HARDWARE-SOFTWARE CO-DESIGN OF EMBEDDED SYSTEMS

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Felice BALARIN, Ellen SENTOVICH
Cadence Berkeley Labs of Cadence Design Systems
Berkeley, California, USA

Massimiliano CHIODO, Paolo GIUSTO
Alta Group of Cadence Design Systems
Sunnyvale, California, USA

Harry HSIEH, Bassam TABBARA, Alberto SANGIOVANNI-VINCENTELLI
University of California Berkeley
Berkeley, California, USA

Attila JURECSKA
Magneti Marelli, Divisione Elettronica
Venaria Reale, Torino, Italy

Luciano LAVAGNO, Claudio PASSERONE
Politecnico di Torino
Torino, Italy

Kei SUZUKI
Central Research Laboratory, Hitachi Ltd.
Tokyo, Japan

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CONTENTS

PREFACE

This book presents the results of a research activity that has been carried out since 1988 and that has grown from a sketchy idea to a full blown design methodology and software system supporting it. The meeting that originated the POLIS project was an exchange of ideas with Magneti Marelli Divisione Elettronica; it was held in the office of the President and General Manager of the Division, Dr. Daniele Pecchini, in June of 1988.

Magneti Marelli is the second largest European producer of automotive electronic subsystems with world-wide clients including Fiat, Mercedes-Benz, Volkswagen, Renault, and Rover. The electronic subsystems designed at Magneti Marelli contain a sizable software component running on micro-controllers and hardware components ranging from analog ASICs to mechanical and chemical sensors and actuators. The products are designed to specifications given by automotive companies that include emissions, fuel consumption, safety, and driveability. [1] The specifications were often vague and given to a larger or lesser extent at all levels of abstraction of the design. Sometimes specifications included detailed architectural choices such as the micro-controllers and the sensors to be used in the product itself, thus leaving a limited freedom to the subsystem designers to exercise their fantasy and expertise.

Dr. Pecchini discussed the key problems and challenges for his company, among which are:

- the difficulty in implementing a set of informal specifications to clients' satisfaction;
- the problem of chasing a set of specifications that continuously changed due to the natural evolution of the mechanical project of the car;
- the software design problem, and in particular:

[1] Driveability is a "fuzzy" concept related to the "feel" of the car when it is driven on the road.

- the debugging problem made extremely difficult by the exclusive use of assembly language;
- the use of hand-written real-time kernels, and the consequent difficulty in verifying the timing properties of the software system;
- the limited amount of computing and memory resources.

- the design methodology, and in particular:
  - little or no use of simulation and extensive use of bread-boarding as a verification tool;
  - hand-layout of the hardware system;
  - hardware and software designed independently and integrated at the last minute;
  - new designs obtained by layering over existing designs in an attempt to keep working parts of previous designs intact;
  - lack of back annotation from the physical implementation of the system to the functional description.

Dr. Pecchini argued that to solve at least some of the problems listed above a new approach was needed and that only with substantial research could this goal be achieved. After a very intense brainstorming session, we laid out a research path that eventually led to POLIS. The research was initially funded by Magneti Marelli who joined the Berkeley MicroAffiliate (BMA) program, and allocated internal resources to monitor and to participate directly in the research activity. Massimiliano Chiodo, at that time working for Magneti Marelli, was the first Magneti Marelli Industrial Fellow to visit the Department of Electrical Engineering and Computer Science of the University of California at Berkeley under the BMA program. He started his research at Berkeley in 1990 by focusing on the problem of formal specification and verification. Shortly after, it was clear that to address some of the concerns expressed by Dr. Pecchini, a formal model of computation for the embedded systems of interest had to be chosen. Luciano Lavagno, then a graduate student, joined us in the research project and started investigating the formal model problem with Chiodo and with two other Marelli engineers, Attila Jurecska and Paolo Giusto. Since most of the applications to be considered were control-dominated, the choice of an extended form of Communicating Finite State Machines, the Co-design FSMs, was made and the foundations of POLIS were established. Lavagno then became the key architect of the POLIS system. The project picked up momentum, and by late 1993 the newly formed Cadence Berkeley Laboratories committed to being a major player in the development of the methodology and of the software tools incorporating it. The Semiconductor Research Corporation supported part of the research by providing funding for graduate students. Hitachi and Daimler-Benz became involved in the research project providing the software estimation techniques and a challenging application respectively. In 1995 CSELT of Turin became involved in the application of the POLIS ideas to the communication and multi-media domains: the design of an ATM component and the analysis of the MPEG 4 proposed standards.

By late 1995, two key events shaped the future of POLIS. Jim Rowson of the Alta Group became a strong promoter of our research, provided technical advice, and architected a plan to develop an industrial version of the POLIS system. Nino Damiano of Magneti Marelli visited Berkeley and provided important feedback to make the POLIS system usable in an industrial environment. He was instrumental in the development of real-time scheduling policies and laid out a precise project timeline.

By mid 1996, the system was demonstrated at the Design Automation Conference on a real dashboard product. The system was linked to a rapid prototyping board provided by Aptix showing a complete path from concept to implementation for a complex automotive design. At the same time, the POLIS system was being considered for adoption at higher levels of system design: the design of a complete Engine Management System.

After the summer of 1996, the system was made available in the public domain at URL

`http://www-cad.eecs.berkeley.edu/Respep/Research/hsc/abstract.html`

(or e-mail address `polis-questions@ic.eecs.berkeley.edu`). It includes software contributions of the University of California at Berkeley, the Politecnico di Torino, the Cadence Berkeley Labs, Magneti Marelli, and Hitachi. The demand for information about the system and its principles led to the idea of writing a book describing the POLIS system and its foundations.

We are greatly indebted to the people of

- Magneti Marelli, and in particular, Dr. Pecchini, Senior Executive Vice President, Dr. Ferrati, General Manager of the Electronic Divisions, Dr. Mortara, General Manager and President of the Engine Control Division, and Nino Damiano, Head of the Software Group of the Electronic Division,

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Alberto Sangiovanni-Vincentelli