Dynamically Reconfigurable Systems

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Editors

Dynamically Reconfigurable Systems

Architectures, Design Methods and Applications

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Foreword

After six years of exciting and intensive research, one of the world's largest and longest-running programs of research into Reconfigurable Computing is concluding with the publication of the research papers in this volume. The research was launched in 2003 by Deutsche Forschungsgemeinschaft, the German Research Foundation, as "Schwerpunktprogramm (SPP 1148)" under the title "Rekonfigurierbare Rechensysteme". This translates as the Priority Programme in Reconfigurable Computing Systems. For convenience, we will refer to it here as SPP 1148.

Several aspects of SPP 1148 made it noteworthy from its inception. Beneath the umbrella of reconfigurable computing systems, several key topics were identified. These included theoretical aspects, modeling, languages, analysis, design methodologies, computer-aided design (CAD) tools, architectures and applications. From the onset, the scope of the research was deliberately formulated to be as multidisciplinary as possible. A national network of excellence was established with the aim of encouraging participation from as many academics with novel individual contributions as possible while simultaneously emphasizing and promoting interdisciplinary collaboration.

The six-year program was organized as three successive funding periods of two-years each. At each interval, new projects were proposed and existing projects were reviewed. The two largest project sub-themes were design methodologies and tools, and architectures and applications. Feedback from graduate students who participated in SPP 1148 indicates that they felt especially privileged to have been able to conduct their studies within the framework of this program. In particular, they benefited from the highly collaborative environment that was nurtured by the participating institutions and the continuity afforded by such a sustained period of research funding.

Throughout the conduct of SPP 1148, we have had the privilege of interacting and collaborated directly with many of the research teams. We have become familiar with the majority of the research projects albeit at different levels of detail. We have had the opportunity to observe the progress of SPP 1148 as a whole from our complementary positions in academia and industry. There can be no doubt that the most immediate impact of the DFG's (German Research Foundation) foresight

was to establish German academia as the foremost group in the world for advanced research into reconfigurable computing over the last six years.

The legacy of the SPP 1148 in Reconfigurable Computing Systems is that Germany has developed an impressive national capability in precisely those areas that will be of greatest relevance for the next decade. As we reach for 40 nm integrated circuits and beyond, it is clear that fewer companies and fewer architectures will be viable at these ever more advanced process nodes. The successful architectures will be highly concurrent and will combine programmability and reconfigurability capabilities.

This book is unique in many different ways. Not only does it provide a structured compilation for the research resulting from this extensive program, it also gives an excellent overall insight into various strategic directions in which the entire field of reconfigurable technologies and systems may be heading. In addition, in the four separate parts of the book, the coverage of each of the subjects is comprehensive. Aspects relating to architectures, design methodologies, design tools and a large number of applications are all included. No other book currently in print has such an extensive and overall coverage as this. As such, it is equally suitable for supporting graduate level courses and for practical engineers working in the field of reconfigurable hardware and particularly in FPGAs. We are delighted to see the work and experience of such a large group of researchers and engineers being shared with the reconfigurable community at large.

Patrick Lysaght, Xilinx Corporation
Peter Cheung, Imperial College London
August 2009

Preface

While the idea of creating computing systems with flexible hardware dates back to the 1960s, it was the emergence of the SRAM-based field-programmable gate array (FPGA) in the 1980s that boosted *Reconfigurable Computing* as a research and engineering field. Since then, reconfigurable computing has become a vibrant area with an increasingly growing research community and exciting commercial ventures.

Reconfigurable computing devices are able to adapt their hardware to application demands and serve broad and relevant application domains from embedded to high-performance computing, including automotive, aerospace and defense, telecommunication and networking, medical and biometric computing. Especially in the embedded computing domain with its many and often conflicting objectives reconfigurable computing systems offer new trade-offs. Embedded systems are fueled by microelectronics where one of the currently biggest challenges is the trade-off between flexibility and cost. Reconfigurable devices, especially FPGAs, fill this gap since they provide flexibility at both design-time and run-time. Consequently, in the last years we have seen declining ASIC design starts but continuously increasing FPGA design starts. Continuing advances in the miniaturization of microelectronic components have made it possible to integrate systems with multiple processors on a single chip at the size of a fingernail (system-on-chip (SoC)). Often, the production volumes for SoCs are rather low jeopardizing their economic benefits. On the other hand, modern FPGAs are basically complex SoCs integrating embedded processors, signal processing capabilities, multi-gigabit transceivers and a broad portfolio of IP cores. Thus FPGAs are positioned to become a real alternative to ASICs and ASPPs.

This book is the first ever to focus on the emerging field of *Dynamically Reconfigurable Computing Systems*. While programmable logic and design-time configurability are well elaborated and covered in various books, this book presents a unique overview over the state of the art and recent results for dynamic and run-time reconfigurable computing systems. This book targets graduate students and practitioners alike. Over the last years, many educational institutions began to offer courses and seminars on different aspects of reconfigurable computing systems. We recommend this book as reading material for the advanced graduate level and entrance into own

research on dynamically reconfigurable systems. Reconfigurable hardware is not only of utmost importance for large manufacturers and vendors of microelectronic devices and systems, but also a very attractive technology for smaller and medium-sized companies. Hence, this book addresses also researchers and engineers actively working in the field and updates them on the newest developments and trends in run-time reconfigurability.

The book is organized into four parts that present recent efforts and breakthroughs in architectures, design methods and tools, and applications for dynamically reconfigurable computing systems:

Architectures: Three chapters on architectures discuss different dynamically reconfigurable platforms, including multigrained and application-specific architectures as well as an FPGA-based computing system supporting efficient partial reconfiguration.

Design Methods and Tools—Modeling, Evaluation and Compilation: The first part on design methods and tools features four chapters focusing on modeling and evaluation aspects for dynamically reconfigurable hardware, on creating compilers for reconfigurable devices, and on supporting dynamic reconfiguration through object-oriented programming.

Design Methods and Tools—Optimization and Runtime Systems: The second part on design methods and tools comprises six chapters that are devoted to resource allocation in dynamically reconfigurable systems, split into challenging optimization problems that need to be solved during compilation time, e.g., temporal partitioning, and online resource allocation which is provided by a novel breed of reconfigurable hardware runtime systems.

Applications: The last part of the book presents seven chapters with applications of dynamically reconfigurable hardware technology to relevant and demanding domains, including mobile communications, network processors, automotive vision, and geometric algebra.

This book presents the results of a six-years research initiative on dynamically reconfigurable computing systems, initiated and coordinated by Jürgen Teich and funded by the German Research Foundation (DFG) within the Priority Programme (Schwerpunktprogramm) 1148 from 2003 to 2009. To make dynamic reconfigurable computing become a reality this joint research initiative bundled multiple projects and, at times, involved up to 50 researchers working in the topic.

Equivalently, this book summarizes more than 100 person years of research work and more than 20 PhD students have already submitted and defended their theses based on research performed in this initiative. The material presented in this book thus summarizes the golden fruits, major achievements and biggest milestones of this joint research initiative.

We are very grateful to the German Research Foundation for funding and continuously supporting this initiative. We would also like to thank all the researchers contributing to the programme and to this book, the many national and international reviewers as well as the industrial companies that have been steadily supporting our efforts. Additionally, we would like to acknowledge the assistance of Josef Angermeier, Martina Jahn, Enno Lübbers, and Felix Reimann in supporting the editorial

process. Last but not least, we thank Springer for giving us the opportunity to publish our results with them.

We hope you enjoy reading this book!

Marco Platzner, Jürgen Teich, Norbert Wehn

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