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19th International Conference
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Volume Editors

Werner Grass
Bernhard Sick
University of Passau
Innstr. 33, 94032 Passau, Germany
E-mail: {grass, sick}@fmi.uni-passau.de

Klaus Waldschmidt
University of Frankfurt/Main
Robert-Mayer-Str. 11-15, 60325 Frankfurt, Germany
E-mail: waldsch@ti.informatik.uni-frankfurt.de

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Preface

Technological progress is one of the driving forces behind the dramatic development of computer system architectures over the past three decades. Even though it is quite clear that this development cannot only be measured by the maximum number of components on a chip, Moore's Law may be and is often taken as a simple measure for the non-braked growth of computational power over the years. The more components are realizable on a chip, the more innovative and unconventional ideas can be realized by system architects. As a result, research in computer system architectures is more exciting than ever before.

This book covers the trends that shape the field of computer system architectures. The fundamenatal trade-off in the design of computing systems is between flexibility, performance, power consumption, and chip area. The full exploitation of future silicon capacity requires new architecture approaches and new design paradigms such as multiple computers on a single chip, reconfigurable processor arrays, extensible processor architectures, and embedded memory technologies. For a successful use in practical applications, it is not enough to solve the hardware problems but also to develop platforms that provide software infrastructure and support effective programming.

A quantum jump in complexity is achieved by embedded computing systems with an unprecedented level of connectivity linking together a growing number of physical devices through networks. Embedded systems will become more and more pervasive as the component technologies become smaller, faster, and cheaper. Their complexity arises not only from the large number of components but also from a lack of determinism and a continual evolution of these systems. The research effort needed to design systems so that they can be developed, deployed, maintained, configured, managed, and trusted will be a key issue for many years. Pervasive computing is therefore much more than an Internet access by mobile devices. The papers presented in this book set out the broadness of the research area established by pervasive computing approaches: input devices for wearable systems, mobile collaborative applications, measurement data acquisition, location awareness, QoS awareness, and context awareness.

One possibility to cope with the growing complexity of computing systems is to make them organic or autonomous, that is, to make them self-learning, self-organizing, self-configuring, self-optimizing, self-healing, self-protecting, and proactive.

In this context, completely new problems arise that should be addressed by an interdisciplinary effort. Natural organic and self-organizing systems have been studied in other scientific discplines such as philosophy and biology, and their results should now be considered by architects of organic computing systems. Some of the key questions are:

1. Do organic systems feature properties that cannot be derived from the properties of its components? Is this emergent behavior desirable in any case or not?
2. Can we really expect to completely control systems with an emergent behavior?
3. Which mathematical formalisms can help in constructing and analyzing this type of system?
4. How is user privacy maintainable?
5. What is the role of trust?

These questions were discussed during the conference stimulated by two keynote and three invited speeches. Two of the speakers have taken the opportunity to present their ideas in this book.

Organic computing is a research area initiated by the special interest group ARCS of the German computer societies (GI and ITG) that are responsible for the organization of the ARCS conference series. Future ARCS conferences will therefore continue to give a platform to revolutionary ideas for a new generation of organic computing systems.

The great interest of the research community in the research field of this conference is expressed in a large number of submitted papers. Altogether, we received 174 papers, 32 of them were accepted and are presented in this book. We were especially pleased by the wide range of countries represented at the conference. We thank all the members of the Program Committee, who did a great job. Many additional reviewers supported us in selecting the best papers. We thank all reviewers for their elaborated reviews which greatly helped the authors to further improve their papers. Readers will appreciate this effort yielding a book with high quality.

The organization of this conference was done at two different locations. Organizational tasks were performed at the University of Frankfurt a.M., while the work on the program was done at the University of Passau. We thank all staff members for their excellent work making this conference a success. Special thanks for their excellent work go to: Markus Damm, Diana Firnges, Jan Haase, Johannes Herr, Wilhelm Heupke, Joachim Höhne, Alexander Hofmann, Andreas Hofmann, Eva Kapfer, Anita Plattner, Franz Rautmann, Rüdiger Schroll.

March 2006

Werner Grass
Bernhard Sick
Klaus Waldschmidt

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ARCS 2006 was jointly organized by GI (German Informatics Society) and ITG (Information Technology Society).

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Life-Inspired Systems and Their Quality-Driven Design

Lech Jóźwiak

Eindhoven University of Technology,
Den Dolech 2, 5600 MB Eindhoven, The Netherlands
L.Jozwiak@tue.nl
http://www.ics.ele.tue.nl/~ljozwiak/

Abstract. The recent spectacular progress in modern microelectronics that enabled implementation of a complete complex system on a single chip created new important opportunities, but also new serious difficulties. This paper briefly analyses the situation, trends and problems in the field of the modern microelectronic-based systems. However, the main aim of the paper is to discuss the paradigms of life-inspired systems and quality-driven design that seem to be adequate to overcome the difficulties, and consider their application to the architecture synthesis for complex real-time embedded systems.

1 Introduction

The recent spectacular progress in modern microelectronics and information technology enabled implementation of a complete complex information processing system on a single chip (SoC), global networking and mobile wire-less communication, and facilitated a fast progress in these areas. New important opportunities have been created. The traditional applications can be served much better and numerous new sorts of systems became technologically feasible and economically justified, especially for applications that require miniaturization, high performance, low power dissipation, and wire-less or distant communication. Various measurement or control systems that can be put on or embedded in (mobile, poorly accessible or distant) objects, installations, machines or devices, or even implanted in human or animal body can serve as an example. A big stimulus has been created towards development of various kinds of application-specific embedded systems.

On the other hand however, the spectacular advances in microelectronics and information technology introduced *unusual complexity* :

- *Silicon Complexity*, in the sense of huge numbers, density, diversity, and small dimensions of devices and interconnections, huge length of interconnections, new materials and mixed technologies, and
- *System Complexity*, in the sense of a huge number of possible system states, number and diversity of subsystems, and extremely complex interactions and interrelations among the subsystems.

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Due to the *Silicon Complexity*, and especially: extremely high device densities, small physical dimensions, power supply reduction, and very high operating frequencies, many previously ignorable phenomena have now a great impact on the system correctness and other quality aspects. This results in *many new difficult to solve hardware issues*, such as:

- power and energy crisis, increased leakage power, and fluctuations in the on-chip power density distribution,
- on-chip communication problems, including delay variation due to substrate coupling and cross-coupling,
- decreased reliability, due to numerous reasons (noise, interference, signal integrity problems, increased defect density, manufacturing process variability, gate insulator tunneling, joule heating, electromigration, single event upsets and transients etc.),
- decreased design predictability (due to the above mentioned and some extra reasons),
- manufacturability problems and decreased yield,
- high manufacturing NRE and production costs, etc.

The *System Complexity* also results in *serious system and design challenges*, such as:

- design, quality assurance and validation of the highly complex and heterogeneous systems with exponentially growing number of states,
- ensuring of the systems' responsiveness, reliability and safety in the light of changing, noisy and unreliable environment and interior,
- reducing the design productivity gap, time-to market, and design NRE costs.

More details and explanations can be found in [1][3][6].

The *application-specific embedded systems are especially difficult to develop and validate.* In addition to the above listed issues, they must appropriately react in real-time to the signals from their surroundings and to be fine-tuned to particular applications through satisfying application specific constraints and objectives related to such attributes as functional behavior, reaction speed and throughput, power dissipation, geometrical dimensions, price etc. Moreover, many of them are used in safety critical applications that impose extremely high quality requirements (e.g. measurement or control systems built in various machines, robots, assembly lines, planes, cars, telecommunication equipment, military systems, safety systems, medical instruments or human body). One more main source of difficulties is related to the fact that *embedded systems play an extremely remarkable role in today's life and are used more and more commonly in virtually all fields of human activity, in all sorts of technical, social and biological systems, in more and more important and demanding applications.* They are even implanted in our bodies. Our life is to a higher and higher degree dependent on their adequate operation. Therefore, the individual and society expectations regarding their quality grow rapidly. In consequence, their responsiveness, robustness and dependability are becoming more and more critical.

Unfortunately, due to the rapidly growing silicon and system complexity, both the hardware and software of the future chips tends inherently to be less reliable and more sensitive to noise and interferences with the environment. However, we certainly cannot tolerate that the future systems will be less reliable.

Consequently, the *development of the future systems should aim at the total multi-objective quality maximization of the systemic solution, with a special focus on the robustness, responsiveness, dependability, safety, security, adaptability, and validation aspects.* However, these important aspects are not new and were already taken into some consideration in the past. What is thus new or different now?

The *new or different character of the current situation includes* the following:

- due to the huge and rapidly growing complexity, more and more demanding applications and growing danger of attacks and manipulations, it will be *more and more difficult to guarantee the system quality*, and particularly, responsiveness, dependability, robustness, safety, security and validation;
- due to the common usage of systems in various kinds of social, technical and biological systems, the whole life on the Earth more and more depends on them; in consequence, their *quality, and specifically responsiveness, dependability, safety and security are becoming more and more critical*; *also applications considered previously as non-critical are becoming more and more critical*, because we more and more rely on them.

Consequently, *high responsiveness, dependability, robustness, safety and security must now become much more common* than in the past when they were seriously considered in relation to only some very special critical systems (i.e. mission or life-critical systems for space, flight, military and similar applications). Due to the common application, reasonably *low-cost solutions must be used.* This means that these features cannot anymore be added on the top of the designed or implemented system, when using simple, but expensive means. *These features must be accounted for from the very beginning of the system specification and design process, implemented using sophisticated effective and efficient solutions, considered in parallel with all other important system aspects to possibly share the implementation costs and account for the consequences of their implementation.* This will allow for an adequate tradeoff exploitation and multi-objective optimization and result in more coherent, compact, comprehensive, reliable, robust and lower-cost solutions.

Moreover, due to the embedded and/or mobile character of the new applications, growing application complexity, power and energy crisis, increased leakage power, and fluctuations in the on-chip power density distribution, power and energy issues are more and more serious.

Summing up, the transition:

- from the *multi-chip systems* to *systems-on-a-single-chip*,
- from the *general-purpose stand-alone computers* to *application-specific embedded systems*,