

Commenced Publication in 1973

Founding and Former Series Editors:

Gerhard Goos, Juris Hartmanis, and Jan van Leeuwen

Editorial Board

David Hutchison, UK

Josef Kittler, UK

Alfred Kobsa, USA

John C. Mitchell, USA

Oscar Nierstrasz, Switzerland

Bernhard Steffen, Germany

Demetri Terzopoulos, USA

Gerhard Weikum, Germany

Takeo Kanade, USA

Jon M. Kleinberg, USA

Friedemann Mattern, Switzerland

Moni Naor, Israel

C. Pandu Rangan, India

Madhu Sudan, USA

Doug Tygar, USA

Advanced Research in Computing and Software Science

Subline of Lectures Notes in Computer Science

Subline Series Editors

Giorgio Ausiello, *University of Rome 'La Sapienza', Italy*

Vladimiro Sassone, *University of Southampton, UK*

Subline Advisory Board

Susanne Albers, *University of Freiburg, Germany*

Benjamin C. Pierce, *University of Pennsylvania, USA*

Bernhard Steffen, *University of Dortmund, Germany*

Madhu Sudan, *Microsoft Research, Cambridge, MA, USA*

Deng Xiaotie, *City University of Hong Kong*

Jeannette M. Wing, *Carnegie Mellon University, Pittsburgh, PA, USA*

Michael O'Boyle (Ed.)

Compiler Construction

21st International Conference, CC 2012

Held as Part of the European Joint Conferences
on Theory and Practice of Software, ETAPS 2012
Tallinn, Estonia, March 24 – April 1, 2012

Proceedings

Volume Editor

Michael O'Boyle
University of Edinburgh
School for Informatics
10 Crichton Street, Edinburgh, EH8 9AB, UK
E-mail: mob@inf.ed.ac.uk

ISSN 0302-9743 e-ISSN 1611-3349
ISBN 978-3-642-28651-3 e-ISBN 978-3-642-28652-0
DOI 10.1007/978-3-642-28652-0
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2012932643

CR Subject Classification (1998): D.2, D.3, D.2.4, C.2, D.4, D.1, F.3.2

LNCS Sublibrary: SL 1 – Theoretical Computer Science and General Issues

© Springer-Verlag Berlin Heidelberg 2012

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)

Foreword

ETAPS 2012 is the fifteenth instance of the European Joint Conferences on Theory and Practice of Software. ETAPS is an annual federated conference that was established in 1998 by combining a number of existing and new conferences. This year it comprised six sister conferences (CC, ESOP, FASE, FOSSACS, POST, TACAS), 21 satellite workshops (ACCAT, AIPA, BX, BYTECODE, CMCS, DICE, FESCA, FICS, FIT, GRAPHITE, GT-VMT, HAS, IWIGP, LDTA, LINEARITY, MBT, MSFP, PLACES, QAPL, VSSE and WRLA), and eight invited lectures (excluding those specific to the satellite events).

The six main conferences received this year 606 submissions (including 21 tool demonstration papers), 159 of which were accepted (6 tool demos), giving an overall acceptance rate just above 26%. Congratulations therefore to all the authors who made it to the final programme! I hope that most of the other authors will still have found a way to participate in this exciting event, and that you will all continue to submit to ETAPS and contribute to making it the best conference on software science and engineering.

The events that comprise ETAPS address various aspects of the system development process, including specification, design, implementation, analysis, security and improvement. The languages, methodologies and tools that support these activities are all well within its scope. Different blends of theory and practice are represented, with an inclination towards theory with a practical motivation on the one hand and soundly based practice on the other. Many of the issues involved in software design apply to systems in general, including hardware systems, and the emphasis on software is not intended to be exclusive.

ETAPS is a confederation in which each event retains its own identity, with a separate Programme Committee and proceedings. Its format is open-ended, allowing it to grow and evolve as time goes by. Contributed talks and system demonstrations are in synchronised parallel sessions, with invited lectures in plenary sessions. Two of the invited lectures are reserved for ‘unifying’ talks on topics of interest to the whole range of ETAPS attendees. The aim of cramming all this activity into a single one-week meeting is to create a strong magnet for academic and industrial researchers working on topics within its scope, giving them the opportunity to learn about research in related areas, and thereby to foster new and existing links between work in areas that were formerly addressed in separate meetings.

This year, ETAPS welcomes a new main conference, *Principles of Security and Trust*, as a candidate to become a permanent member conference of ETAPS. POST is the first addition to our main programme since 1998, when the original five conferences met in Lisbon for the first ETAPS event. It combines the practically important subject matter of security and trust with strong technical connections to traditional ETAPS areas.

A step towards the consolidation of ETAPS and its institutional activities has been undertaken by the Steering Committee with the establishment of *ETAPS e.V.*, a non-profit association under German law. ETAPS e.V. was founded on April 1st, 2011 in Saarbrücken, and we are currently in the process of defining its structure, scope and strategy.

ETAPS 2012 was organised by the *Institute of Cybernetics at Tallinn University of Technology*, in cooperation with

- ▷ European Association for Theoretical Computer Science (EATCS)
- ▷ European Association for Programming Languages and Systems (EAPLS)
- ▷ European Association of Software Science and Technology (EASST)

and with support from the following sponsors, which we gratefully thank:

INSTITUTE OF CYBERNETICS AT TUT; TALLINN UNIVERSITY OF TECHNOLOGY (TUT); ESTONIAN CENTRE OF EXCELLENCE IN COMPUTER SCIENCE (EXCS) FUNDED BY THE EUROPEAN REGIONAL DEVELOPMENT FUND (ERDF); ESTONIAN CONVENTION BUREAU; and MICROSOFT RESEARCH.

The organising team comprised:

General Chair: *Tarmo Uustalu*

Satellite Events: *Keiko Nakata*

Organising Committee: *James Chapman, Juhan Ernits, Tiina Laasma, Monika Perkmann* and their colleagues in the *Logic and Semantics* group and *administration* of the *Institute of Cybernetics*

The ETAPS portal at <http://www.etaps.org> is maintained by *RWTH Aachen University*.

Overall planning for ETAPS conferences is the responsibility of its Steering Committee, whose current membership is:

Vladimiro Sassone (Southampton, Chair), Roberto Amadio (Paris 7), Gilles Barthe (IMDEA-Software), David Basin (Zürich), Lars Birkedal (Copenhagen), Michael O’Boyle (Edinburgh), Giuseppe Castagna (CNRS Paris), Vittorio Cortellessa (L’Aquila), Koen De Bosschere (Gent), Pierpaolo Degano (Pisa), Matthias Felleisen (Boston), Bernd Finkbeiner (Saarbrücken), Cormac Flanagan (Santa Cruz), Philippa Gardner (Imperial College London), Andrew D. Gordon (MSR Cambridge and Edinburgh), Daniele Gorla (Rome), Joshua Guttman (Worcester USA), Holger Hermanns (Saarbrücken), Mike Hinchey (Lero, the Irish Software Engineering Research Centre), Ranjit Jhala (San Diego), Joost-Pieter Katoen (Aachen), Paul Klint (Amsterdam), Jens Knoop (Vienna), Barbara König (Duisburg), Juan de Lara (Madrid), Gerald Lüttgen (Bamberg), Tiziana Margaria (Potsdam), Fabio Martinelli (Pisa), John Mitchell (Stanford), Catuscia Palamidessi (INRIA Paris), Frank Pfenning (Pittsburgh), Nir Piterman (Leicester), Don Sannella (Edinburgh), Helmut Seidl (TU Munich),

Scott Smolka (Stony Brook), Gabriele Taentzer (Marburg), Tarmo Uustalu (Tallinn), Dániel Varró (Budapest), Andrea Zisman (London), and Lenore Zuck (Chicago).

I would like to express my sincere gratitude to all of these people and organisations, the Programme Committee Chairs and PC members of the ETAPS conferences, the organisers of the satellite events, the speakers themselves, the many reviewers, all the participants, and Springer-Verlag for agreeing to publish the ETAPS proceedings in the ARCoSS subline.

Finally, I would like to thank the Organising Chair of ETAPS 2012, Tarmo Uustalu, and his Organising Committee, for arranging to have ETAPS in the most beautiful surroundings of Tallinn.

January 2012

Vladimiro Sassone
ETAPS SC Chair

Preface

This volume contains the paper presented at CC 2012, the 21st International Conference on Compiler Construction held on March 28–29 in Tallinn, Estonia as part of the European Joint Conferences on Theory and Practice of Software (ETAPS 2012). Papers were solicited from a wide range of areas including compiler analysis, code generation and optimization, runtime systems, just-in-time compilation, programming tools, techniques for specific domains and the design and implementation of novel language constructs. The submissions and the papers in this volume reflect the variety of our research domain.

There were 51 submissions. Each submission was reviewed by at least three Program Committee members and was subjected to several rounds of thorough discussions. The Program Committee finally decided to accept 13 papers.

Many people contributed to the success of this conference. First of all, I would like to thank the authors for submitting their papers of high quality. I would particularly like to thank the members of the Program Committee for their insightful reviews and keeping to often tight timescales. Also thanks are due to the developers and supporters of the EasyChair conference management system for making life so much easier for the authors and the Program Committee.

CC 2012 was made possible by the ETAPS Steering Committee and the Local Organizing Committee. Finally, I would like to thank Francois Bodin for his CC 2012 invited talk entitled “Programming Heterogeneous Many-Cores Using Directives.”

January 2012

Michael O’Boyle

Organization

Program Committee

Erik Altman	IBM, USA
Rastislav Bodik	UC Berkeley, USA
John Cavazos	University of Delaware, USA
Nathan Clark	Georgia Tech, USA
Murray Cole	University of Edinburgh, UK
Alain Darte	CNRS, France
Bjorn De Sutter	Ghent University, Belgium
Amer Diwan	University of Colorado, USA
Derek Dreyer	Max Planck Institute for Software Systems, Germany
Matthew Flatt	University of Utah, USA
Sumit Gulwani	Microsoft Research, USA
Atsushi Igarashi	Graduate School of Informatics, Kyoto University, Japan
Ranjit Jhala	UC San Diego, USA
Andreas Krall	TU Wien, Austria
Julia Lawall	DIKU/INRIA-Regal, France
Anton Lokhmotov	ARM Ltd., UK
Püschel Markus	ETH Zurich, Switzerland
Michael O'Boyle	University of Edinburgh, UK
Erez Petrank	Microsoft Research and Technion, Israel
David Sands	Chalmers, Sweden
Vivek Sarkar	Rice University, USA
Jan Vitek	Purdue University, USA

Invited Program

Programming Heterogeneous Many-Cores Using Directives

Francois Bodin

CAPS Enterprise, Rennes, France
<http://www.caps-entreprise.com/>

Abstract. Directive-based programming models are a pragmatic way of adapting legacy codes to heterogeneous many-cores such as CPUs coupled with GPUs. They provide programmers an abstracted and portable interface for developing many-core applications. The directives are used to express parallel computation, data transfers between the CPU and the GPU memories and code tuning hints. The challenge for such environment is to achieve high programming productivity and at the same time provide performance portability across hardware platforms.

In this presentation we give an overview the state of the art of directives based parallel programming environments for many-core accelerators. In particular, we describe OpenACC (<http://www.openacc-standard.org/>), an initiative from CAPS, CRAY, NVIDIA and PGI that provides a new open parallel programming standard for C, C++ and Fortran languages. We show how tuning can be performed in such programming approach and specifically address numerical library inter-operability issues.

Table of Contents

GPU Optimisation

Improving Performance of OpenCL on CPUs	1
<i>Ralf Karrenberg and Sebastian Hack</i>	
Automatic Restructuring of GPU Kernels for Exploiting Inter-thread Data Locality	21
<i>Swapneela Unkule, Christopher Shaltz, and Apan Qasem</i>	

Program Analysis

Programming Paradigm Driven Heap Analysis	41
<i>Mark Marron, Ondřej Lhoták, and Anindya Banerjee</i>	
Parallel Replication-Based Points-To Analysis	61
<i>Sandeep Putta and Rupesh Nasre</i>	
A New Method for Program Inversion	81
<i>Cong Hou, George Vulov, Daniel Quinlan, David Jefferson, Richard Fujimoto, and Richard Vuduc</i>	
Analytical Bounds for Optimal Tile Size Selection	101
<i>Jun Shirako, Kamal Sharma, Naznin Fauzia, Louis-Noël Pouchet, J. Ramanujam, P. Sadayappan, and Vivek Sarkar</i>	

Objects and Components

Static Detection of Unsafe Component Loadings	122
<i>TaeHo Kwon and Zhendong Su</i>	
Object Model Construction for Inheritance in C++ and Its Applications to Program Analysis	144
<i>Jing Yang, Gogul Balakrishnan, Naoto Maeda, Franjo Ivančić, Aarti Gupta, Nishant Sinha, Sriram Sankaranarayanan, and Naveen Sharma</i>	
GC-Safe Interprocedural Unboxing	165
<i>Leaf Petersen and Neal Glew</i>	

Dynamic Analysis and Runtime Support

Compiler Support for Value-Based Indirect Branch Prediction	185
<i>Muhammad Umar Farooq, Lei Chen, and Lizy Kurian John</i>	
Compiler Support for Fine-Grain Software-Only Checkpointing	200
<i>Chuck (Chengyan) Zhao, J. Gregory Steffan, Cristiana Amza, and Allan Kielstra</i>	
VMAD: An Advanced Dynamic Program Analysis and Instrumentation Framework	220
<i>Alexandra Jimborean, Luis Mastrangelo, Vincent Loechner, and Philippe Clauss</i>	
<i>Sambamba</i> : A Runtime System for Online Adaptive Parallelization	240
<i>Kevin Streit, Clemens Hammacher, Andreas Zeller, and Sebastian Hack</i>	
Author Index	245