Preface

This volume, *Prospects for hardware foundations*, explores the theoretical foundations of hardware design. It contains twelve papers on

(*i*) mathematical foundations of hardware modelling;
(*ii*) models of hardware and dynamical systems; and
(*iii*) verification and deductive design of systems.

The papers investigate some of the problems at the heart of our theoretical understanding of hardware systems, their design and their integration with other physical or biological systems. The volume aims to make a conceptual contribution to the theory of hardware and to offer prospects for its development.

Specifically, the articles address theoretical topics, including: stream processing, spatially extended systems, hierarchical structures, integration of analogue and digital models. There are case studies of superscalar processors, the Java Virtual Machine, and biological excitable media. There are design and verification techniques including higher order verification, process algebra, state charts, simulation and reasoning of analogue models. Also there are reflections on constructs for future generation hardware description languages.

This volume is also a scientific memoir of the NADA Working Group, the ESPRIT Basic Research Action 8533. The Action existed over the period April 1994 – October 1997. The Action brought together nine research groups, with interests in theoretical computer science, mathematical logic, formal methods for system design, dynamical systems, and hardware, to pursue a multidisciplinary research programme in the foundations of hardware. It held five general meetings and four specialist workshops, at which the groups met together, with some invited guests, for intensive exchanges; it also sponsored several visits between sites. The introduction to this volume gives further information about NADA; here we describe its origins and scientific purpose.

NADA

At the NATO Summer School at Marktoberdorf on *Logic and algebra of specification*, July 23 – August 4, 1991[1], the second of the foundations-

[1] F L Bauer, W Brauer and H Schwichtenberg (eds.), *Logic and algebra of specification*, NATO ASI Series F, Vol. 94, Springer-Verlag 1993

oriented "Blue Series" of this distinguished institution, there was enthusiastic discussion of hardware systems by people who were studying theoretical aspects of hardware, or were drawn to hardware systems in their work on design and verification. There was excitement about the wealth of problems and the possibilities of solving them. Discussions between John Tucker, Helmut Schwichtenberg, Hans Leiss, Bernhard Möller, Walter Dosch, Carlos Delgado Kloos and Manfred Broy created a common vision of a wide-ranging collaborative study of hardware systems, integrating knowledge of theoretical computer science, mathematical logic, formal methods, and hardware systems. After the Summer School, Jan Bergstra, Viggo Stoltenberg-Hansen and Arun Holden completed the team. Our group wanted to collaborate on research that might

(*i*) reveal the essential scientific structure of hardware systems;
(*ii*) shape a future generation of hardware description languages;
(*iii*) produce new mathematical methods for design and verification;
(*iv*) yield interesting theoretical and mathematical problems; and
(*v*) perform advanced case studies.

A first proposal for a Basic Research Action in the ESPRIT Programme, in October 1991, was rewarded with polite comments from referees and no funds. Undeterred and keen to collaborate, and with Keith Hanna joining the team, the revised application succeeded: the NADA Basic Research Action Working Group 8533 was awarded in 1993, with one of us (BM) as Coordinator, and held its inaugural meeting in April 1994 at TU Munich.

The aim of the Action was to collaborate in research on new, mathematically sound methods for the description and design of hardware systems. We interpreted the term "hardware systems" very generally to include circuits, architectures and the hardware/software interface. More controversially, we also included the interface between hardware and physical and biological systems.

One goal was the search for a next generation hardware description language having a high level of abstraction and a clean, formally defined semantics. NADA was to analyse the requirements for such an idealised language which was called NIL. Description aspects included general questions of timing, parameterisation and modularisation. The design techniques included verification, deductive design in the small, and structured design in the large.

The goal of the research on modelling hardware and dynamical systems was to elicit requirements on design methodologies and description languages. Architectures, circuits, and emerging new paradigms for hardware systems were studied, as well as various standard technologies, in the

search for unified mathematical models of hardware. Representative case studies were also needed for demonstrations of the developed techniques.

The goal of the research on algebraic and logical foundations for hardware design was to support the above tasks. Appropriate mathematical methods were taken from computability theory, algebraic specifications, higher order algebra, proof theory and process algebra.

In publishing this volume we wish to bring together some of our results and make available our agenda and approach. It is interesting to reflect on progress in the theory of hardware. This volume may be compared with, for example, a volume[2] edited by one of us (JVT), almost ten years ago, on the then current state of hardware foundations. There has been clear progress on most fronts: mathematical tools, semantic frameworks, verification and specification techniques, deductive methods, and complexity of case studies have all been advanced. However, we are far from completing the important scientific task of creating a comprehensive theory of hardware.

Acknowledgements

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On behalf of the Group, we thank the European Commission for extending an award for our proposal and granting a five month extension. Working together has brought us forward in our research and led to fruitful interactions. The positive influence of NADA will be felt by its members for years to come.

Finally, on behalf of all the NADA participants, one editor (JVT) would like to thank the other editor (BM) for his outstanding contribution in establishing, sustaining and managing the project: Bernhard, you have our heartfelt gratitude and admiration.

November 1998 B Möller and J V Tucker

[2] K McEvoy and J V Tucker (eds.), *Theoretical foundations of VLSI design*, Cambridge Tracts in Theoretical Computer Science 10, Cambridge University Press, 1990.