthias S. Mueller, ZIH, TU Dresden, Germany
<b>Committee Members</b>	Dieter an Mey, CCC, RWTH Aachen University, Germany Eduard Ayguade, Barcelona Supercomputing Center (BSC), Spain Mark Bull, EPCC, UK Barbara Chapman, CEO of cOMPunity, USA Rudi Eigenmann, Purdue University, USA Guang R. Gao, University of Delaware, USA Ricky Kendall, Oak Ridge National Laboratory, USA Michael Krajecki, University of Reims, France Rick Kufrin, NCSA/University of Illinois, USA Federico Massaioli, CASPUR, Italy Larry Meadows, Intel, OpenMP CEO, USA Arnaud Renard, University of Reims, France Mitsuhisa Sato, University of Tsukuba, Japan Sanjiv Shah, Intel Bronis R. de Supinski, NNSA ASC, LLNL, USA Ruud van der Pas, Oracle America, USA Matthijs van Waveren, Fujitsu, France Michael Wong, IBM, Canada Weimin Zheng, Tsinghua University, China

## Additional Reviewers

Duran, Alex  
Garcia, Elkin  
Livingston, Kelly  
Manzano, Joseph  
Orozco, Daniel

# Table of Contents

## Using OpenMP with Applications

Parallelising Computational Microstructure Simulations for Metallic Materials with OpenMP .....	1
<i>Ralph Altenfeld, Markus Apel, Dieter an Mey, Bernd Böttger, Stefan Benke, and Christian Bischof</i>	

Hybrid Programming Model for Implicit PDE Simulations on Multicore Architectures .....	12
<i>Dinesh Kaushik, David Keyes, Satish Balay, and Barry Smith</i>	

An Experimental Model to Analyze OpenMP Applications for System Utilization .....	22
<i>Mark Woodyard</i>	

## Tools for OpenMP

ompVerify: Polyhedral Analysis for the OpenMP Programmer .....	37
<i>V. Basupalli, T. Yuki, S. Rajopadhye, A. Morvan, S. Derrien, P. Quinton, and D. Wonnacott</i>	

A Dynamic Optimization Framework for OpenMP .....	54
<i>Besar Wicaksono, Ramachandra C. Nanjegowda, and Barbara Chapman</i>	

Towards NUMA Support with Distance Information .....	69
<i>Dirk Schmidl, Christian Terboven, and Dieter an Mey</i>	

## Extensions for OpenMP

Thread-Local Storage Extension to Support Thread-Based MPI/OpenMP Applications .....	80
<i>Patrick Carribault, Marc Pérache, and Hervé Jourden</i>	

OpenMP Extensions for Heterogeneous Architectures .....	94
<i>Leo White</i>	

OpenMP for Accelerators .....	108
<i>James C. Beyer, Eric J. Stotzer, Alistair Hart, and Bronis R. de Supinski</i>	

Unifying Barrier and Point-to-Point Synchronization in OpenMP with Phasers .....	122
<i>Jun Shirako, Kamal Sharma, and Vivek Sarkar</i>	



## Implementation and Performance

Performance Evaluation of OpenMP Applications on Virtualized Multicore Machines .....	138
<i>Jie Tao, Karl F�rlinger, and Holger Marten</i>	
Performance Analysis and Tuning of Automatically Parallelized OpenMP Applications .....	151
<i>Dheya Mustafa, Aurangzeb, and Rudolf Eigenmann</i>	
A Runtime Implementation of OpenMP Tasks .....	165
<i>James LaGrone, Ayodunni Aribuki, Cody Addison, and Barbara Chapman</i>	
<b>Author Index</b> .....	179