Preface

Embedded systems now include a very large proportion of the advanced products designed in the world, spanning transport (avionics, space, automotive, trains), electrical and electronic appliances (cameras, toys, televisions, home appliances, audio systems, and cellular phones), process control (energy production and distribution, factory automation and optimization), telecommunications (satellites, mobile phones and telecom networks), and security (e-commerce, smart cards), etc. The extensive and increasing use of embedded systems and their integration in everyday products marks a significant evolution in information science and technology. We expect that within a short timeframe embedded systems will be a part of nearly all equipment designed or manufactured in Europe, the USA, and Asia.

There is now a strategic shift in emphasis for embedded systems designers: from simply achieving feasibility, to achieving optimality. Optimal design of embedded systems means targeting a given market segment at the lowest cost and delivery time possible. Optimality implies seamless integration with the physical and electronic environment while respecting real-world constraints such as hard deadlines, reliability, availability, robustness, power consumption, and cost. In our view, optimality can only be achieved through the emergence of embedded systems as a discipline in its own right.

Embedded systems are of strategic importance in modern economies. They are used in mass-market products and services, where value is created by supplying either functionality or quality. Europe currently has a strong position in sectors where embedded technologies play a central role. It has a lead in civil avionics where fly-by-wire technology provides an overwhelming competitive advantage in the cost of operating aircraft. Europe is also well positioned in the space sector, specifically for launch vehicles and satellites. In the automotive industry, European manufacturers and their suppliers enjoy a leading technological advantage for engine control, and emerging technologies such as brake-by-wire and drive-by-wire. Railway signalling in Europe relies on embedded systems, and allows faster, safer, and heavier traffic. Embedded applications will be extensively used to make energy distribution more flexible, especially in view of the coming market liberalization. Embedded technologies are strategic for the European telecommunications sector. Finally, Europe is also well positioned for e-services (e-banking, e-health, e-training), based on the leading edge in smart-card related technologies.

Embedded systems design raises challenging problems for research, including:

- Security
  Economic, citizenship, and societal activities in Europe rely increasingly on embedded applications. Widespread acceptance and reliance on these will depend on the availability of seamless solutions for securing rights and privacy.
- Reliable, mobile, embedded services
  Electronic commerce and e-services in a wireless world will need provably correct foundations to ensure further growth.

- Large-scale heterogeneous distributed systems
  Applications such as automated highways, advanced air traffic control, or next-generation factory automation require full-scale, industry-ready paradigms, methodologies, and advanced prototypes. These need to integrate heterogeneous elements from different, perhaps competing providers, in evolving embedded environments.
- Adaptive embedded systems
  Tomorrow's resource-constrained applications, such as image processing, telecommunications, and industrial automation, are expected to see drastic advances in performance and dependability, with the ability to adapt to dynamic changes in resource needs, including power/energy, bandwidth, memory, and computing power.
- Component-based design, validation, and tool-based certification
  Development costs and time-to-market could be vastly reduced, by enabling the incremental design and formal validation of arbitrarily complex systems.

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The ARTIST FP5 workplan includes, in addition to providing this roadmap, advancing the state of the art and structuring research on embedded systems in Europe. It gathered together 28 leading European research institutions, as well as many top researchers in the area.

The aim of ARTIST FP5 was to coordinate the R&D effort in the area, to improve awareness of academics and industry, especially about existing innovative results and technologies, standards, and regulations, and to define innovative and relevant work directions, identify obstacles to scientific and technological progress, and propose adequate strategies for circumventing them.

ARTIST FP5 was implemented as a set of four coordinated actions, each centred on a high-priority thematic area of research on embedded systems. Correspondingly, the roadmap is organised into four parts.

Action 1: Hard Real Time. This action was led by Professor Albert Benveniste of INRIA (France), and focused on aspects of hard real-time applications, bringing together competencies from synchronous languages, time-triggered systems, and schedulers.

Action 2: Component-Based Design and Development. This action was led by Professor Bengt Jonsson of Uppsala University (Sweden), and focused on both theoretical and practical aspects of modelling complex systems with emphasis on methods (compositionality, composability) and standards (e.g. UML).

Action 3: Adaptive Real-Time Systems for QoS Management. This action was led by Professor Giorgio Buttazzo of the University of Pavia (Italy), and focused on soft real-time approaches and technology for telecommunications, large open systems, and networks. It gathered together teams with expertise in real-time operating systems and middleware.

Action 4: Execution Platforms. This action was led by Professor Lothar Thiele of the Swiss Federal Institute of Technology (ETHZ), and focused on issues at the frontier between hardware and software – and their implications for embedded systems design.

To enhance readability, each of the four parts of the roadmap follows a similar structure, although there are domain-related specificities. Also, inevitably, some topics may be treated in more than one part of the document, but the index should help the reader find the different relevant texts for a given topic.

Oversight for ARTIST FP5 was provided by the Artist Industrial Advisory Board (IAB), which reviewed the roadmap. The ARTIST IAB is chaired by Dr. Dominique Potier, Scientific Director for Software Technologies, Thalès.

We would like to thank all the contributors to the roadmap, including the engineers and researchers who participated in the various technical meetings and workshops, as well as the industrial leaders who granted interviews and/or provided information in the questionnaire. Special thanks also go to the Artist FP5 reviewers and the project officer, for constructive and stimulating comments.

The elaboration of this roadmap provided the opportunity for fertile interaction between key players in the area of embedded systems, and proved to be useful for structuring the area.

The work and the strategic orientations and conclusions of ARTIST FP5 led to the creation of the ARTIST2 FP6 Network of Excellence on Embedded Systems Design. Information about ARTIST2 is available on the web-site: http://www.artist-embedded.org/FP6.

This roadmap usefully complements other existing roadmapping work from ITEA and MEDEA+. We hope that it will be useful for both research and industry and that it will serve to advance awareness about the state of the art and provide insights on possible avenues for R&D.

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