Dynamic Resource Allocation in Embedded, High-Performance and Cloud Computing

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The Netherlands

Tel.: +45369953197
www.riverpublishers.com

ISBN: 978-87-93519-08-4 (Hardback)
978-87-93519-07-7 (Ebook)

Cover design by Andrea Monteiro and Leandro Soares Indrusiak

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Preface

The availability of many-core computing platforms enables a wide variety of technical solutions for systems across the embedded, high-performance and cloud computing domains. However, large scale many-core systems are notoriously hard to optimise. Choices regarding resource allocation alone can account for wide variability in timeliness and energy dissipation (up to several orders of magnitude). This book covers dynamic resource allocation heuristics for many-core systems, aiming to provide appropriate guarantees on performance and energy efficiency. It addresses different types of systems, aiming to harmonise the approaches to dynamic allocation across the complete spectrum between systems with little flexibility and strict performance guarantees all the way to highly flexible systems with soft performance guarantees.

Resource allocation is one of the most complex problems in large multiprocessor and distributed systems, and in general it is considered NP-hard. The theoretical evidence shows that the number of possible allocations of application tasks grows exponentially with the increase of the number of processing cores. The empirical evidence points in the same direction, with case studies showing that for a realistic multiprocessor embedded system (40–60 application components, 15–30 processing cores) a well-tuned search algorithm had to statically evaluate hundreds of thousands of distinct allocations before it finds one that meets the systems performance requirements.

In this book, we argue that the only way to cope with such complexity is to design systems that are capable to explore the allocation space during runtime. This is commonly done in cloud and high-performance computing, mainly because the workload of such systems cannot be accurately predicted in advance and static allocations are thus impossible. In embedded systems, the workload is more predictable in terms of its worst-case behaviour, but static allocations that take such characterisation into account tend to produce underutilised platforms. We therefore set the scene for dynamic resource allocation mechanisms by identifying and evaluating allocation heuristics that can be used to provide different levels of performance guarantees, and that cope with different levels of dynamism on the application workload.

The book starts with a description of the common practices and challenges in dynamic resource allocation, highlighting the peculiarities of each domain: embedded, HPC and cloud computing. Then, each of the challenges is addressed in detail within the following chapters, which are largely self-contained and therefore can be read in any order. To facilitate understanding, all of them follow the same structure: a specific challenge is motivated and the respective problem is precisely formulated; a detailed description of a solution to the problem is then given, followed by experimental work showing quantitative evidence of the strengths and weaknesses of that solution; related work is reviewed; and a summary of the chapter is given at the end.

The technical work that resulted in this book was done within the frame of the DreamCloud project, and the project website[1] makes available a number of reference implementations of the models and heuristics described here. Updates to this book will also be made available on that website.

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York, summer of 2016.

[1] http://www.dreamcloud-project.org

Acknowledgements

The research work that resulted in this book was done within the frame of the DreamCloud project, funded by the European Commission under Framework Programme 7 (Ref. 611411). The authors would like to acknowledge and thank the commission for the funding, as well as the project officers and reviewers for their suggestions and feedback on the project outcomes.

The authors would like to thank Hashan Roshantha Mendis, whose work provided most of the foundations and the experimental results reported in Chapter 6.

The authors would also like to thank all the members of the DreamCloud consortium, particularly Scott Hansen, Björn Saballus, Devendra Rai, Manuel Selva, Abdoulaye Gamatié, Gilles Sassatelli, Luciano Copello Ost, Leonardo Zordan, David Novo, Alexey Cheptsov, Dennis Hoppe, Thomas Baumann, Fridtjof Siebert, Malek Ben Salen, Raj Patel, José Miguel Montañana and Neil Audsley.

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List of Abbreviations

ACPI	Advanced Configuration and Power Interface
ALU	Arithmetic Logic Unit
AMIGO	Approximate M-constraint Integral Gain Optimization
AT	Arrival Time
AUTOSAR	Automotive Open System Architecture
BCET	Best Case Execution Time
CL	Closed Loop
CPU	Central Processing Unit
DAG	Directed Acyclic Graph
DBC	Deadline and Budget Constraints
DSE	Design Space Exploration
DSP	Digital Signal Processing
DVFS	Dynamic Voltage and Frequency Scaling
ECG	Electrocardiogram
ECU	Electronic Control Unit
EDF	Early Deadline First
ET	Execution Time
FCPS	Fixing Cores Power States
FIFO	First In First Out
flit	Flow control digIT
FPGA	Field Programmable Gate Array
FSM	Finite State Machine
FTPS	Fixing Tasks Power States
GA	Genetic Algorithm
GoP	Group of Pictures
HLRS	High Performance Computing Center Stuttgart
HP	HPC Platform
HPC	High-Performance Computing
HRT	Hard Real-Time
IA	Interval Algebra

IQR	Inter-Quartile Range
MMKP	Multi-Choice Knapsack Problem
MPSoC	Multiprocessor System-on-Chip
NBA	Non-profiling Based Approach
NoC	Network-on-Chip
OL	Open Loop
OS	Operating System
P	Proportional
PBA	Profiling Based Approach
PE	Processing Element
PG	Platform Graph
PI	Proportional-Integral
PID	Proportional-Integral-Derivative
PID-AC	PID-based Admission Control
PMF	Probability Mass Function
PS	Pheromone Signalling
QoS	Quality of Service
RM	Resource Manager
RMA	Rotating Mapping Algorithm
RTA	Response Time Analysis
RTM	Real-Time Manager
RTS	Real-Time Scheduling
SDF	Synchronous Dataflow
SoC	System-on-Chip
ST	Spanning Tree
TG	Task Graph
TLM	Transaction-Level Modelling
ValOpt	Value Optimization
VC	Value Curve
VM	Virtual Machine
VS	Voltage Scaling
WCET	Worst Case Execution Time
WCRT	Worst Case Response Time