Project IST-2001-34820

ARTIST

Advanced Real-Time Systems

April 1st 2002 – March 31st 2006

Public Report

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ARTIST FP5 Consortium

This public document provides an overview of the ARTIST FP5 activities in the ARTIST FP5 project over the entire project duration.

ARTIST FP5 Participants

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5	Universitaet des Saarlandes	Reinhard Wilhelm
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14	University of Twente	Ed Brinksma
15	Malardalen University	Gerhard Fohler
16	University of Pavia	Giorgio Buttazzo
17	Scuola Superiore S. Anna of Pisa	Giuseppe Lipari
18	Universidad de Cantabria	Michael Gonzalez
19	Universidade de Aveiro	Luis Almeida
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22	Universidad Carlos III de Madrid	Marisol Garcia Valls
23	Centre National de la Recherche Scientifique / VERIMAG	Joseph Sifakis
24	Institut National Polytechnique de Grenoble / VERIMAG	Joseph Sifakis
25	Swiss Federal Institute of Technology – Zurich	Lothar Thiele
26	Technical University of Braunschweig	Rolf Ernst
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1. Executive Overview of Artist FP5

1.1. High-Level Objectives

The IST 34820 ARTIST Accompanying Measure on Advanced Real-Time Systems started April 1st, 2001 and ended March 31st 2006. Initially planned for 3 years, it was extended by 1 year to allow further work on International Collaboration activities.

It gathered together 30 leading European research institutions, as well as many top researchers in the area. The aim of Artist FP5 has been 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
- Define innovative and relevant work directions, identify obstacles to scientific and technological progress and propose adequate strategies for circumventing them.

The Initiative focused on three relevant work directions, called Actions:

- Hard Real-Time Systems
- Component based Design and Development
- Adaptive Real-Time Systems for QoS Management
- Execution Platforms

The work directions included:

- Establishing a roadmap mapping future directions in advanced real-time systems
- Proposing curricula for Education and Training in advanced real-time systems
- Dissemination and International Collaboration
- Creating strong two-way ties with industry

Achieving these aims required mobilization and tight collaboration between research teams, system developers and technology providers.

To ensure success; the consortium was fortunate to get the best European teams involved, by offering an attractive and appropriate framework for collaboration which improves in many respects the current situation concerning the level of funding, project evaluation and monitoring, flexibility in the use of resources in particular, by simplification of administrative procedures.

1.2. Structure of the Consortium

Overall Project and Scientific Coordinator :
Joseph Sifakis - VERIMAG, Grenoble

Technical Coordinator :
Bruno Bouyssounouse - VERIMAG, Grenoble

One of the underlying purposes in creating this Accompanying Measure was to promote interaction in the European embedded systems research community. In particular, this was done by bringing together leading teams from different sub-areas to work on structuring the field and strengthening the European position.

The project activities were structured along two distinct dimensions: Actions and Workpackages.

ARTIST FP5 Actions were each centred on a high-priority thematic area of research on embedded systems:

1.2.a. Action 1: Hard Real-Time Systems

Led by Prof. Albert Benveniste – INRIA

Historically, the main focus in embedded systems has been on large Hard Real-Time (HRT) systems, such as flight controllers, railway signalling, process control in many different areas such as power production, chemical processing, oil refinement, steel manufacturing, etc.. A hard real time system is one in which hard temporal deadlines are set for providing computing results – matching events in the real world.

Objective: Consolidate and further improve a strong European competence and know-how that is strategic for safety or mission critical applications (Synchronous languages-TTA- Fixed priority scheduling).

Partners:

- INRIA (Prof. Albert Benveniste)
  - Signal Group, Dr Jean-Pierre Talpin
  - Pop Art Group, Dr. Alain Girault
  - Esterel Group, Dr Robert De Simone
  - SynDex group, Dr Yves Sorel
- VERIMAG Dr Paul Caspi
- Technische Universitat Wien, Prof. Hermann Kopetz
- Uppsala University. prof. Wang Yi
- Universität des Saarlandes, Prof. Reinhard Wilhelm
- PARADES, Rome, Prof. Alberto Sangiovanni-Vincentelli
- OFFIS R&D Division of Embedded Systems, Dr. Bernhard Josko
- Aalborg University, Prof. Dr. Kim Guldstrand Larse
- Eindhoven University of Technology, Jos C. M. Baeten

1.2.b. Action 2: Component-based Design and Development

Led by Prof. Bengt Jonsson – UPPSALA

This area is orthogonal to HRT and SRT. It addresses how to build complex systems incrementally, in a real-world environment where each part of the system has its own lifecycle, design objectives, market position, etc.. Component-based approaches are fundamental for the future expansion of embedded software and systems. They aim to solve the many problems arising from the complexity of increasingly sophisticated products, in a multi-tiered industrial complex.

Objectives: Transfer, enhance interaction between teams working on compositionality/composability problems and software and systems engineering teams involved in the definition of standards e.g. UML, SDL.

Partners:

- University of Uppsala, Prof. Bengt Jonsson
- Aalborg University Research Prof. Dr. Anders Peter Ravn,
- CEA, Gif sur Yvette, France Dr. Francois Terrier,
- INRIA/IriSA, Dr. Benoit Caillaud
- VERIMAG, Dr. Susanne Graf
- Lancaster University, Prof. Gordon Blair
- LSV, Ecole Normal Supérieure de Cachan, Dr.Michel Bidoit,
- Univ. of Twente, Prof. Ed Brinksma,
- OFFIS, R&D Division of Embedded Systems, Oldenburg, Prof.Dr.Ernst-Ruediger Olderog
- Mälardalen University, Prof. Ivica Crnkovic,
- University of York, Dr. Andy Evans

1.2.c. Action 3: Adaptive Real-Time Systems for Quality of Service Management

Led by Prof. Giorgio Buttazzo – Pisa

Also called Soft Real Time (SRT) systems, where the temporal deadlines are not as strict as for HRT systems. Examples include telecommunications and entertainment, where missed temporal deadlines with effects such as skipped frames, short-term unavailability, or temporarily reduced bandwidth lower the overall quality of service, but are acceptable within certain limits. Also, significant effort is made to optimize resources.

In general, embedded systems are one of either hard or soft real time. The techniques used are very different.

Objective: Soft real-time approaches and technology for telecommunications, large open systems and networks Teams with expertise in real-time operating systems and middleware.

Partners:

- University of York, Prof. Alan Burns
- Scuola Superiore S. Anna of Pisa, Prof. Giuseppe Lipari
- University of Cantabria, Prof. Michael Gonzalez Harbour
- Malardalen University, Prof. Gerhard Fohler
- University of Aveiro, Prof. : Luis Almeida
- Technical University of Catalonia, Prof. : Josep M. Fuertes

- INRIA, Dr. Jean-Bernard.Stefani
- University of Lisboa Faculty of Sciences (FCUL), Prof. Paulo Esteves Veríssimo
- Universidad Carlos III de Madrid, Prof. Carlos Delgado Kloos

1.2.d. Action 4: Execution Platforms

Led by Prof. Lothar Thiele – ETHZ added in year 2

Embedded systems are executed on increasingly complex platforms. They are heterogeneous both in modes of processing and in modes of communication. They also interact with physical phenomena by means of sensors, actuators and other devices. It is mandatory that future research in embedded systems takes this complexity into account.

A second important characteristic of embedded systems is the need for low power, which is present over the whole range of embedded systems, from large, cubic meter-size systems to small cubic millimeter-size (or even smaller) ones. It is obvious that the current, spectacular growth of the number of processors per person can only continue if we succeed in dramatically lowering the power consumption per processor. Many applications, such as in-clothing or in-body devices, can only be successful if they are energy-autonomous, meaning that they can scavenge their own energy. It is clear that this requires extreme energy-efficiency.

Objective: Examines issues at the frontier between hardware and software – and their implications for embedded systems design.

Partners:

- ETHZ, Prof. Lothar Thiele
- TU Braunschweig, Prof. Dr.-Ing. Rolf Ernst
- TU Denmark, Prof. Jan Madsen
- KU Leuven, Geert Deconinck
- Linköping University, Prof. Petru Eles
- University of Bologna, Prof. Luca Benini

Within the FP5 Accompanying measure, these actions were chosen for their strategic interest for embedded software and systems. Others have been identified, and have formed the initial basis for the Artist2 Network of Excellence (“ARTIST2”) on Embedded Systems Design (http://www.artist-embedded.org/FP6/).

1.3. Workpackages

In parallel to the structure by Actions described above, the work in Artist FP5 was divided into a set of coordinated workpackages, which allowed focus on specific project results.

We believe that this work provided an additional benefit in allowing the European embedded systems community to start thinking as a whole, to address key issues for building up the embedded systems research community.

The concrete results for each workpackage are described in detail in the main body of this document Artist FP5 Public Report.

1.3.a. **Roadmap** (WP1)

The ARTIST Roadmap for Research was edited by Bruno Bouyssounouse (ARTIST Technical Coordinator, Verimag) and Joseph Sifakis (ARTIST Scientific Coordinator and Director of Verimag Laboratory). The roadmap combines input from top European researchers within the consortium, and high-level technical experts from major industrial partners, as well as from high-technology SMEs in the area. The final roadmap (492 pages) is published in Springer Verlag's LNCS series (http://www.springeronline.com/sgw/cda/frontpage/0,11855,5-40109-22-44223599-0,00.html).

This book assesses and strategically advances the state of the art in embedded systems. The coherently written monograph-like book is a valuable source of reference for researchers active in the field and serves well as an introduction to scientists and professionals interested in learning about embedded systems design.

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.

The elaboration of the 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.

1.3.b. **Education and Training** (WP2)

A main responsibility for the research community is to provide the means for education. A first observation has been that comprehensive and structured approaches to education in embedded systems have been slow to emerge. We believe that in the coming years the great majority of information sciences and computing will deal with embedded systems. Our objective has been to provide guidelines for a curriculum and obtain its widespread acceptance by teachers, as unified discipline in its own right.

ARTIST has organised, written, and published :

- "ARTIST Guidelines for a Graduate Curriculum on Embedded Software and Systems" http://www.artist-embedded.org/Education/Education.pdf
- "ACM Transactions on Embedded Computing Systems: Special Issue on Education" http://www.artist-embedded.org/ACM_Education/

  It has also organised world-class workshops on this topic (see web links for resulting conclusions and white papers):

- WESE'05: Workshop on Embedded Systems Education (September 22nd, 2005) http://www.artist-embedded.org/FP6/ARTIST2Events/Events/WESE05/
  Organised in Jersey City, New Jersey (USA).
- International Collaboration Day: Education in Embedded Systems Design (Oct 11th 2003) http://www.artist-embedded.org/PastEvents/ICD_2003/Education/
  Organised in Philadelphia (USA).
- The high-level result from Artist has been in lifting Education and Training from ground zero, to a situation in which the educational community on embedded systems is discussing and working towards an integrated approach to teaching this emerging discipline.

1.3.c. Dissemination and International Collaboration (WP3)

This workpackage contains activities with lasting impacts for disseminating the results obtained in the first two workpackages. It is composed of specific events organized by Artist (workshops, conferences, etc.) and specific contacts with major industrial European players for embedded systems.

The activities thus far have generated considerable interest in both the research community and with industrial partners, mainly in Europe, in the USA, and in Asia (Korea, India, Macau). Through these International Collaboration events, the ARTIST consortium and its activities are well known in embedded systems groups throughout the world.

1.3.d. Industrial Liaison (WP4)

Although the Artist FP5 consortium is composed exclusively of academic partners, to ensure that the main focus remains on the research issues, there is a consensus that these activities are relevant only if they lead to industrial results. For this reason, significant links have been forged with an impressive number of main European industrial players. These links include providing presentations at Artist events, contributing to or reviewing the roadmaps, and long-term technical discussions with researchers on the state of the practice.

Dissemination is an important part of the structuring effort working towards an integrated European Research Area for embedded systems. Artist participants publish very widely and are present in all the significant events in the area. It is fair to say that the Artist consortium plays a large role in leading the European scientific community in the area.

Beyond the advancement of the state of the art, benefits from these dissemination efforts include:

- Direct collaboration with external partners. External industrial participants have often been invited to participate in discussions at the Artist technical meetings, or to collaborate on the technical work. This has significantly contributed to the roadmaps.
- Structuring the European research area. Over the course of the second year, members of the Artist consortium have continued the work in structuring research on embedded software and systems, leading to the ARTIST2 Network of Excellence proposal submitted in October 2003.

  It is worth noting that this proposal was rated highest amongst all those submitted for embedded systems in this call. Numerous technical meetings and presentations were held to publicise the proposal, to select partners (amongst 1200 initial contacts), and to define the Joint Programme of Activities. Several presentations were made at information and concertation meetings held by the European Commission.

2. ARTIST Roadmap

The Artist consortium has produced a final roadmap (492 pages), published in Springer Verlag's LNCS series (http://www.springeronline.com/sgw/cda/frontpage/0,11855,5-40109-22-44223599-0,00.html). It assesses the current state of the art, and gives recommendations for future work in the area. These roadmaps are written by and for researchers, with a view on the industrial relevance of the topics covered.

The Roadmap was edited by Bruno Bouyssounouse (ARTIST Technical Coordinator, Verimag) and Joseph Sifakis (ARTIST Scientific Coordinator and Director of Verimag Laboratory).

The roadmap is organised into four parts, corresponding to the four Artist actions. To enhance readability, each of the four parts of the roadmap follows a similar structure, although there are domain-related specificities.

The roadmap usefully complements other existing roadmapping work, including:

- ITEA Technology Roadmap for Software-Intensive Systems, edition 2
  http://www.itea-office.org/index.php?pagina=ROADMAP2
- MEDEA+ Roadmaps
  http://www.medeaplus.org/webpublic/publ_relation_eda.htm
- Embedded Systems Roadmap 2002
  http://www.stw.nl/progress/ESroadmap/
- AMSD: A Dependability Roadmap for the Information Society in Europe
  (no longer available)

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.

Embedded Systems

Embedded systems applications 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, television, washers, dryers, 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 relative weight of software in the value of embedded systems is constantly expanding. The extensive and increasing use of embedded systems and their integration in everyday products marks a significant evolution in information science and technology.

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 means 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.

2.1. Part I) Hard Real-Time Development Environments

(Executive Summary)

2.1.a. Motivation and Objectives

Traditionally, hard real-time includes task scheduling, real-time OS and executables, and “meeting deadlines” as the ultimate objective. These topics are indeed covered in part III of the roadmap, but as the background for the OS needed to support Quality of Service (QoS) requirements in future real-time systems. The argument can be made that research on task scheduling should shift to adaptivity and QoS issues.

We believe research on pure hard real-time systems is still needed, but that it now needs to focus on issues other than RTOS and deadlines. Hard real-time systems design has become part of a larger engineering activity: designing embedded systems for control or information processing. Research on hard real-time must therefore shift from a single technology research to the broader perspective of systems design.

2.1.b. Essential Characteristics

Real-time embedded systems are of particular interest to the European community. Real-time embedded systems interact continuously with the environment and have constraints on the speed with which they react to the environment stimuli. Examples are power-train controllers for vehicles, embedded controllers for aircrafts, health monitoring systems and industrial plant controllers. Timing constraints introduce difficulties that make the design of embedded systems particularly challenging. We classify as hard real-time (HRT) the embedded systems that have tight timing constraints, i.e., they are difficult to achieve and they may not be violated, with respect to the capability of the hardware platforms used. HRT constraints challenges the way in which software is designed at its roots. Standard software development practices do not deal with physical properties of the system as a paradigm. We need a new system science where functionality is married to physical aspects. The roadmap presented here focuses on the design of distributed hard real-time embedded systems with particular emphasis on software.

We intend it to be a Roadmap for research, rather than for R&D in general and as such, it takes a longer view and has a more speculative approach than a typical industrial roadmap.

2.1.c. Role in Future Embedded Systems

The general trend for the future is that more systems and objects will contain computer- controlled components. The increasing role of embedded electronics in systems such as automobiles, trains, planes, power systems, military systems, consumer electronics, and other telecommunication systems is discussed in detail throughout the roadmap. However, the set of applications that use embedded systems will continue to grow exponentially.

Emerging sensor systems technologies, often distributed and autonomous, will call for more embedded signal and information processing power. Most of it will consist in adaptive (not hard) real-time processing, however. Autonomy, adaptivity, communicating ability, and higher number crunching capability, will be the main issues. We do not expect issues of hard real-time to be central for such distributed, autonomous, sensor systems.

2.1.d. Overall Challenges and Work Directions

The challenges described below point out that there is a need for a revolutionary approach to embedded software design.

Increasing Complexity of the Application Space

Research is needed to raise the levels of abstraction at which a design is entered. There is almost no hope of improving productivity substantially without this step since productivity problems originate from a number of difficulties, including verification and testing. For embedded controllers, the objective is to keep the control requirements orthogonal with respect to implementation.

From the algorithm design to implementation, we need to develop a suite of automatic synthesis tools where the implementation process is fast and at the same time highly optimized. Today, automatic code generation is available only for small parts of the design flow, mostly for embedded code generation for single components. Furthermore, even when available, this technique is not widely used in practice. Research is needed to enlarge the target of code generation to distributed architectures. Solving this problem requires the development of specification languages based on rigorous semantics, which are accepted in both the control and the software engineering communities, which unambiguously represent the behaviour of the embedded system. The semantics of Matlab/Simulink descriptions is not formally defined: the behaviour of a system is determined by the execution of the simulators! In addition, we need to develop models and methods to assess whether the performance of the final implementation meets the constraints.

Interaction with the Physical World

Apart from the increase in complexity, the needs for the design of embedded systems have broadened to encompass not only the functional aspects of systems, but also to capture and analyze the extra-functional ones, such as timing and energy consumption. Often the physical parameters are subject to variation. Hence, there is a link between such extra-functional aspects of systems and hybrid systems and stochastic systems that needs to be explored. The notion of time has played a fundamental role in research recently both at abstract levels and at the implementation level. Timing issues have been tackled at the abstract level introducing synchronous abstractions (e.g., the ones incorporated into synchronous languages and time-triggered protocols and architectures) but there is a growing interest in studying with the same mathematical rigor asynchronous paradigms of various sorts. These approaches tend to establish a formal relation between different levels of abstraction so that certain properties at lower levels are guaranteed to hold. More research will be needed to offer a framework where coordination policies can be traded-off and chosen with a theoretical underpinning.

Safety-Critical Nature of Designs

Many embedded controllers operate on systems that may cause severe damages to people and property if they malfunction, i.e., they are safety critical. Clearly, the emergence of X-by-wire technologies in the transportation industry will increase their number and importance significantly. Safety has a dramatic impact on the design processes and techniques used. Because of safety concerns, the embedded systems have to have zero defects. Ideally, the design methodology should guarantee correct-by- construction implementations of a complete specification.

Diagnosis

The integration of software from different vendors into a single component demands a new approach towards fault containment, error containment and diagnosis. Hard real-time aspects raise specific problems, but offers in turn special means to fix these. Quick detection of a fault can be critical. Transient faults may reveal malfunctioning that can become fatal. Fault effect propagation requires on-line sophisticated filtering of alarms. Proper instrumentation, fault-tolerant architecture, and mechanisms for online probing of the system, are needed to account for these special issues. Such mechanisms can benefit in turn, from using hard real-time as an advantage for several purposes, including time as a basis for fault isolation and fault containment, and fault detection with bounded delay reaction time.

Certification

The trend is to move from process-based certification to process-and-tool-based certification. This calls for new trustable tools and methods. To reduce the cost of certification, it would be a great advantage if the certification can proceed in a modular fashion, i.e., if certification arguments that have been developed for a particular subsystem can be used in a modular fashion. Modular certification depends very much on the partitioning properties provided by the distributed architecture, which in turn can take advantage of the hard real-time nature of the system. So-called formal methods are an essential enabling factor in support of certification; they need to scale up to much more complex designs.

Dependability

Safety critical systems must achieve a dependability (a commonly used value is 1 failure in 10^9 hours) which is better than the dependability of any of its constituting components. Such systems require a safety case that must be based on a combination of experimental evidence and analytical modelling. In ultra-dependable systems even a very small correlation of failures of the replicated units can have a significant impact of the overall dependability. New approaches are needed to isolate component failures and to eliminate even very low probability error propagation. In doing this, real-time should be taken as an advantage, not as a problem.

Formal Methods

By formal methods, we mean fundamental techniques for analysis, validation, composition, or transformation of systems or software, in a provably sound way. Formal methods are enabling technologies for exploring specifications and models, for validating designs against requirements, for generating code, for deploying designs on architectures, and are a support for the certification of designs or tools. Formal methods include numerous technologies such as model checking, automatic test generation, proofs, automatic code generation from high level specifications, static program analysis, timing analysis, code validation, theorem proving, and more; the main ones are detailed hereafter in the roadmap. No safety critical design will be possible in the future without a significant use of formal methods. New domains have been included during the last decade, in the scope of formal verification and validation. This includes in particular aspects of timing and hybrid systems– i.e., the mixing of discrete and continuous features.

Formal methods have scaled up drastically in the last decade, and this process is going to continue even faster. In this respect, automatic code generation from high level specifications now allows to handle quite large components or subsystems. Being more complex in nature, formal validation or analysis techniques have quite often stayed behind the needs of real life designs. Still, skilled engineers managed to use them by properly phrasing or decomposing their validation or analysis problems into tractable parts. Nevertheless, it is a constant and stringent need that formal methods and tools scale up to follow the increasing complexity of designs.

Complexity of Design Flows and Supply Chains

Supply chains for electronic systems are changing rapidly. System companies are retrenching in core competencies that favour market access and sales channels versus product development and implementation. The electronics industry is increasingly disaggregating: new opportunities are now opening up for subsystem and component suppliers. These dynamics are stressing the interfaces among the supply chain players. Several quality problems and time-to-market delays can be traced to specification and system integration difficulties. Among the most challenging supply chains to support are the automotive and avionics chain.

The complexity of supply chains has several consequences. Firstly, it calls for a design approach at the level of each component (systematically investigated by the “components” action roadmap), offering means to specify components to suppliers and facilitate their subsequent integration. Secondly, the strategy of systems integrators for preserving added value will put virtual prototyping and platform-based design in the fore (see the landscape on automobile, in the roadmap).

It is the essence of embedded systems design that diverse tools based on different paradigms coexist within the overall design flow. This situation will continue.

Integrating these tools has become a major concern. Scientific engineering tools and physical systems modellers, on the one hand, and formal verification, code generation over distributed architectures on the other hand, will continue to rely on different underlying paradigms. Should UML establish itself as an overall framework for the entire design process, the issue would still remain in the form of the coherence among the multi-faceted semantics supporting the different views and profiles. Thus paradigm integration emerges as the needed mathematical foundation to support the semantic integration of different tools and frameworks.

Research must be done on open semantics, to support smooth transitions between different technologies along the design flow. Paradigm integration emerges as the necessary mathematical foundation to support the semantic integration of different tools and frameworks. Paradigm integration is not the exercise of embodying different paradigms into a “most general” one, since this would require developing tools to handle this “most general” framework, something not possible due to complexity issues. The objective is rather to develop approaches that will upgrade existing tools with semantic adaptors toward tools supported by other paradigms.

2.1.e. Contributors to Part I

Coordinator: Albert Benveniste INRIA, France

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2.2. Part II) Component-Based Design and Integration Platforms

(Executive Summary)

Component-Based Design is expected to increase software productivity by reducing the effort needed to develop, update, and maintain systems. This is achieved by giving structure to system design and system development, thus making system verification and maintenance more tractable. It allows the reuse of development effort by allowing components to be re-used across products and in the longer term by paving the way for a market for software components.

Component based technology has become widespread in general: program development with platforms such as JavaBeans/EJB from Sun, .NET/COM from Microsoft, and the manufacturer independent CORBA initiative from OMG. Adoption for the development of embedded and real-time systems is significantly slower. Major reasons are that real-time systems must satisfy requirements of timeliness, quality-of-service, predictability, that they are often safety-critical, and that they must obey stringent constraints on resource usage (memory, processing power, communication).

2.2.a. Motivation and Objectives

Component-Based Design and Development is key for developing advanced real-time systems in a cost- and time effective manner. It will provide a qualitative jump in software development methodology, comparable to the transition from assembly language programming to high level problem oriented languages around 1970.

Many challenges remain to developing a suitable component technology for embedded systems. The roadmap presents a survey of selected topics important for component-based design of embedded systems, and directions for further work.

2.2.b. Essential Characteristics

In this report, we consider a component as a software implementation that can be executed on a physical or logical device. This includes components delivered in high-level languages, and allows build-time (or design-time) as well as run-time composition. This more liberal view is partly motivated by the special requirements for embedded systems.

There are two prerequisites that enable components to be integrated and work together:

- A *component model* specifies the standards and conventions that components must follow to enable proper interaction.
- A *component framework* is the design-time and run-time infrastructure that manages resources for components and supports component interactions.

There is an obvious correspondence between the conventions of a component model and the supporting mechanisms and services of a component framework.

Component models and frameworks can be specified at different levels of abstraction. Some component models (e.g., COM) are specified on the level of the binary executable, and the framework consists of supporting OS services. Some component models (e.g., JavaBeans, CCM, or .Net) are specified on the level of processor independent byte code. And yet other component models (e.g., Koala) are specified on the level of a programming language (such as C). The framework can contain “glue code” and possibly a runtime executive, which are bundled with the components before compilation.

With respect to the evolution of different component technologies for real/time and embedded systems, we can observe several trends. A clear trend is to adapt widely used component technologies, such as COM or CORBA, to embedded systems. Another trend is to define technologies dedicated to applications in certain domains. A third trend is the evolution of design tools for designing systems by composing possibly heterogeneous modules.

2.2.c. Role in Future Embedded Systems

If the technological and organizational challenges for component based development of embedded systems are overcome, the benefits can be summarized as follows.

- Giving Structure to System Development.
- Reuse of Development Effort.
- Supporting System Maintenance and Evolution.
- Enabling a Market for Software Parts.

2.2.d. Overall Challenges and Work Directions

Findings, Synthesis, Needs

Here is a brief summary of the findings of the roadmap, concerning the current state of the art, and needs for further development.

We lack support for system development, early in the development process :

- Specification of functional and extra-functional properties of components as part of their interfaces.
- Determination of QoS, timing, and resource properties of components.
- Prediction of system properties such as QoS, timing, and resource consumption, from component properties.
- Handling interference between components.
- Handling heterogeneous system descriptions.

Wider adoption of component technologies for embedded system design is needed, to motivate investment in tools, platforms, component repositories:

- **Widely adopted component models**. Needs vary between industrial sectors.
- **Implementation of suitable Component Frameworks for embedded systems**. Such platforms should support a suitable component model, not require a large supply of resources, and provide well-chosen generic system functionalities, e.g., for safety, reliability, and availability.
- **Uniformisation of interface specifications**. Convergence and standardization of existing approaches is necessary to motivate investment in tools for verification of component properties, prediction of system properties.
- **Component Certification**. This may need advances in component verification (including testing, simulation, formal verification), and in procedures for documenting the efforts made in verification.

- **Tool support** for different development activities, including tools to analyse and predict system properties of systems.
- **Standards** and **implementations of component frameworks** are needed. A single technology will not suit all the various domains, and in fact domain specific standardization efforts are underway in several industrial sectors. A standard should preferably be independent of a particular platform or vendor, to avoid future dominance by a single platform provider.

Challenges and Work Directions

Extra-functional Properties in Component-Based Development of Embedded Systems give rise to a number of hard technical problems:

- Specification of extra-functional properties including QoS, timing, and resource properties of components.
- Prediction of extra-functional system properties.
- Handling interference between components.

The development of widely adopted component technologies for embedded system design should be supported by working along several directions, including the following.

- Widely adopted component models can be obtained via established component technologies, such as COM, and adapted and extended for embedded systems, especially to cover extra-functional properties.
- Implementation of Component Frameworks is necessary for a wider adoption of a component technology. Platforms that support established component technologies and suit the needs of embedded systems by using a constrained supply of resources, and having predictable resource and timing behaviour, do not exist today, but should be developed.
- Development of application-specific system architectures that support the development of components suiting specific needs in such an architecture. Such architectures are being defined in several industrial sectors.

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2.3. Part III)
Adaptive Real-Time Systems for Quality of Service Management
(Executive Summary)

2.3.a. Motivation and Objectives

The main goal for a Quality of Service management layer in an adaptive embedded system is to provide predictability and flexibility for systems and environments where requirements on resources are inherently unstable and difficult to predict in advance.

For most of these systems, the classical real-time approach based on a rigid off-line design, worst-case assumptions and a priori guarantee would keep resources unused for most of the time, therefore is not acceptable for efficiency reasons. When resources are scarce, they cannot be wasted. On the other hand, an off-line design based on average-case behaviour is also critical, because it would be difficult to guarantee timing constraints when resources are overloaded.

To prevent unpredictable performance degradations due to overloads, a real-time system must react to load variations, degrading its performance in a controlled fashion acting on system, as well as application parameters. The process of controlling the performance of a system as a function of workload variations is referred to as Quality of Service (QoS) Management. Performing efficient QoS management requires specific support at different levels of the system architecture. Hence, new software methodologies are emerging in Embedded Systems, which strictly relates to Real-Time Operating Systems (RTOS), Middleware, and Networks.

The objective of the roadmap is to provide a complete picture of these elements in the context of Embedded Systems, and to show how they relate to Quality of Service Management. After analyzing the state of the art of the available software and methodologies currently used in real-time applications, we describe the limitations of current solutions and the new research trends emerging to overcome them.

2.3.b. Essential Characteristics

An embedded system is adaptive if it is able to adjust its internal strategies in response to a change in the environment, to keep the system performance at a desired level.

The implementation of adaptive real-time embedded systems requires several issues to be considered at the same time. They involve predictable scheduling strategies, time-bounded operating systems mechanisms, QoS management policies, adaptive middleware software, and expressive programming languages. Moreover, most of embedded systems work under several resource constraints, due to space, weight, energy, and cost limitations imposed by the specific application. Often, such limitations also affect memory and computing power. As a consequence, efficient resource management is a critical aspect in embedded systems, that must be considered at different architecture levels.

2.3.c. Role in Future Embedded Systems

Consumer Electronics (Set-top boxes, TVs, DVD players, etc.) are increasingly using microprocessors as a core system component, instead of using dedicated hardware. This trend is expected to continue in the near future. There are extensive research work on topics such as ambient intelligence, pervasive systems, disappearing computer, home automation, and ubiquitous computing, which deal with integrating computers in our lives even more, and in a way that they are hidden.

Most of these devices share a number of important properties, such as: 1) Limited resources, 2) Demanding quality requirements, and 3) Applications with time requirements.

The challenge is how to implement applications that can execute efficiently on limited resources, that meets extra-functional requirements, such as timeliness, robustness, dependability, performance etc.

2.3.d. Overall Challenges and Work Directions

The combination of real-time features in dynamic environments, together with cost and resource constraints, creates new problems to be addressed in the design of such systems, at different architecture levels. The classical worst-case design approach, typically adopted in hard real-time systems to guarantee timely responses in all possible scenarios, is no longer acceptable in highly dynamic environments, because it would waste the resources and prohibitively increase the cost.

Instead of allocating resources for the worst case, smarter techniques are needed to sense the current state of the environment and react as a consequence. This means that, to cope with dynamic environments, a system must be adaptive; that is, it must be able to adjust its internal strategies in response to a change in the environment, to keep the system performance at a desired level.

Real-Time Operating Systems

The most important mechanism in the operating system affecting adaptiveness is scheduling. Unfortunately, however, the majority of today's commercial operating systems schedule tasks based on a single parameter, the priority. Recent research on flexible scheduling showed that a single parameter is not enough to express all the application requirements. In order to provide effective support to QoS management, modern operating systems should be:

- **Reflective**. They should reflect the application characteristics into a set of parameters, which can be used by appropriate scheduling algorithms to optimize system performance.
- **Resource aware**. They should give the possibility of partitioning the resources to enforce a form of temporal protection that would prevent reciprocal interference among the tasks during overload conditions.
- **Informative**. They should provide information on the current state of execution to allow the implementation of adaptive management schemes at different levels of the software architecture.

To achieve these general objectives, further research is needed in Overload Handling, Feedback-Based Scheduling, Combined Scheduling Schemes, and Energy-Aware Scheduling (see roadmap for details).

Real-Time Middleware

The recent emergence of new application areas for middleware, such as embedded systems, real-time systems, and multimedia, has imposed new challenges in terms of resource sharing, dynamism, and timeliness.

QoS capabilities and adaptive resource management will play an important role in next generation middleware, especially in fields like multimedia processing. This will allow a high utilization of the system resources such as CPU, memory and network, in order to enhance the system performance. Also, it will distribute and allocate system resources according to the application requirements. Resource aware middleware systems will need to use QoS management techniques to ensure that the solicited service requirements are met.

Communication Networks

Technological advances in hardware made possible the embedding of both processing and communication functions in highly integrated, low-cost components, fostering the use of a distributed approach in the particular field of embedded systems, either breaking whole systems into separated nodes interconnected through a network or connecting together different pieces of equipment to form a new more integrated system. Both approaches led to the development of many different interconnecting networks, with protocols and services specifically tailored to embedded systems but, nevertheless, based on different paradigms and exhibiting different properties, which are in some cases specifically designed for particular applications.

Mainly along the last decade, distributed embedded systems (DESs) evolved growing numbers of nodes, higher connectivity and scalability requirements – leading to a stronger impact of the network on the global system properties.

However, several limitations to the use of networks in embedded systems arise due to different options concerning conflicting concepts, taken in the design of the respective protocols. For example, static versus dynamic communication requirements, shared versus exclusive bandwidth allocation, replica determinism versus low communication overhead, retransmissions versus real-time requirements, replication versus low cost and power consumption. Proper design of the network can help solving these conflicts while at the same time keeping the cost of the final system at low level.

Several trends concerning network design for DESs have thus been identified and discussed. Namely, the continuing move towards higher distribution, the renewed interest for higher integration, dependability integrated within the lower layers, the quest for higher flexibility, the efficient integration of time-triggered and event-triggered traffic, the use of wireless connections and Internet connectivity. These trends are establishing the basis for supporting a new generation of applications that are dynamic and exhibit real-time, dependability and efficiency requirements.

Programming Languages

Embedded real-time systems are mainly small scale but can sometimes be extremely large. For small embedded applications, sequential languages like C and C++ remain the most widely used. For the larger real-time high integrity systems, Ada still dominates. In the telecommunications market, CHILL is popular. In Germany, Pearl is widely used for process control and other industrial automation applications.

Although there is little doubt that the Java language has been immensely successful in a wide range of application areas, it has yet to establish itself completely in the real-time and embedded markets. The introduction of a Real-Time Specification for Java could dramatically alter the status quo. In the future, C# programming language starts to gain momentum, extensions will inevitably be considered to make it more appropriate for real-time systems.

The future for Ada is unclear, as it is perceived to be an “old” language in many areas of computing. This makes it more difficult to obtain funding for research. However, the Ada real-time community in Europe is still very active and topics currently being addressed include: subsets for high integrity applications, kernels, and better support for scheduling. As the need to support more flexible real-time applications grows, the expressive power of the programming systems (language and OS) may become a limiting factor. The more advanced features of Ada (requeue, ATC etc) may then cause a resurgence in interest in Ada.

Interestingly although Ada is considered in some senses 'out of date', an even older language, C, remains very popular. In contrast with Ada, the future for Java augmented by its real-time extensions is more positive. However, there are still obstacles to be overcome before Java can replace its main competitors in the embedded and real-time systems application areas. The main issues are in the areas of inconsistencies in the specification, lack of profiles, lack of efficient implementations and lack of user experience. There is also a need to maintain momentum during the development of the technology. Ada suffered from high expectations that were slow to be delivered – the same could occur to Java.

While Java strives to assert itself into engineering practice, the need for a language that supports the OO paradigm has lead to increased popularity in C++ even though it is acknowledged that its definition has a number of problems. With C++ (and C) the support for concurrency and real-time comes not from the language but from the underlying operating system. The debate about language provision or OS provision (in terms of support for concurrency and real-time) continues with little sign of an early conclusion.

2.3.e. Contributors to Part III

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2.4. Part IV) Execution Platforms

(Executive Summary)

Prof. Hugo De Man of the IMEC research centre in Leuven, Belgium, calls the rise of embedded systems the 'third innovation wave' in ICT. First there was the period of the main frames, where many users shared one computer. Then we have seen the period of the personal computers, with each user having one computer, and now we enter the period with many computers for each 'user'. These networked computers form new, sophisticated architectures, consisting of large numbers of interconnected programmable devices and ASICs.

Heterogeneity is an important characteristic of modern, complex, embedded systems. Such systems are heterogeneous in at least two respects. They contain different types of processors, such as microcontrollers, general-purpose processors (CPUs), reconfigurable processors (FPGAs), and dedicated hardware components (ASICs), and they contain unusual means of input/output, such as sensors, actuators, antennas, and cameras. The second respect in which they are heterogeneous is in their means of communication, both on-chip and off-chip. Many different modes of communication are employed, including multi-hop strategies, which should be taken into account in the performance modelling.

A second important characteristic is the need for *low power*. This need occurs over the whole range of embedded systems, from large, cubic meter-size systems to small cubic millimetre-size (or even smaller) ones. It is obvious that the current, spectacular growth of the number of processors per person can only continue if we succeed in dramatically lowering the power consumption per processor. Many applications, such as in-clothing or in-body devices, can only be successful if they are energy autonomous, meaning that they can scavenge their own energy. It is clear that this requires extreme energy-efficiency.

In the roadmap we survey the use of (heterogeneous) execution platforms and low-power techniques in two different industrial sectors: the automotive industry and the mechatronics industry. These sectors have been chosen because they provide rather challenging and trying environments for the application of embedded systems. Automobiles require an extreme level of reliability, but as consumer goods they also have to be cost-effective. This makes traditional reliability engineering less applicable. Mechatronic systems are extremely heterogeneous in that they span a very wide technology spectrum, ranging from motion control and robotics to administrative transactions with stock-control and resource-planning systems. Both automotive and mechatronics are industrial sectors in which innovative companies (such as Daimler- Chrysler, BMW, and ASML) have extensive experience with complex embedded systems. Other companies in these and other sectors will be able to learn from these experiences.

2.4.a. Motivation and Objectives

Embedded systems are executed on increasingly complex platforms. They are heterogeneous both in modes of processing and in modes of communication. They also interact with physical phenomena by means of sensors, actuators and other devices. It is mandatory that future research in embedded systems takes this complexity into account. Embedded systems enter many industrial sectors. The automotive sector is extensively discussed in this chapter, but it is only an example of a sector that was earlier confronted with these systems than others. If the complexity of modern embedded is underestimated and if tools or methods are used that are not tailored to this complexity, then we are faced with the risk that these systems will increasingly become unreliable.

It is of utmost importance for industry that this problem is realized and that adequate research actions are undertaken.

2.4.b. Essential Characteristics

The overall characteristic of modern computing platforms for embedded systems is complexity. It is because of the complexity of advanced, heterogeneous systems that well-trusted methods and tools are not suited for their tasks anymore. Complexity is a many-faceted phenomenon. There are many views on complex, embedded systems, and each of such views has its own merits. We need to become these different viewpoints, and integration of this multi-view landscape is the only way out of the complexity trap.

A second characteristic has to do with energy-efficiency. Whereas traditional software design was aimed at optimizing memory usage and processing time, we have now entered an era in which (for many applications) low power and energy-efficiency are the discriminating factors. It will take a while before (embedded) software designers will realize the importance of low-power engineering.

2.4.c. Role in Future Embedded Systems

The era of embedded systems is the era of embedded software. Of course, embedded systems contain software components (compilers, graphical user interfaces, feedback algorithms, etc.) just like they contain mechanical, optical, and electronic components.

But the software is also used to integrate components and subsystems into complete systems. Therefore, the real distinction between, for example, mechatronic systems and embedded systems is in the integrating software. The field of embedded systems is about integration and software.

This section of the roadmap contains quite adequate analyses of the landscape in the automotive sector. Automotive is an industrial sector in which Europe is the global leader. There is no automotive company in the world that is, in embedded systems, as far developed as some European players. These globally advanced companies face serious problems, problems that others in the world are not yet aware of. It is the strength of the roadmap that these global leaders are willing to share with others the problems they expect on their own roadmaps.

2.4.d. Overall Challenges and Work Directions

In the challenges and work directions two areas of attention are distinguished: heterogeneous platforms and low power.

We see four important directions that relate to execution platforms:

- **Models**. Models are extremely important, but different models that correspond to various viewpoints must be integrated.
- **Design Space Exploration**. Methods for design space exploration must be extended to complex, heterogeneous systems.
- **Programmable Hardware**. The challenge is to arrive at an effective set of (heterogeneous) programmable hardware components.
- **System Integration**. Modern, complex embedded systems will not reach the required level of reliability if we are not able to effectively solve the integration-and- test issue.

In the realm of low-power engineering we distinguish the following challenges and work directions:

- **Middleware**. We must investigate how the middleware can exploit the flexibility in voltage levels, clock frequencies and various sleep modes.
- **Instruction Memory**. We have to look for effective ways to compress the code size of embedded software.

- **Data Memory**. We have to find ways to transform the software code in such a way that it obeys energy/efficient access patterns.

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3. Education and Training for Embedded Systems Design

The long-range goal for Education and Training – shared by the ES academic community as a whole - is to bring existing curricula into step with current industrial needs. Currently, topics such as real-time programming, systems architecture, control techniques, electrical engineering, are often taught separately.

Through concerted international efforts, ARTIST has been able to start discussions within the international research community about common curricula for embedded systems. This is not an easy task – mainly because the body of knowledge is quite large, and it is difficult to bring into a single coherent and reasonably-sized curriculum.

These efforts continue within the Artist2 NoE, and will probably be pursued by the ARTIST community beyond the initial NoE funding period.

3.1. Significant Publications

3.1.a. ARTIST Guidelines for a Graduate Curriculum on Embedded Software and Systems

Full paper : http://www.artist-embedded.org/Education/Education.pdf

Executive Overview

Although computer based embedded systems have been designed for more than thirty years, they have recently taken an ever-growing economic importance with the generalisation of computers in every day devices such as mobile phones, cars and consumer electronics. This has led Artist to propose a workpackage on education, to investigating whether embedded systems is adequately taught and whether current education meets industrial and research needs.

Three actions were undertaken:

- Elaborate a questionnaire on the industrial relevance of an embedded systems curriculum,
- Survey existing courses and curricula, with a focus on Europe and the USA,
- Propose guidelines for a graduate level curriculum in the area.

This work is characterized by the following difficulties and constraints:

- The diversity of educational systems and approaches in Europe, which complicates the elaboration of concrete and detailed curricula. For this reasons, only guidelines and abstract curricula have been proposed.
- The Artist consortium is geared towards software, and has fewer competencies in hardware and electrical engineering.

Furthermore, the following considerations have shaped the work:

- In current curricula for embedded systems, there is a lack of a unified vision for computer science. This is a surprising fact, which has several explanations:
    1. The multi-disciplinary nature of embedded systems, which have many application domains: telecommunication, automotive, aeronautics and space, mechanics, consumer electronics, etc. Each has tended to organize its own computer studies, and tends to consider computing as a mere technique.

2. In parallel, computer science curricula have not always taken into account the application domain perspective.

- The lack of maturity of the domain results in a large variety of industrial practices, often due to cultural habits more than to actual technical differences. This situation, unfortunately, has also consequences in teaching. Many courses and curricula that are proposed concentrate on one technique and do not present a sufficiently wide perspective.

As a result, industry has difficulty finding adequately trained engineers, fully aware of design choices.

Parallel to the fragmentation of industrial practices is the fragmentation of research.

The proposal contains elements aiming to remedy this situation. It is based on three ideas:

1. Computer science can play an important role in avoiding this fragmentation. It has a body of knowledge that can serve as a framework, provided it integrates approaches and techniques from the different application domains.
2. Education is one area where this fragmentation can be fought, and the subsequent gaps can be bridged. For this reason, we propose that the different application domains be fully represented in course material and lab work, including experimentation, specific methods and tools.
3. University education is the main point in an engineer's career to learn the foundations. Techniques may evolve drastically over the course of professional career. In this case, in-house training will provide the necessary skills. It is unlikely that the underlying theory and basic concepts be covered in this way.

The proposal considers that the following bodies of knowledge are necessary for a well-rounded education in embedded systems:

- **Control and signal processing**, required for encompassing applications where the embedded device acts as a controller on the physical environment.
- **Computing theory** provides algorithms, methods and tools for formal description and analysis (including verification and validation) of computing devices. This is complementary to control and signal processing, which focuses on the interaction with the physical environment. Interaction between these two bodies in the curricula should give rise to interesting syntheses;
- **Real-time** is the core of the domain. It is composed of several approaches, which should be covered, with a critical and synthesis point of view. For instance, approaches from control, such as synchronous languages, should be more thoroughly taken into account;
- **Distributed systems**, also core knowledge in the field, is not always satisfactorily covered, although it provides answers to relevant and difficult problems. Theory for distributed systems has been developed by the relatively separate "Distributed and Fault-Tolerant" community;
- **Optimisation and evaluation**, including traditional engineering methods and tools for measuring, evaluating, optimising non-functional properties specific to embedded systems: such as dependability, performance, power consumption, weight, etc.

In addition, a transverse body of knowledge must be considered:

- **System architecture and engineering** providing rigorous design methods and tools for building systems meeting given requirements. These approaches should rely on the above bodies of knowledge. Several systems engineering approaches should be promoted and compared in an embedded systems curriculum.

Finally, **Practice** on real systems and a simulator is essential for training engineers, with the adequate hands-on skills in embedded systems.

From the curricula examples in the appendix, it is appears that none covers the full spectrum of knowledge needed. This can be explained by relative youth of the area as widespread technique in industry. Efforts should be made to meet the emerging industrial needs for engineers.

Implementation of the proposed curricula will require overcoming inertia and difficulties due to cultural habits and fragmentation.

To move forward, a solution could be through student mobility cycling through European centres with complementary expertise as is done on a national level by the Swedish ARTES network. Nevertheless, differences in scale can be a limitation. It may be impractical to exchange students through Europe for short durations. An alternative could be to exchange and train teachers instead.

3.1.b. ACM Transactions on Embedded Computing Systems Special Issue on Education

ACM Transactions on Embedded Computing Systems
Vol. 4, No. 3, August 2005: Special Issue on Education
http://www.artist-embedded.org/ACM_Education/
Special Editors: *By Alan Burns and Alberto Sangiovanni*

Motivation and Scope

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 means 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.

An important factor for the emergence of embedded systems as a discipline is the existence of integrated curricula for training engineers and researchers, able to tackle a range of topics which until now had been spread across many different areas, including: general computer science and engineering, real-time computing, systems architecture, control and signal processing, security and privacy, networking, mathematics, electronics.

This special issue of the ACM Transactions in Embedded Computing Systems aims to provide the basis for integrated undergraduate and graduate curricula covering the essential areas of knowledge for tomorrow's embedded systems engineers and researchers.

Editorial

By Alan Burns and Alberto Sangiovanni

As embedded systems activities are increasingly being recognized as a single coherent endeavor, it is not surprising that those concerned with education are striving to define appropriate curricula for this emerging engineering discipline. In this special issue of the Transactions on Embedded Computing Systems, we focus on university education. We provide examples of existing practices, look at initiatives to develop new curricula, and take an educationally centered view on the evolution of this new engineering domain. Although there is a significant and growing agreement as to what defines embedded systems engineering, there is not a universal consensus as to what constitutes the discipline boundaries and, hence, what should be covered in “university provision.” This special issue is, therefore, of interest to those involved in education and those interested in the development of the discipline itself. Industrial practice constrains this development, but so does the knowledge base and skills that graduates obtain. Indeed, it is perhaps only possible within universities to take a holistic view of any engineering discipline to define its core topics, necessary foundations, and linked themes.

In this special issue eight papers are presented. Four describe experiences gained from teaching (partially or completely) embedded systems as a distinct subject and are from United States institutions that are well known for their research work in embedded systems. What is of interest here is not only what is taught, but how the required teaching is organized. Important issues are the balance between formal lectures and project work, between student-centered and class-based learning, between theory and practice, and between methods and tools. The first paper describes the courses in embedded systems at the University of California at Berkeley with particular emphasis on the graduate curriculum. Their guiding principle is to bring together system theory and computer science. The curriculum has been growing since 1988 out of a bottom-up approach typical of U.S. institutions and is spread over a number of experimental and established courses that provide the foundation from which a future graduate and undergraduate program in embedded systems will rise as a coherent whole. At the CMU, an undergraduate course has evolved over the last three decades. Key areas covered are small and single microprocessor applications, control systems, distributed embedded control, system on chip, networking, embedded PCs, critical systems, robotics, computer peripherals, wireless data systems, signal processing, and command and control. Additional cross-cutting areas cover security, dependability, energy-aware computing, software/systems engineering, real-time computing, and human–computer interaction. The paper from UCLA reviews their curriculum, but focuses more on the importance and organization of student projects. The final paper in this set describes the efforts conducted at Vanderbilt University to establish a curriculum in embedded software and systems. Given the compartmentalized nature of traditional engineering schools, where each discipline has an independent program of study, they devised innovative ways to bring together the two disciplines.The emphasis of the paper is on using learning technology to construct, manage, and deliver computer-aided learning modules that can supplement the traditional course structure in the individual disciplines through out-of-class and in-class use.

The next three papers aim at presenting the criteria to follow for developing modern curricula for embedded systems. The first paper is a personal view by Rudolph Seviora. He builds from the IEEE-CS/ACM Computer Engineering curriculum to detail a complete undergraduate degree course. Particular emphasis is placed on the role of control theory, both as an application area and as a key component of the internal management of any dynamic embedded system. In contrast to this personal view, the next paper presents guidelines distilled from a large consortium (the ARTIST group) of mainly, but not exclusively, European academics. This paper has a software focus and identifies six major bodies of knowledge: formulations, basic control and signal processing, theory of computing, real-time computing, distributed computing, and evaluation and optimization (of extra-functional properties). To these they add two transversal themes: system architecture and design and applications. The third paper in this set is again very different in its pedigree. It describes a national program organized by the Taiwan government to significantly increase the quality and quantity of graduates specializing in embedded software. The program is top-down—courses are designed and prototyped before being made available (with full teaching support materials) to a wide range of universities. As well as courses, emphasis is placed on the student experience, with a number of joint activities (including competitions) being central to the program. International cooperation is also a key part of their plans.

Taking these seven papers together (four on experience and three on future plans), a perhaps surprisingly consistent view is provided of what a student with a degree in "Embedded Systems Engineering" needs to know. It is clear that this is not just computer science with a few extra courses, or electronics with software engineering on top, but an integration of material whose formulations need to be comprehensive, but coherent. For example, to deal with discrete and continuous time and to deliver effective abstractions without ignoring critical non-functional properties, such as power, communication and computational resources, security, reliability, and safety. The final paper in this special edition explores this narrative further by applying didactical analysis to embedded systems education. Didactics is the study of subjects as they are constructed and taught within educational establishments and institutions. It provides four dimensions on which to judge the current state of a body of knowledge that is to be incorporated into a single coherent subject. The paper notes that embedded systems engineering is progressing down a path that has been trodden previously by subjects such as chemical engineering and mechatronics. The starting point is a collection of distinct disciplines that are linked together in educational programs, then cross-disciplinary new courses are developed, and, from these, themes emerge which give rise to new curricula. The significance of the original disciplines diminishes as a distinct new discipline emerges. This will be supported by new organizations, such as, departments, schools or faculties. This progression is illustrative, but it also has an important resonance for how we teach the subject. While we are in the thematic stage (which seems to be the case) educationalists recommend certain "rules" for constructing the curriculum. The final paper by Grimheden and Torngren covers this material and contributes an excellent conclusion to this special issue.

3.1.b.1 An Overview of Embedded System Design Education at Berkeley

Alberto L. Sangiovanni-Vincentelli and Alessandro Pinto
PARADES and University of California, Berkeley

Abstract: Embedded systems have been a traditional area of strength in the research agenda of the University of California at Berkeley. In parallel to this effort, a pattern of graduate and undergraduate classes has emerged that is the result of a distillation process of the research results. In this paper, we present the considerations that are driving our curriculum development and we review our undergraduate and graduate program. In particular, we describe in detail a graduate class (EECS249: Design of Embedded Systems: Modeling, Validation and Synthesis) that has been taught for six years. A common feature of our education agenda is the search for fundamentals of embedded system science rather than embedded system design techniques, an approach that today is rather unique.

3.1.b.2 Undergraduate Embedded System Education at Carnegie Mellon

Philip Koopman, Howie Choset, Rajeev Gandhi, Bruce Krogh, Diana Marculescu, Priya Narasimhan, Joann M. Paul, Ragunathan Rajkumar, Daniel Siewiorek, Asim Smailagic, Peter Steenkiste, Donald E. Thomas, and Chenxi Wang -- Carnegie Mellon University

Abstract: Embedded systems encompass a wide range of applications, technologies, and disciplines, necessitating a broad approach to education. We describe embedded system coursework during the first 4 years of university education (the U.S. undergraduate level). Embedded application curriculum areas include: small and single-microcontroller applications, control systems, distributed embedded control, system-on-chip, networking, embedded PCs, critical systems, robotics, computer peripherals, wireless data systems, signal processing, and command and control. Additional cross-cutting skills that are important to embedded system designers include: security, dependability, energy-aware computing, software/systems engineering, real-time computing, and human–computer interaction.

We describe lessons learned from teaching courses in many of these areas, as well as general skills taught and approaches used, including a heavy emphasis on course projects to teach system skills.

3.1.b.3 Skiing the Embedded Systems Mountain

Ingrid Verbauwhede -- University of California at Los Angeles, and Katholieke Universiteit Leuven
Patrick Schaumont -- University of California at Los Angeles

Abstract: UCLA teaches students how to master the steep slopes of the embedded systems mountain. The EE201A graduate course connects high-level design specification to embedded implementation. There is a long-standing and wide culture gap between system designers that create those abstract specifications and the system architects that need to implement them. In industry, the culture gap has separated software from hardware teams, and platform creators from platform users. In a embedded context, where these are very tightly connected, this leads to large inefficiencies both in design time and design results. Our course takes students to both sides of the gap and lets them look at this problem from different perspectives. For a given application, it teaches how to select target architectures, tools, and design methods. The course covers a stepwise systematic design process.

It includes specification, transformation, and refinement of an application. Specifications enable systematic and structured expression of an application. Transformations rework specifications into ones that are a better match for a given target architecture. Refinements lower the abstraction level toward the target architecture. The embedded systems mountain is traversed in two directions.

A vertical refinement axis covers elements such as power-memory-reduction methods or fixedpoint refinement. A horizontal exploration axis covers various architecture alternatives including application-specific integrated circuits (ASIC), domain-specific processors, digital signal processors (DSP), embedded cores, programmable processors, and system-on-chip (SOC). During the course, the students also go through an extensive design project to apply the methods learned in this course.

A typical embedded application is used to drive the project. In this paper it is illustrated using an embedded version of an image encoder, more specifically a JPEG encoder. Several commercial tools, design environments, and platforms have been used as alternative implementation targets for this application.

3.1.b.4 Introducing Embedded Software and Systems Education and Advanced Learning Technology in an Engineering Curriculum

Janos Sztipanovits, Gautam Biswas, Ken Frampton, Aniruddha Gokhale, Larry Howard, Gabor Karsai, T. John Koo, Xenofon Koutsoukos, and Douglas C. Schmidt
Institute for Software Integrated Systems (ISIS), Vanderbilt University

Abstract: Embedded software and systems are at the intersection of electrical engineering, computer engineering, and computer science, with, increasing importance, in mechanical engineering. Despite the clear need for knowledge of systems modeling and analysis (covered in electrical and other engineering disciplines) and analysis of computational processes (covered in computer science), few academic programs have integrated the two disciplines into a cohesive program of study. This paper describes the efforts conducted at Vanderbilt University to establish a curriculum that addresses the needs of embedded software and systems. Given the compartmentalized nature of traditional engineering schools, where each discipline has an independent program of study, we have had to devise innovative ways to bring together the two disciplines. The paper also describes our current efforts in using learning technology to construct, manage, and deliver sophisticated computer-aided learning modules that can supplement the traditional course structure in the individual disciplines through out-of-class and in-class use.

3.1.b.5 System Engineering

Rudolph E. Seviora -- University of Waterloo

Abstract: The paper presents a curriculum for a 4-year undergraduate program in Embedded System Engineering (ESE). The curriculum was developed using a two-step approach. First, a body of education knowledge for Embedded System Engineering was defined. The body consists of sixteen knowledge areas. Each area is composed of several knowledge units, some designated as core and others as electives. The minimum lecture time for the core of each knowledge area is identified. The Body of *Knowledge* for Computer Engineering, developed by the IEEE-CS/ACM task force for Computing Curricula, was used as a reference. The education knowledge for ESE then served as the base for the development of the program curriculum. The curriculum has a strong mathematics and basic science base, an in-depth exposure to engineering science and design of systems implemented with digital hardware and software, and coverage of two prominent application areas of embedded systems. The curriculum core takes approximately 3 years of the program; the remaining part is elective.

3.1.b.6 Guidelines for a Graduate Curriculum on Embedded Software and Systems

P. Caspi, A. Sangiovanni-Vincentelli, L. Almeida, A. Benveniste, B. Bouyssounouse, G. Buttazzo, I. Crnkovic, W. Damm, J. Engblom, G. Folher, M. Garcia-Valls, H. Kopetz, Y. Lakhnech, F. Laroussinie, L. Lavagno, G. Lipari, F. Maraninchi, Ph. Peti, J. De La Puente, N. Scaife, J. Sifakis, R. De Simone, M. Torngren, P. Verissimo, A. J. Wellings, R. Wilhelm, T. Willemse, and W. Yi
The Artist Education Group

Abstract: The design of embedded real-time systems requires skills from multiple specific disciplines, including, but not limited to, control, computer science, and electronics. This often involves experts from differing backgrounds, who do not recognize that they address similar, if not identical, issues from complementary angles. Design methodologies are lacking in rigor and discipline so that demonstrating correctness of an embedded design, if at all possible, is a very expensive proposition that may delay significantly the introduction of a critical product. While the economic importance of embedded systems is widely acknowledged, academia has not paid enough attention to the education of a community of high-quality embedded system designers, an obvious difficulty being the need of interdisciplinarity in a period where specialization has been the target of most education systems. This paper presents the reflections that took place in the European Network of Excellence Artist leading us to propose principles and structured contents for building curricula on embedded software and systems.

3.1.b.7 The Embedded Software Consortium of Taiwan

Tai-Yi Huang, Chung-Ta King, and Youn-Long Steve Lin -- National Tsing Hua University
Yin-Tsung Hwang -- National Yunlin University of Science and Technology

Abstract: The advancement of semiconductor manufacturing technology makes it practical to place a traditional board-level embedded system on a single chip. The evolvement of system-on-chip (SoC) techniques presents new challenges for integrated circuit designs as well as embedded software and systems. To address these challenges, the Ministry of Education (MOE) of Taiwan has been running the VLSI Circuits and Systems Education Program since 1996. This program adopts a topdown approach by forming six domain-specific, intercollegiate consortia. The Embedded Software (ESW) consortium addresses the challenges of embedded software for SoC systems. This paper first introduces the six-consortium architecture and the organization and programs of ESW. We next describe the embedded software curriculum developed by ESW. This curriculum will later be implemented in most universities and colleges in Taiwan to promote the capabilities of embedded software design and implementations. Finally, we present an execution summary of ESW 2004.

3.1.b.8 What Is Embedded Systems and How Should It Be Taught? Results from a Didactic Analysis

Martin Grimheden and Martin Torngren -- KTH - Royal Institute of Technology

Abstract: This paper provides an analysis of embedded systems education using a didactic approach. Didactics is a field of educational studies mostly referring to research aimed at investigating what's unique with a particular subject and how this subject ought to be taught. From the analysis we conclude that embedded systems has a thematic identity and a functional legitimacy. This implies that the subject would benefit from being taught with an exemplifying selection and using an interactive communication, meaning that the education should move from teaching "something of everything" toward "everything of something." The interactive communication aims at adapting the education toward the individual student, which is feasible if using educational methods inspired by project-organized and problem-based learning. This educational setting is also advantageous as it prepares the students for a future career as embedded system engineers. The conclusions drawn from the analysis correlate with our own experiences from education in mechatronics as well as with a recently published study of 21 companies in Sweden dealing with industrial software engineering.

3.2. Workshops Organized

The workshops organized have been quite successful in generating international momentum towards a unified approach to teaching embedded systems. We believe this movement will continue through Artist2, and will lead to strong bottom-up evolution in the way that embedded systems are taught.

3.2.a. WESE'05: Workshop on Embedded Systems Education (September 22nd, 2005)

http://www.artist-embedded.org/FP6/ARTIST2Events/Events/WESE05/

September 22nd, 2005, Jersey City, New Jersey, USA (a satellite event of EMSOFT 2005)

Organisation

Chairs:

- Jeff Jackson (University of Alabama, USA)
- Paul Caspi (Verimag-CNRS, France)

Programme Committee:

- Moon Hae Kim (Konkuk University, Korea)
- Bruce Krogh (Carnegie-Mellon University, USA)
- Yann-Hang Lee (Arizona State University, USA)
- Giuseppe Lipari (Scuola Superiore S.Anna, Pisa, Italy)
- Gregory D. Peterson (University of Tennessee, USA)
- Kenneth Ricks (University of Alabama, USA)

Scope & Format

It is widely recognized that the embedded system domain is a multidisciplinary one, requiring a large variety of skills from control and signal processing theory, electronics, computer engineering and science, telecommunication, etc., as well as application domain knowledge. This has motivated a recent but ever growing interest in the question of educating specialists in this domain and this has also been recognized as a particularly difficult problem. This first workshop on the subject aims to bring researchers, educators, and industrial representatives together to assess needs and share design, research, and education experiences in embedded systems.

The workshop involved:

- invited presentations by:
  - Alberto SanGiovanni-Vincentelli (Berkeley, USA)
  - Martin Grimheden (KTH, Sweden)
- presentations of accepted papers
- poster sessions for accepted papers (as necessary)
- a roundtable discussion involving a panel of embedded-systems experts

Topics and Focus

Particular topics of interest include but are not limited to:

- Industrial needs regarding embedded systems education
- Embedded systems curricular design and implementation
- Control and signal processing issues
- Computer science issues
- Real-time computing issues
- Distributed systems issues
- Extra-functional properties evaluation and optimization
- Architecture and design issues
- Hardware/software co-design
- Hands-on experiences and labs
- Teaching embedded systems

Programme

Invited Speakers :

- Alberto Sangiovanni-Vincentelli (Berkeley, USA)
- Martin Grimheden (KTH, Sweden)

Invited Session

- **Alberto San Giovanni-Vincentelli**: *Embedded System Education: A New Paradigm for Engineering Schools?*

Curricula and Contents

- **Suehee Pak, Eunha Rho, Juno Chang and Moon Hae Kim:** *Demand-Driven Curriculum for Embedded System Software in Korea*
- **Masaki Yamamoto, Hiroyuki Tomiyama, Hiroaki Takada, Kiyoshi Agusa, Kenji Mase, Nobuo Kawaguchi, Shinya Honda and Nobuyuki Kaneko:** *NEXCESS: Nagoya University Extension Courses for Embedded Software Specialists*
- **Peter Marwedel:** *Towards laying common grounds for embedded system design education*
- **Jogesh K. Muppala:** *Experience with an Embedded Systems Software Course*

Invited session

- **Martin Grimheden and Martin Torngren:** *How should embedded systems be taught? Experiences and snapshots from Swedish higher engineering education*

Teaching Experiences

- **Bettina Weiss, Günther Gridling and Markus Proske:** *A Case Study in Efficient Microcontroller Education*
- **Voin Legourski, Christian Trödhandl and Bettina Weiss:** *A System for Automatic Testing of Embedded Software in Undergraduate Study Exercises*

Labs and Platforms

- **Stephen A. Edwards**: *Experiences Teaching an FPGA-based Embedded Systems Class*

- **Kenneth G. Ricks, David J. Jackson and William A. Stapleton:** *An Evaluation of the VME Architecture for Use in Embedded Systems Education*
- **Falk Salewski, Dirk Wilking and Stefan Kowalewski:** *Diverse Hardware Platforms in Embedded Systems Lab Courses: A Way to Teach The Differences*

Panel: *Embedded Systems Education: Future Directions, Initiatives, and Cooperation*

3.2.b. International Collaboration Day: Education in Embedded Systems Design (October 11th 2003)

http://www.artist-embedded.org/PastEvents/ICD_2003/Education/

Organised in Philadelphia (USA).

Objectives

This was an open meeting to discuss important action lines in the area of Embedded Systems - in which strong synergy between international teams had the greatest benefits. Work over the first year had concentrated on discussion between top researchers in the field, summarized in white papers that were presented and discussed here.

Programme

Chair: J. Sifakis, VERIMAG

Helen Gill - National Science Foundation
"*Challenges in Interdisciplinary Education for Embedded Systems*"

Tom Clausen - European Commission, IST Programme
"*IST in the 6th FP*"

Bruno Bouyssounouse - VERIMAG
"*ARTIST International Collaboration Days Education*"

Paul Caspi - VERIMAG
"*Guidelines for a European Graduate Curriculum in Embedded Systems*"

Alberto S. Vincentelli - University of California at Berkeley
"*A Graduate Embedded System Education Program*"

Chair: B. Bouyssounouse, VERIMAG

Hans Hansson - Malardalen University, ARTES
"*European Summer School on Embedded Systems '2003 - Experiences and Perspectives*"

Giorgio Buttazzo - Università di Pavia
"*ARTIST Summer School On Real-Time Scheduling October 11th, 2003 Philadelphia*"

Wayne Wolf - Princeton University
"*Thoughts on Curriculum for Embedded Computing*"

Hermann Kopetz - TU Vienna
"An Outline of a Course on Safety-Critical Embedded Systems"

Moon Hae Kim - Konkuk University
"*Human Resource Development in the area of Embedded Systems in Korea*"

Chair: George Pappas, University of Pennsylvania

Ed Lee - University of California at Berkeley
"*Are 'Embedded Systems' Just Systems Made with Small Computers?*"

Alan Burns - University of York
"The Role of Programming Languages in the Curriculum for Teaching Embedded and Real-Time Systems"

Gábor Péceli - Budapest University of Technology and Economics (BUTE)
"*Major in Embedded Information Systems Engineering at the Budapest University of Technology and Economics: Experiences, short- and long-term considerations*"

Panel Discussion
Moderator: J. Sifakis
Alan Burns, Paul Caspi, Hermann Kopetz, George Pappas, Alberto Sangiovanni, Wayne Wolf

Participants

Hans Hansson	ARTES
Gabor Peceli	Budapest University of Technology and Economics
Pedro Mejia-Alvarez	CINVESTAV-IPN, Mexico
Pablo Basanta Val	Carlos III of Madrid University
Stephen Edwards	Columbia University
Hyung Seok Lee	ETRI
Naly Rakoto-Ravalontsalama	Ecole des Mines de Nantes, France
Tom Clausen	European Commission
Albert Benveniste	INRIA
Benoit Caillaud	IRISA / INRIA Rennes
Janos Sztipanovits	ISIS-Vanderbilt
Moon Kim	Konkuk University
Gerhard Fohler	Mälardalen
Stewart Tansley	Microsoft Corporation
Helen Gill	NSF
Alberto Sangiovanni-Vincentelli	PARADES
Wayne Wolf	Princeton University
Neeraj Suri	TU Darmstadt
Luca Carloni	U.C. Berkeley
Edward Lee	U.C. Berkeley
Carlos Eduardo Pereira	UFRGS
Lui Sha	University of Illinois
Wang Hongxia	University of Maryland
Vida Kianzad	University of Maryland
Pushkin Pari	University of Maryland, College Park
Gang Qu	University of Maryland, College Park
Zonghua Gu	University of Michigan
Ali Ahmadzadeh	University of Pennsylvania
Rajeev Alur	University of Pennsylvania
Insup Lee	University of Pennsylvania
George Pappas	University of Pennsylvania
Hermann Kopetz	University of Technology Vienna
Alan Burns	University of York
Bruno Bouyssounouse	VERIMAG
Paul Caspi	VERIMAG
Christos Kloukinas	VERIMAG
Joseph Sifakis	VERIMAG
Sergio Yovine	VERIMAG

Conclusions

This was a very successful meeting - gathering some outstanding figures in the area, including representatives from the European Commission (Tom Clausen) and the NSF (Helen Gill), the Editor in Chief of the ACM Transactions on Embedded Systems Journal (Wayne Wolf) and the Chairman of the ACM of the SIGBED (Special Interest Group on Embedded Systems) Janos Sztipanovits.

There is a strong willingness to collaborate on Education for embedded systems. An international working group has been set up, led by Alberto Sangiovanni and includes Wayne Wolf (Princeton), George Papas (Upenn), Ed Lee (UC Berkeley), Alan Burns (York), Paul Caspi (Verimag), Hans Hansson (Mälardalen). This working group prepared a call for a Special Issue on Education of the Transactions on Embedded Systems Journal. The guest editors for this special issue were Alan Burns and Alberto Sangiovanni.

4. Dissemination and International Collaboration

4.1. Motivation and Approach

One of the underlying purposes in creating this Accompanying Measure was to promote dissemination and international collaboration, to ensure that:

- European research is aware of the main research trends and to benefit from advances occurring in other parts of the world.
- To disseminate European know-how in the area, thus influencing trends beyond Europe's borders.
- To enhance the attractivity of Europe for top students and researchers.

It is clear that International Collaboration should fit into a global win-win strategy for achieving the participants' long-range aims. Over the course of the project, we have strived to define and implement such a strategy.

International Collaboration has covered a wide range of activities, which are detailed in this document. These include:

- High-level meetings gathering top representatives from industry, funding agencies, and research, to discuss avenues for International Collaboration, including on R&D and standards.
- Organisation of technical meetings for exploring possible avenues for research and education in a chosen topic. These meetings generally have led to white papers and reports.
- Organisation and sponsoring of international conferences and schools, to disseminate recent research results, and promote the emergence of embedded systems as a discipline.
- Participation by Artist FP5 partners and sponsoring for international conferences and schools with significant impacts outside Europe's borders. These are either held outside Europe, or have significant participation from non-EU researchers.
- International Collaboration Working Groups. These were defined at the first International Collaboration Day, held October 6th 2002 in Grenoble, and presented white papers (included as previous deliverables of this project) on topics of interest.
- International Collaboration Publications. Several high-level publications organised and financed by Artist FP5 have a significant impact outside Europe's borders.
- Joint international projects. These are extensions of existing projects, that have been allotted an extra budget from the NSF of about 100k$, for international collaboration.
- Travel outside Europe. International Collaboration funds have also been used widely by the Artist FP5 partners to attend world-class events outside Europe – in most cases presenting Artist-related work.

These events have been implemented mainly in collaboration with the USA, building on existing international relations between the consortium and US teams, as well as on existing links between IST and the US funding agencies (mainly NSF).

Nonetheless, the project has also made significant efforts to establish international collaboration activities with Asian counterparts. These are mainly with Korea and China. We have also explored possibilities for collaboration with Latin America and India. Although these have not yet born clearly visible result, these links are progressing and may lead to joint initiatives in the future within Artist2.

Given the overlaps between Artist FP5 and Artist2 (consortium, topics, objectives, and temporal), there are some unavoidable overlaps in their International Collaboration activities.

4.2. Overview

The activities have generated considerable interest in both the research community and with industrial partners, in the USA, and in Asia (Korea, India, and Macau). Through International Collaboration, the ARTIST community has gained in visibility. It is now recognized as a key player in the area worldwide. This is attested by:

- The consortium has actively associated to its technical work a large number of external partners, from academia, industry and SMEs. This cooperation extends to joint projects, and events.
- The consortium has sponsored the main scientific events in the area, including the Embedded Systems Week, organised in New Jersey, in October of this year. It also plays a leading role in their organization of conferences such as RTSS, EmSoft, CODES/ISSS, CASES, MEMOCODE, and LCTES, and actively promotes structuring the scientific events' landscape.
- The consortium has been very successful in organizing high-level events for International Collaboration, in close interaction with the NSF. This is recognized through the funding by the NSF of specific collaborative actions between Artist partners and NSF projects.
- The ARTIST participants have an impressive publication record. Furthermore, as a result of the integration achieved via the NoE, over 50 joint papers have been published in international conferences as well as 7 books.
- The consortium has a strong impact for structuring R&D in Europe, through its actions for launching Integrated Projects, such as DECOS, ASSERT and more recently SPEEDS, as well as through its contribution to the definition of the Strategic Research Agenda of the ARTEMIS platform.
- The consortium sets up or participates in the main leading events in the area (see the deliverable on Spreading Excellence). The materials presented in these events are regularly made available to the public through the Artist web site. Furthermore, in Year2 we will set up a repository for courseware, also made available to the public.
- The NSF has opened extra funds to selected projects for international collaboration with Artist.
- Following a joint EU-US workshop on Education in Embedded Systems, the ACM TECS group has asked the Artist consortium to appoint guest editors for a Special Issue on Embedded Systems Education – which has served as a deliverable for Artist FP5.

Other main tangible achievements for International Collaboration in Artist FP5 are:

- Building up a large set of specific links with top teams in the USA. These now form a network of top international teams, who have now become international affiliated partners within Aritst2, and are regularly invited to participate in technical meetings.
- A number of public documents have been produced, including 4 white papers, a technical report, and the Special Issue on Education for Embedded Systems.
- Participation in the international collaboration activities of selected NSF projects (see section 4.8.a. of this document).

Overall, International Collaboration activities in Artist FP5 created a solid basis for further International Collaboration in Artist2, as seen in the continuing International Collaboration events described in section 4.9.c.

4.3. High-Level Meetings Organised

These High-Level Meetings gather top representatives from industry, funding agencies, and research, to discuss avenues for International Collaboration, including on R&D and standards. They are of foundational importance for creating the high-level interaction and political momentum for future research programmes and investment.

The detailed programme, as well as the slides presented, are available through the web links provided.

4.3.a. ARTEMIS - European Technology Platform on Embedded Systems (Rome, June 28th and 29th, 2004)

http://www.artist-embedded.org/PastEvents/Rome04/

Artist FP5 has largely contributed to the organisation (publicity, registration, logistics, etc) of this high level event, which was a precursor for the ARTEMIS annual conference.

Speakers included:

- **Jan van den Biesen** - VP Philips Research
- **Theo Claasen** - Executive VP and CTO, Philips Semiconductors
- **Andrea Cuomo** - Corporate Vice President, General Manager Advanced System Technology STMicroelectronics:
- **Adriano De Maio** – CNR
- **Hugo De Man** - IMEC co-founder & Senior Research Fellow
- **Juergen Deutrich** - Vice-Chairman for MEDEA+ Applications
- **Philippe Geyres** - Corporate Vice President and General Manager Consumer and Microcontroller Groups – STMicroelectronics
- **Jean-Pierre Lacotte** - ITEA
- **Erkki Liikanen** - European Commissioner for Enterprise and Information Society
- **Yrjö Neuvo** –Nokia Senior Vice President and Technology Advisor
- **Paul Mehring** - ITEA
- **Sylvain Prudhomme** - Chief Technologist, Airbus
- **Atiq Raza** - Chairman and CEO of Raza Microelectronics, Inc
- **Alberto Sangiovanni-Vincentelli** – PARADES
- **Mauro Sentinelli** - Managing Director, Telecom Italia Mobile
- **Joseph Sifakis** – Director of VERIMAG Laboratory
- **Peter Zangl** - Deputy Director General - Information Society DG
- **Rosalie Zobel** - European Commission - Director of "Miniaturisation, Embedded Systems, Societal Applications" - Information Society DG

Participants included top representatives from:

ABB – AIRBUS – ALCATEL - AUSTRIAN MINSTRY FOR TRANSPORT, INNOVATION – TAETMCHENL ORLOOMGAY - ATMEL ROME – BT- BUDAPEST UNIVERSITY - CADENCE - CEA/LETI - CEA-LIST - CEGELEC - CNR - COMAU - CONTINENTAL AUTOMOTIVE SYSTEMS – CZECH TECHNICAL UNIVERSITY - DAIMLERCHRYSLER - UNIVERSITÃ DI BOLOGNA – DELFT UNIVERSITY OF TECHNOLOGY - DLR E.V. - EADS DEFENCE AND SECURITY SYSTEMS SA - ÉCOLE NORMALE SUPÉRIEURE CACHAN - ERICSSON AB - ESTEREL TECHNOLOGIES – EUROPEAN COMMISSION - EUROPEAN SPACE AGENCY - EUTEMA - FINMECCANICA – FRAUNHOFER IGD - FZI - IMC GMBH - IMEC - INFINEON TECHNOLOGIES AG - INRIA (FRANCE) – IRION MANAGEMENT CONSULTING - ISRAEL AIRCRAFT INDUSTRIES - ITEA - KURATORIUM OFFIS - MEDEA+ - MINISTRY OF INDUSTRY-SPAIN - MONDRAGON CORP. – NATIONAL TECHNOLOGY AGENCY OF FINLAND - NERGAL - NOKIA CORPORATION - PARADES - PHILIPS RESEARCH - PHILIPS SEMICONDUCTORS - POLITECNICO DI MILANO - RAZA FOUNDRIES - SAP - SCHNEIDER ELECTRIC - ST MICROELECTRONICS - TAMPERE UNIVERSITY OF TECHNOLOGY - TECHNICAL UNIVERSITY BERLIN - TELECOM ITALIA MOBILE - TELVENT - THALES - THOMSON – TU DRESDEN - UNIVERSITY OF BOLOGNA - UNIVERSITY OF TECHNOLOGY, VIENNA - VALIOSYS - VERIMAG

Press Release

Invisible essential technologies: EU launches “ARTEMIS” drive to become world leader in intelligent embedded systems

The Commission and seventeen senior executives from “embedded systems” research and industry, which builds the tiny computer chips and software used to make everything from car brakes to mobile phones to bank cards safer and more user-friendly, today tabled plans to make the EU world leader in the design, integration and supply of these systems. Central to the plans is a private/public partnership, the European Technology Platform in Advanced R&D on Embedded Intelligent Systems (“ARTEMIS”), to be set up by the end of 2004. Its task, outlined in the “Building Artemis” declaration today in Rome, is to mobilise and co-ordinate the private and public resources needed to meet business, technical and structural challenges. These challenges include ensuring that systems developed by different vendors can communicate and work with each other via industry standards. The technical challenges include system design, seamless connectivity, reliability, security and quality of service. Embedded technologies are the fastest growing sector in IT today. Unlike the PC market, which is dominated by a few players, Embedded Systems is still an open field with many business opportunities.

The “Building Artemis” declaration sets out the technology, business and structural challenges. ARTEMIS participants will now draw up a joint “vision” of the embedded systems industry’s future. This document will be tabled at the November IST 2004 event in The Hague. At the same time, they will prepare a detailed Strategic Research Agenda, due by the end of 2004, providing for platform work on research, human resources, infrastructure, regulatory issues, standardisation and road-mapping activities.

Members of the Platform : ABB, Airbus Industrie, BT Exact, Continental Teves, Daimler Chrysler, Ericsson, IMEC, Nokia, Parades, Philips , Robert Bosch , ST Microelectronics, Symbian, Telenor, Thales, Verimag, Technical University of Vienna

4.3.b. IST-NSF: Component-based Engineering for Embedded Systems (Paris, July 7th 2005)

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/IST-NSF/

The aim was to gather together leading researchers from academia and industry, to discuss research challenges and emerging industrial trends on component-based engineering. The ultimate goal is to identify complementarities and synergies in standardization to respond to the needs for a more cross-sectoral approach to embedded systems.

Organisers: **Joseph Sifakis** (VERIMAG and ARTIST2 NoE)
Janos Sztipanovits (Vanderbilt University - ISIS)

Speakers included:

- **Eric Conquet** - European Space Agency
- **Albert Benveniste** - INRIA
- **Gert Döhmen** – Airbus
- **Philippe Kajfasz** - Head of Advanced Architecture Lab, Thalès Land & Joint Systems
- **Gabor Karsai** - Vanderbilt University
- **David Lesens** - EADS Space Transportation
- **Véronique Normand** (replacing **Serge Salicki**) - Architecture & Engineering Department, Thalès Research and Technology Software Research Group
- **George Pappas** - University of Pennsylvania
- **Claire Tomlin** - Stanford University
- **András Tóth** - Ericsson AB, Corporate Research
- **Steve Vestal** - Fellow, Honeywell Labs
- **Don Wilson** - Senior Fellow, Raytheon Co.
- **Don Winter** - Director, Network Centric Operations; Boeing Phantom Works

Panel members included:

- **David Corman** - Technical Fellow, Boeing
- **Dominique Potier** - Scientific Director for Software Technologies, Thalès
- **Joseph Sifakis** - Director, Verimag Laboratory and ARTIST2 Scientific Coordinator
- **Janos Sztipanovits** - Distinguished Professor at Vanderbilt University, Director of Institute for Software Integrated Systems
- **Michael Winokur** - Corporate R&D and Business Development Manager of Embedded Computer Systems at Israel Aircraft Industries

List of Participants

See the list of participants for the “IST-NSF: Transatlantic Research Agenda on Future Challenges in Embedded Systems Design” (July 8th, 2005), below.

4.3.c. IST-NSF: Transatlantic Research Agenda on Future Challenges in Embedded Systems Design (Paris, July 8th, 2005)

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/IST-NSF/

Organisers: **Helen Gill** (National Science Foundation)
Alkis Konstantellos (European Commission)
Shankar Sastry (UC Berkeley)
Joseph Sifakis (VERIMAG and ARTIST2 NoE)
Janos Sztipanovits (Vanderbilt University - ISIS)
Mateo Valero (Technical University of Catalonia)

Keynote speakers

- **Helen Gill** NSF - Computer and Network Systems Division, Program Director
- **Kostas Glinos** - European Commission - IST, Embedded Systems Unit Head

Collaborating Projects presented:

- **Hipeac** - **Rutgers, Princeton**
  Olivier Temam (IRISA), Nacho Navarro (UPC),
  Liviu Iftode (Rutgers University), Margaret Martonosi (Princeton University)
- **DECOS** - **University of California, Irvine / Vanderbilt University**
  Roman Obermaisser (TU Vienna)
- **RUNES** - **Berkeley, Caltech**
  András Tóth (Ericsson)
- **ARTIST/ARTIST2 – Berkeley/Vanderbilt University**
  Joseph Sifakis (Verimag&Artist) / Janos Sztipanovits (ISIS-Vanderbilt)
  Claire Tomlin (Stanford University & Chess-Berkeley),
  Mary Margaret Sprinkle (Chess-Berkeley: The Trust Project)

Views on Challenging Topics / Priorities:

- Security
  Catherine Meadows, Head of the Formal Methods Section - Center for High Assurance Computer Systems - Naval Research Laboratory
- Component-based Design
  Joseph Sifakis, Scientific Coordinator of the Artist2 NoE, and Director of Verimag Lab
- Networked Embedded Systems:
  Margaret Martonosi (Princeton University)

Mechanisms for EU-USA International Collaboration:

- **Helen Gill** (NSF), **Alkis Konstantellos** (European Commission)

Means for Synchronisation, Announcement, Evaluation

- Chair: **Bruno Bouyssounouse** (Verimag)

Informal synthesis

- **Tariq Samad** (Honeywell) and **Brian Krogh** (CMU)

Participants

This workshop was by invitation only, and gathered a particularly impressive set of top industrial experts from both the USA and Europe:

AIRBUS - BOEING COMPANY - UC BERKELEY - CHESS - CARNEGIE MELLON UNIVERSITY - POLYTECHNIC OF CATALONIA - CEA-DRT - CEA-LIST - CNRS – EADS SPACE TRANSPORTATION - ERICSSON AB, CORPORATE RESEARCH - EMBEDDED SYSTEMS INSTITUTE (NETHERLANDS) - EUROPEAN COMMISSION - EUROPEAN SPACE AGENCY - FORD RESEARCH (AACHEN, GERMANY) - HONEYWELL LABS - INRIA - ISIS, VANDERBILT UNIVERSITY - I-SOURCE GESTION – ISRAEL AIRCRAFT INDUSTRIES – NAVAL RESEARCH LABORATORY - NSF - OFFIS – PHILIPS RESEARCH - PORTO ADVANCED ENGINEERING INSTITUTE (ISEP) – PRINCETON UNIVERSITY - ROLLS ROYCE UTC - RAYTHEON CO. - RUTGERS UNIVERSITY - SAARLAND UNIVERSITY - STANFORD UNIVERSITY - THALÈS – UNIVERSITY OF CALIFORNIA, BERKELEY - UNIVERSITY OF PENNSYLVANIA – UPPSALA UNIVERSITY - VERIMAG - VIENNA UNIVERSITY OF TECHNOLOGY – VOLVO TECHNOLOGY CORP.

4.4. Technical Meetings Organised

Artist2 has organised technical meetings for exploring possible avenues for research and education in a chosen topic. Speakers include star researchers and engineers, and generally have led to white papers and reports.

4.4.a. International Collaboration Day: Trends in Embedded Systems Design (Philadelphia, October 12th 2003)

http://www.artist-embedded.org/PastEvents/ICD_2003/Trends/

Objectives: This was an open meeting to discuss important action lines in the area of Embedded Systems - in which strong synergy between international teams had the greatest benefits. Work over the first year had concentrated on discussion between top researchers in the field, summarized in white papers that were presented and discussed here.

Speakers included:

- **Albert Benvensite** – INRIA
- **Giorgio Buttazzo** - University of Pavia
- **Tom Clausen** - European Commission DG INFSO
- **Paolo Gai**, Evidence Srl
- **Moon-Hae Kim** (KonKuk University)
- **Thomas A. Henzinger** - University of California, Berkeley
- **Krishna Palem** - CREST - Georgia Tech
- **Raj Rajkumar** - Carnegie Mellon University
- **Alberto Sangiovanni Vincentelli** - University of California at Berkeley
- **Joseph Sifakis** - Verimag Lab
- **Jack Stankovic**, Univ. of Virginia, USA
- **Hyung-Seok Lee** (ETRI, Korea)
- **Liesbeth Steffens**, Philips Research, NL
- **Stavros Tripakis** - Verimag Laboratory
- **Dave Whalley** - Florida State University

Participants included top researchers and representatives from:

AALBORG UNIVERSITY - UNIVERSITY OF AVEIRO - CINVESTAV-IPN, MEXICO - CARNEGIE MELLON UNIVERSITY - CREST - CARLOS III OF MADRID UNIVERSITY - COLUMBIA UNIVERSITY - DAIMLERCHRYSLER, RESEARCH AND TECHNOLOGY (GERMANY) - ETRI - EUROPEAN COMMISSION - EVIDENCE SRL - FLORIDA STATE UNIVERSITY - INRIA - KONKUK UNIVERSITY - MALARDALEN UNIVERSITY - PARADES - PHILIPS RESEARCH - RICE UNIVERSITY - TEMPLE UNIVERSITY - UC BERKELEY - UFRGS - UNIV NORTH CAROLINA - UNIV. OF MARYLAND, COLLEGE PARK - UNIVERSITY OF ILLINOIS - UNIVERSITY OF MARYLAND - UNIVERSITY OF MICHIGAN - UNIVERSITY OF PAVIA -UNIVERSITY OF PENNSYLVANIA - UNIVERSITY OF VIRGINIA - UNIVERSITY OF YORK - VERIMAG - WIND RIVER

4.4.b. International Collaboration Day: Education in Embedded Systems Design (Philadelphia, October 11th 2003)

http://www.artist-embedded.org/PastEvents/ICD_2003/Education/

This workshop is also described in the section on Education.

Objectives: This was an open meeting to discuss important action lines in the area of Embedded Systems - in which strong synergy between international teams had the greatest benefits. Work over the first year had concentrated on discussion between top researchers in the field, summarized in white papers that were presented and discussed here.

Speakers, chairs and panel members included:

- **Bruno Bouyssounouse** - VERIMAG
- **Alan Burns** - University of York"
- **Giorgio Buttazzo** - Università di Pavia
- **Paul Caspi** - VERIMAG
- **Tom Clausen** - European Commission, IST Programme
- **Helen Gill** - National Science Foundation"
- **Hans Hansson** - Malardalen University, ARTES
- **Moon Hae Kim** - Konkuk University
- **Hermann Kopetz** - TU Vienna"
- **Ed Lee** - University of California at Berkeley
- **George Pappas** – University of Pennsylvania
- **Gábor Péceli** - Budapest University of Technology and Economics (BUTE)
- **Alberto Sangiovanni Vincentelli** - University of California at Berkeley
- **Joseph Sifakis** – VERIMAG Laboratory
- **Wayne Wolf** - Princeton University

Participants included top researchers and representatives from:

ARTES - BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS - CINVESTAV-IPN, MEXICO - CARLOS III OF MADRID UNIVERSITY - COLUMBIA UNIVERSITY - ETRI – ECOLE DES MINES DE NANTES, FRANCE - EUROPEAN COMMISSION - INRIA – IRISA / INRIA RENNES - ISIS-VANDERBILT - KONKUK UNIVERSITY - MÄLARDALEN - MICROSOFT CORPORATION - NSF - PARADES - PRINCETON UNIVERSITY - TU DARMSTADT - U.C. BERKELEY - UFRGS - UNIVERSITY OF ILLINOIS - UNIVERSITY OF MARYLAND - UNIVERSITY OF MICHIGAN - UNIVERSITY OF PENNSYLVANIA – UNIVERSITY OF TECHNOLOGY VIENNA - UNIVERSITY OF YORK - VERIMAG

Conclusions: This was a very successful meeting - gathering some outstanding figures in the area, including representatives from the European Commission (Tom Clausen) and the NSF (Helen Gill), the Editor in Chief of the ACM Transactions on Embedded Systems Journal (Wayne Wolf) and the Chairman of the ACM of the SIGBED (Special Interest Group on Embedded Systems) Janos Sztipanovits.

There is a strong willingness to collaborate on Education for embedded systems. An international working group has been set up, led by Alberto Sangiovanni and includes Wayne Wolf (Princeton), George Papas (Upenn), Ed Lee (UC Berkeley), Alan Burns (York), Paul Caspi (Verimag), Hans Hansson (Mälardalen). This working group will prepare a call for a Special Issue on Education of the Transactions on Embedded Systems Journal. The guest editors for this special issue were Alan Burns (York) and Alberto Sangiovanni (PARADES).

4.4.c. ARTIST / IEEE Session on Adaptive Real-Time Systems (Austin, Texas – December 2nd 2002)

http://www.artist-embedded.org/PastEvents/Austin/

Real-time and embedded systems of the past were restricted to process control and small devices. Lately, more effort has been spent in broadening the scope of usage of these systems and bringing in technologies that pertain to a wide gamut of research fields. In particular, the scalability of such systems has become a crucial point, since embedded systems now encompass sensor networks, distributed networks of small devices, widely distributed meteorological prediction systems, high-energy physics accelerators, digital telescopes, as well as distributed systems and control. These systems will be composed of thousands of embedded computers, from DSPs to general-purpose low-power processors, to systems-on-a-chip.

The goal of this workshop is to stimulate discussion on the real-time aspects of large scale embedded systems, as embodied by systems such as the ones mentioned above.

Several issues are pertinent to such systems, and the workshop will focus on the real-time aspects these large-scale embedded systems, the real-time applications that run on such systems, and the application and suitability of real-time research in these large-scale embedded systems. Workshop submissions may concentrate on hard or soft real-time systems, as long as the timeliness and predictability of the system are integral components of the submissions.

Topics of interest:

- power consumption and management of mobile platforms
- static and dynamic reconfiguration of applications and systems
- system fault
- tolerance and survivability
- scalability issues
- composability issues
- service availability
- time-sensitive data collection
- time-sensitive routing
- real-time data mining
- new paradigms for network protocols
- real-time applications for large-scale embedded systems
- timeliness assessment of existing protocols

4.4.d. International Collaboration Day on Embedded Software and Systems (Grenoble, Sunday October 6th 2002)

http://www.artist-embedded.org/PastEvents/ICD_2002/index.html

The first major event for International Collaboration within Artist was the International Collaboration Day held in Grenoble October 6th, 2002. A number of working groups on specific topics were proposed.

Opening remarks

Joseph Sifakis is the ARTIST project coordinator, and director of Verimag Laboratory in Grenoble.

DARPA

John S. Bay is program manager for the Model-Based Integration of Embedded Software at DARPA. The program will create a new generation on system/software co-design technology which is highly

customizable and composable according to the specific needs of different application domains.

Boeing

David Sharp is a Technical Fellow at Boeing Phantom Works in St. Louis. He is the Principal Investigator (PI) for the DARPA MoBIES program, Lead Architect for Boeing's Bold Stroke product line avionics software initiative, PI for the Air Force Research Laboratory (AFRL) Real-Time Java for Embedded Systems (RTJES) program, and Co-PI on the DARPA Networked Embedded Systems Technology (NEST) program.

Lockheed Martin

Jonathan Preston is a technology program manager within the Advanced Development Programs branch of Lockheed Martin Aeronautics Company. He has managed several government-funded technology programs.

ASSERT : European Integrated Project
Aeronautics and Space Software Engineering for Real-Time Applications

Bernard Dion is CTO of Esterel Technologies.

BBN/GTE

Joseph Loyall is a senior scientist and technical lead at the Distributed Systems Technology group in the Distributed Systems and Logistics Department at BBN. He has been a key technical contributor to several DARPA-sponsored research projects.

Espace : European Integrated Project
Multi-functional Open and Integrative Development Environment for Software Intensive and Safety Critical Embedded Systems

Dr. Michael Winokur is Corporate R&D and Business Development Manager of Embedded Computer Systems at Israel Aircraft Industries (IAI). He directs the corporation's Systems and Software Process Improvement Program (SPIP) and is responsible for development, acquisition and technology transfer of methods, and tools for Embedded Computer Systems and Software.

Konkuk University, Seoul National University, - slides
and the Electronics and Telecommunications Research Institute (ETRI)
Korean R&D in Real-Time and Embedded Systems

Moon Hae Kim is a professor at Konkuk University in Seoul, with research interests in real-time distributed systems, networked embedded software, and network management. Seongsoo Hong is a Professor and Principal Investigator for the Real-Time Operating Systems Laboratory at Seoul National University.

DECOS : European Integrated Project
Dependable Embedded Components and Systems

Hermann Kopetz is a professor for Real-Time Systems at the Vienna University of Technology in Austria. He is the chief architect of the Time-Triggered Protocol (TTP) for distributed fault-tolerant real-time systems with applications in automotive electronics.

Honeywell Laboratories

Tariq Samad is Chief Fellow at Honeywell Laboratories in Minneapolis, Minnesota, and is a Honeywell Star Inventor with eleven awarded patents. A prolific author, he is the editor of several books and research papers. He currently servers as the Editor-in-Chief of IEEE Control Systems Magazine.

Ford Research Laboratory

Ken Butts leads a research team at the Ford Research Laboratory that has been creating and deploying a model-based software development environment for automotive powertrain controllers. Dr. Butts has more than eighteen years experience in automotive powertrain control research and advanced development.

SEA : European Integrated Project

Thomas Thurner is senior manager at DaimlerChrysler, R&T, Stuttgart/Germany. He has managed several projects in the field of automotive electronic systems. e.g. x-by-wire, fault-tolerant systems, and

network management.
Dr. Hermann von Hasseln is researcher at DaimlerChrysler, R&T, Stuttgart/Germany. He worked on several projects for automotive on/off board diagnosis systems, and future electronic architectures.

4.5. International Conferences, Schools Organised

Artist FP5 has organised international conferences and schools, to disseminate recent research results, and promote the emergence of embedded systems as a discipline.

The objective for these was to promote awareness in the larger research community, of topics and approaches that we feel that show the way to future development in embedded systems design. These include Synchronous Languages and Real-time Programming, Modelling and Analysis techniques, Component-based Design and Model-driven Engineering, Communication-centric Systems, Hybrid Systems, as well as education for embedded systems.

The conferences and schools cited here all have an International Collaboration dimension, in the sense that they involve strong participation and interaction with researchers outside Europe. Other events organized by Artist FP5 that do not have such an international dimension are not cited here.

4.5.a. SLAP'06 (Synchronous Languages, Applications, and Programming) (March 25th, 2006)

http://www-verimag.imag.fr/SYNCHRONE/SLAP06/

SLAP'06: Synchronous Languages, Applications, and Programming), organized in Vienna on March 25th within ETAPS by Verimag (Maraninchi) and the LRI Orsay (Pouzet).

SLAP'06 receives no funding from Artist FP5 (it had initially been planned to fund participation by students, but this had not been possible due to restrictions at the University Joseph Fourier administration. It is included here to provide a more complete picture of Artist partners' involvement in workshops having an International Collaboration dimension.

SLAP is a workshop dedicated to synchronous languages. Such languages have emerged in the 80s as a new method to design real-time embedded critical systems. There exists now a strong interest for them in industry: Lustre, Esterel, and Signal are used with success to program real-time and safety critical applications, from nuclear power plant management layer to Airbus air flight control systems. The purpose of the SLAP workshop is to bring together researchers and practitioners who work in the field of embedded systems. The workshop topics are covering all these issues: synchronous models of computation, synchronous languages and programming formalisms, compiling techniques, formal verification, test and validation of programs, case-studies, education, etc.

SLAP'06 is the fifth edition of the workshop. We had an invited speaker from Philips research, paper presentations, and open discussions.

The proceedings will be published in the Electronic Notes in Computer Science.

4.5.b. ARTIST Workshop: "Design Issues in Distributed, Communication-Centric Systems" (at DATE'06 March 10th, 2006)

http://www.artist-embedded.org/FP6/ARTIST2Events/Events/Date06/

Chairs

Bruno Bouyssounouse, VERIMAG Laboratory, FR

Rolf Ernst, TU Braunschweig, DE

Lothar Thiele, ETH Zurich, CH

Objectives

The workshop will present relevant, innovative, and holistic topics in communication-centric systems, sensor networks, dynamic real-time architecture, distributed computing, minimal operating systems, and self-organisation.

More generally, these workshops aim to extend existing links between related multi-disciplinary communities, through world-class presentations and discussion on cutting-edge topics. The ARTIST2 Network of Excellence on embedded systems software design aims to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. To achieve this, ARTIST2 gathers together the best European teams from the composing disciplines, and aims to forge a scientific community. This interdisciplinary effort in research is mandatory for establishing Embedded Systems Design as a discipline, combining competencies from electrical engineering, computer science, electronic engineering, applied mathematics, systems theory, and control. The ambition is to compete on the same level as equivalent centres in the USA (Berkeley, Stanford, MIT, Carnegie Mellon), for both the production and transfer of knowledge and competencies, and in terms of impact on industrial innovation.

Target Audience

Prominent members of the ARTIST2 NoE and DATE communities, wishing to explore relevant and innovative work directions common to both, and to extend contacts and establish long-term links.

Programme

ARTIST2 NoE on Embedded Systems Software Design: Structuring the Research Area in Europe
Bruno Bouyssounouse, VERIMAG Laboratory, FR

Distributed Safety-Critical Applications in Automotive: New Developments in CAN
Luis Almeida, Aveiro U, PT

Current Trends and Work Directions in Sensor Networks
Tarek Abdelzaher, U Illinois at Urbana Champaign, US

Communication Issues on MPSoC Platforms: Performance, Power and Predictability
Luca Benini, DEIS – Bologna U, IT

Model-based Design and Network Centric Systems
Marcello Coppola, ST Microelectronics, FR

Model-based Design and Network Centric Systems
Janos Sztipanovits, Vanderbilt U, US

Modelling Networked Embedded Systems: From MPSoC to Sensor Networks
Jan Madsen, TU Denmark, DK

Optimisation of Robust Communication-Centric Systems
Rolf Ernst, TU Braunschweig, DE

Cooperating Objects in Wireless Sensor Networks
Paul Havinga, Twente U, NL

Interface-based Design and Performance Analysis of Distributed Embedded Systems
Ernesto Wandeler, ETH Zurich, CH

4.5.c. MARTES - Modelling and Analysis of Real Time Embedded Systems (October 4th, 2005)

http://www.martes.org/

Organised by Susanne Graf (Verimag) October 4, 2005 in Montego Bay, Jamaica

Description

The OMG initiative, called MDA -- for "Model Driven Architecture" puts forward the idea that future process development will be centred around models, thus keeping application development and underlying platform technology as separate as possible. The aspects influenced by the underlying platform technology concern mainly non functional aspects and communication primitives. The first significant result of the MDA paradigm for engineers is the possibility for them to build application models that can be conveniently ported to new, emerging technologies - implementation languages, middleware, etc.- with minimal effort and risk in one hand, but also that can be analyzed either directly or through a model transformation toward a specific formal technological space in order to validate or/and verify real-time properties such as for example schedulability.

In the area of DRES (distributed, Real-time and Embedded Systems), this model-oriented trend is also very active and promising. But DRES are different from general-purpose systems. The purpose of this workshop is to serve as an opportunity to gather researchers and industrials in order to survey some existing experiments related to modelling and model-based analysis of DRES.

Moreover in order to be able to exchange models with the aim to apply formal validation tools and to achieve interoperability, it is important to have also a common understanding of the semantics of the given notations. Other important issues in the domain of real-time are methodology and modelling paradigms allowing breaking down the complexity, and tools which are able to verify well designed systems.

Topics

This workshop seeks contributions from researchers and practitioners interested in all aspects of the representation, analysis and implementation of DRES models, on the following principal topics:

- Modelling RT/E using UML
  - How to specify real-time requirements and characteristics in UML
  - How to enhance UML to capture real time, embedded and distributed aspects in a convenient manner
  - Declarative versus operational real-time specifications
  - Notations for defining the architecture of heterogeneous systems
  - Behaviour Modelling
  - RT/E platforms modelling, integration of scheduling aspects
- Semantic aspects of real-time in UML
  - Formal semantics, in particular, semantic integration of heterogeneous systems
  - Interpretations of annotations
  - Executability of models
- Methods and tools for analysis of RT systems and components
  - Ensure consistency of timing constraints throughout the system
  - Validation of time and scheduling related properties
  - Validation of functional properties of time dependent systems

The workshop gathered people from academia and industry to discuss the needs and possible solutions for handling *Modelling, semantic and validation* related issues which should help to define a work programme in the context of model based Development.

Programme

Introduction
The organizers slides

Session I : Quantitative analysis

A Unified Approach for Predictability Analysis of Real-Time Systems using UML-based Control Flow Information Vahid Garousi paper slides abstract

Modular Verification of Safe Online-Reconfiguration for Proactive Components in Mechatronic UML Holger Giese, Martin Hirsch paper slides abstract

Timing analysis and validation of the embedded MARS bus manager Iulian Ober, Susanne Graf, Yuri Yushtein paper slides abstract

Validating temporal properties of a deployed application with an MDD approach Jean-Louis Houberdon, Pierre Combes, Jean-Philippe Babau, Isabelle Auge-Blum paper slides abstract

Discussion of presentations in session I

Session II : UML Profiles

Modeling and Analysis of Concurrent and Real-Time Object-Oriented Designs Robert G. Pettit IV, Hassan Gomaa paper slides abstract

Introducing Control in the Gaspard2 Data-Parallel Metamodel: Synchronous Approach Ouassila Labbani, Jean-Luc Dekeyser, Pierre Boulet and Éric Rutten paper slides abstract

Some Requirements for Quantitative Annotations of Software Designs Dorina C. Petriu, Murray Woodside paper slides abstract

A General Structure for the Analysis Framework of the UML MARTE Profile Huáscar Espinoza, Hubert Dubois, Sébastien Gérard, Julio Medina paper slides abstract

Discussion of presentations in session II and general discussion

4.5.d. ARTIST2 Summer School on Component & Modelling, Testing & Verification, and Static Analysis of Embedded Systems (Sept 29 - Oct 2, 2005)

The ARTIST2 Summer School was held at Nässlingen, Sweden, September 29 - October 2, 2005, in conjunction with the 3rd International Conference on Formal Modelling and Analysis of Timed Systems (FORMATS'05). The Summer School offers a number of foundational tutorials accompanied by a selection of exiting new emerging technologies all given by absolute leading scientific experts of the community.

It was targeted for young researchers working or wanting to work in the fields of modelling, validation and performance analysis of embedded systems as well as engineers from industry with practical background in design and testing of embedded systems.

The Summer School was organised with strong contributions from three of its research clusters: Modelling & Components, Testing & Verification and Compilers & Timing Analysis. The school was open for participation for any interested parties. However, some previous training and/or experience in fundamentals of computer science as well as knowledge of computer architecture were required.

The school attendance was full, with approximately 60 participants.

Target Audience

The ARTIST2 Summer School is a 4 day summer school for young researchers working or wanting to work in the fields of modelling, validation and performance analysis of embedded systems as well as engineers from industry with practical background in design and testing of embedded systems.

The Summer School is organised by the ARTIST2 Network of Excellence with strong contributions from three of its research clusters: Modelling & Components, Testing & Verification and Compilers & Timing Analysis. The school is open for participation for everybody, however, some previous training and/or experience in fundamentals of computer science as well as knowledge of computer architecture is required.

Steering Committee

- Bengt Jonsson (Uppsala Univ., Sweden)
- Kim G. Larsen (Aalborg Univ., Denmark)
- Reinhard Wilhelm (Univ. Saarland, Germany)

Programme

- Ileana Ober: UML and UML 2.0
- Sebastien Gerard: UML for Real Time Systems
- Alberto Ferrari: Modelling of Heterogeneous Systems in Metropolis (Components & Modelling)
- PA Muller: Applications of model transformations MDE)
- Reiko Heckel: Foundations of Model Transformations
- Joseph Sifakis: Component-Based Modelling of Real-Time Systems
- Susanne Graf: Verification of UML models.
- Jean-Francois Raskin: Controller Synthesis and Code Generation
- Reinhard Wilhelm: Runtime Guarantees for Real-Time Systems
- Reinhard Wilhelm: Worst Case Execution Time Analysis
- Ed Brinksma: Foundations of Testing
- Thierry Jeron: Test Generation using Model Checking
- Brian Nielsen: On-line Testing for Real-time Systems
- Foundation for Timed Systems, Patricia Bouyer
- Gerd Behrmann: Real-time Model Checking
- Stavros Tripakis: Fault-Diagnosis for Real-time Systems
- Joost-Pieter Katoen: Foundations for Stochastic Systems
- Joost-Pieter Katoen: Applications of Stochastic Model Checking
- David Parker: PRISM a Tool for Stochastic Model Checking

4.5.e. WESE'05: Workshop on Embedded Systems Education (September 22nd, 2005)

http://www.artist-embedded.org/FP6/ARTIST2Events/Events/WESE05/

September 22nd, 2005, Jersey City, New Jersey, USA (a satellite event of EMSOFT 2005)

This event is described in section 3.2.a. of this document.

4.5.f. 31st EuroMicro Conf. -Special session: Component-Based Software Engineering track (Aug 30th - Sept 3rd 2005)

http://www.idt.mdh.se/ecbse/2005/

Chair: Ivica Crnkovic (Malardalen University, Sweden)

Component-based software engineering (CBSE) is a development paradigm that promises to accelerate software development and to reduce costs by assembling systems from prefabricated software components. Designing, developing and maintaining components and component-based applications for reuse is, however, a very complex process, which places high requirements not only for the component functional and non-functional properties, but also for the development organization. CBSE covers many software engineering disciplines and different techniques. Many of them have been developed and successfully implemented. CBSE has been successful in certain engineering domains, such as office applications and distributed internet-based applications but it is still in the early stage of utilization in many other domains, in particular those which have specific requirements on different quality attributes.

The CBSE track, fifth in a row, has a goal to point out the overall challenges and problems of the component-based approach, but also show the new ideas, solutions and practices. The aim of the track is to bring together researchers and practitioners from academia and industry to improve the theories, technologies, and processes in component-based software development. We encourage submissions of both theoretical nature and experience reports from academia and especially from industry. Suggested areas of interest include, but are not restricted to:

Component models and technologies	*Component compositions*
Component specifications	*Components and Quality Attributes*
Dependability of component-based systems	*Components for real-time and embedded systems*
Component-based software architecture	*COTS components*
Component-based requirements engineering	*Components and Open Source*
Evaluation of components	*Middleware solutions for CBSE*
Component design, implementation, testing	*Development environment and tools*
Component development processes	*Component markets and businesses*
Evolution of Component-based applications	*CBSE organizational issues*
Software product-line approach	*Case studies and experience reports*

CBSE and emerging disciplines (services, model-driven development, aspect-oriented programming, etc.)

4.5.g. 31st Euromicro Conference -Special session: Model Driven Engineering (Aug 30th - Sept 3rd, 2005)

http://www.md.kth.se/RTC/ecbse2005/

PORTO, Portugal,

Session Program Chair: Martin Törngren (KTH)

Session Programme Committee

Karl-Erik Arzen (Sweden), Jakob Axelsson (Sweden), Iain Bate (UK), Jan Broenink (Netherlands), Jim Cooling (UK), Jacky Estublier (France), Peter Fritzson (Sweden), Ulrich Freund (Germany), Sebastien Gerard (France), Chris Gill (USA), Wolfgang Halang (Germany), Hermann von Hasseln (Germany), Jean-Marc Jezequel (France), Bernhard Josko (Germany), Guiseppe Lipari (Italy), Dorina Petriu (USA), Pierre-Alain Muller (France), Ola Redell (Sweden), Joseph Sifakis (France), Francoise Simonot (France), Neraj Suri (Germany), Simin Nadjm Tehrani (Sweden), Michael Winokur (Israel), Wayne Wolf (USA, Wang Yi (Sweden)

Scope

Model driven engineering - or model based development as it is often called in traditional engineering disciplines - is an approach that promises to accelerate development, to improve systems quality, to reduce costs, and also to enable reuse. However, while the use of models and related computer aided engineering tools is very common in established engineering disciplines, MDE approaches are still rarely used in industry for the development of embedded systems. This is despite the realization that higher levels of abstraction are required to describe and analyze systems, large problems in systems integration, and despite numerous efforts in developing modelling languages, methods and tools. These deficiencies along with industrial needs have stimulated many research efforts to overcome the current situation.

Problems facing researchers and developers include the fact that the area of embedded systems is very large. It does not only cover many application domains and different requirements, but is also strongly characterized by multi-disciplinarity, where each discipline has its own traditions, concepts, modelling languages and tools. Embedded systems are characterized by a multitude of relations and interactions between its constituent units and with the environment. Moreover, products including embedded systems typically have to be not only cost-efficient, but also dependable and flexible.

These facts to some extent explain the multitude of efforts in different directions, and the incompatibility between different modelling languages and tools. Other problems may be due to the nature of software, allowing unprecedented design flexibility and constituting an intermediate design representation that can be implemented in a variety of ways. Today, model based development is mainly used for developing subsystems and with little consideration or treatment of cross-cutting aspects such as dependability, real-time performance, and flexibility. On the other hand, taking a more optimistic view, learning from experiences made in more mature disciplines, and taking the strong industrial needs into account, there is plenty of room for innovative research efforts!

Objectives

This session aims to gather researchers and engineers from different domains and disciplines, industry and academia, all focusing on different aspects of MDE, in order to stimulate cross-fertilization and thus further the development of successful model based development approaches for embedded systems.

4.5.h. Artist Workshop "Embedded Systems Design: An Emerging Unified Discipline" at DATE'05 (March 11th, 2005)

Objective

In order to increase the awareness of other communities, ARTIST2 has organized a workshop held during DATE (http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/Date05/), the largest conference on electronic design automation in Europe, and by the number of paper submissions, worldwide. The first workshop – initiated within Artist FP5 - provided a broad introduction to embedded and real-time systems to the DATE community. Due to the success of this workshop at DATE 2004, a second workshop was held on March 11th, 2005. The second workshop focussed on hard and soft real-time computing. The technology presented included the timing verification methodology used for Airbus software.

About 80 attendees were present at the workshop. The goal of the workshop was reached.

Chairs

Organisers: Albert Benveniste, INRIA, FR
Bruno Bouyssounouse, VERIMAG Laboratory, FR
Giorgio Buttazzo, Pavia U, IT
Peter Marwedel, Dortmund U, DE
Reinhard Wilhelm, Saarland U, DE

Description

The workshop's objectives are to strengthen the links between the ARTIST2 and the DATE communities, through a presentation by prominent members of selected topics which may be of interest. The ARTIST2 Network of Excellence on embedded systems software design aims to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. To achieve this, ARTIST gathers together the best European teams from the composing disciplines, and aims to forge a scientific community. This interdisciplinary effort in research is mandatory to establish Embedded Systems Design as a discipline combining competencies from electrical engineering, computer science, electronic engineering, applied mathematics, and control theory. The ambition is to compete on the same level as equivalent centres in the USA (Berkeley, Stanford, MIT, Carnegie Mellon), for both the production and transfer of knowledge and competencies, and for the impact on industrial innovation. The workshop will present overviews of strategic challenges and work directions faced in selected topics within ARTIST, including work on Hard Real-Time systems, Testing and Verification, Timing Analysis, and System-on-Chip. In addition, the workshop will provide an opportunity for discussion around structuring the embedded systems research area in Europe.

Target Audience

Prominent members of the ARTIST2 NoE and DATE communities, wishing to know more about topics common to both, and to extend contacts and establish long-term links.

Programme

Information Society Technologies in the 6th Framework Programme
IST Work Programme 2005-2006
Tom Clausen, European Commission

ARTIST2 NoE on Embedded Systems Software Design: Structuring the Research Area in

Europe
Bruno Bouyssounouse, Verimag Laboratory, FR

Heterogeneous Systems Modelling and Design
Alberto Sangiovanni-Vincentelli, UC Berkeley, US

From Synchronous Designs to Delay-Insensitive Components
Benoit Caillaud, INRIA, FR

Modelling Real-Time Systems
Joseph Sifakis, Verimag Laboratory, FR

Using Rich Component Models in the Development of Automotive and Avionics Applications
Werner Damm, OFFIS, DE

Adaptive Task Scheduling
Giorgio Buttazzo, Pavia U, IT

Do Safely-Critical Systems Really Need to be Static?
Luis Almeida, Aveiro U, PT

Towards a System Modelling Platform
Jan Madsen, TU Denmark, DK

Timing Analysis of Hard Real-Time Systems
Reinhard Wilhelm, Saarland U, DE

Timing Analysis: New Directions After the Breakthrough
Andreas Ermedahl, Malardalen U, SE

4.5.i. ARTIST workshop "Embedded Systems Research in Europe" (at DATE'04 - Feb 20th 2004)

http://www.artist-embedded.org/PastEvents/Date04/index2.html

Chairs

- Bruno Bouyssounouse, VERIMAG Laboratory
- Peter Marwedel, University of Dortmund
- Eugenio Villar, University of Cantabria

Objectives

The workshop's objectives are to strengthen the links between the ARTIST (initiative on embedded systems design) and the DATE communities, through a presentation by prominent members of selected topics which may be of interest. The workshop is composed of two parts, and discussions:

1. ARTIST Overview and Selected Topics. ARTIST aims to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. To achieve this, ARTIST gathers together the best European teams from the composing disciplines, and aims to forge a scientific community. This interdisciplinary effort in research is mandatory to establish Embedded Systems Design as a discipline combining competencies from electrical engineering, computer science, electronic engineering, applied mathematics, and control theory.

The ambition is to compete on the same level as equivalent centres in the USA (Berkeley, Stanford, MIT, Carnegie Mellon), for both the production and transfer of knowledge and competencies, and for the impact on industrial innovation. The workshop will present overviews of strategic challenges and work directions faced in selected topics within ARTIST, including work on Hard Real-Time systems, Testing and Verification, Timing Analysis, and System-on-Chip. In addition, the workshop will provide a first glance into the future scope and goals for ARTIST.

2. Hardware-dependent Software on SoC: Overview and Selected Topics. The heterogeneous and multiprocessing nature of SoC raises software implementation problems never faced before. Although they also affect the software development phase, these problems are strongly related with the implementation of hardware-dependent software on SoC. Efficient, embedded SoC software implementations cannot be made independently of the hardware platform, where the HAL may not be known. In this particular context, general-purpose, platform-independent embedded SW design methodologies are no longer valid. The integration of HW-related SW and SW-related HW increases. As a consequence, both the SW and HW functions have to be implemented and integrated tight together. In this workshop, the main challenges in hardware-dependent software integration on multiprocessing SoC platforms will be analysed and discussed.

Target Audience

Prominent members of the ARTIST (initiative on embedded systems design) and DATE communities, wishing to know more about topics common to both, and to get first contacts for establishing links.

Programme

ARTIST – Challenges And Work Directions For Europe
Joseph Sifakis*, VERIMAG, FR
Bruno Bouyssounouse*, VERIMAG, FR

Quantitive Testing And Verification Of Embedded Systems
Kim Larsen*, Aalborg U, DK
Ed Brinksma*, Twente U, NL

Challenges In The Design Of Safety-Critical Embedded Systems
Hermann Kopetz*, TU Vienna, AT

WCET – Industrial Requirements And Available Tools
Reinhard Wilhelm*, Saarland U, DE

Challenges For The Electronic Industry, International Cooperation And Research Agenda
Alberto Sangiovanni-Vincentelli*, PARADES/Berkeley, US
presented by Luciano Lavogno, Politecnico di Torino, IT*

System-On-Chip – Design Challenges For Future Embedded Systems
Jan Madsen*, TU Denmark, DK

The Medea Eda Roadmap: Hw-Dependent Sw
Eugenio Villar, Cantabria U, ES

Data Management For Heterogeneous Multiprocessor Systems
Miguel Miranda, IMEC, BE

Hardware Dependent Software In Embedded Defined Radio Applications
Phillip Kajfasz, Thales Software, FR

Fast, Predictable, And Low-Energy Memory References Through Architecture-Aware Compilation
Peter Marwedel*, Dortmund U, DE

Performance Modelling And Verification Of Embedded Multiprocessors
Rolf Ernst*, TU Braunschweig, DE

4.5.j. ARTIST Summer School on Real-time Scheduling and Resource Management (July 5th-9th, 2004)

The Artist Summer School on Real-time Scheduling and Resource Management, was held in Piazza Armerina (EN), Sicily, Italy: http://www.artist-embedded.org/SummerSchools/

Objective

The objective of the school was to provide an overview of the main scheduling algorithms and resource management policies for supporting the development of predictable, as well as flexible, real-time systems with hard and soft timing constraints.

Intended Audience

The school was aimed at graduate students, PhD students and engineers with some background on computer science and operating systems. No specific knowledge is required to understand the course, since all new concepts are explained and illustrated with concrete examples.

Structure

The school was divided in 5 courses, one per day, of 6 hours each:

1. Fixed Priority Scheduling
   This part introduces the basic concepts of real-time computing systems and provides a theoretical background for analyzing fixed priority systems. Different task models are presented to apply the analysis in different contexts, including resource constraints, release jitter, and fault tolerant requirements. The course also discusses real-time programming issues and advanced research topics.
2. Dynamic Priority Scheduling
   This part presents a theoretical background for analyzing dynamic priority systems, where task scheduling is performed based on explicit timing constraints. A set of scheduling algorithms and analysis techniques are presented to cope with periodic and aperiodic activities, and shared resources. This part also intoduces some QoS management techniques for coping with transient and permanent overload conditions.
3. Off-line Scheduling
   This part focuses on table driven scheduling for time critical applications. It presents the time triggered and the event triggered activation paradigm, together with a method for constructing an offline schedule based on complex timing constraints. It also presents a method for integrating offline and online scheduling to increase flexibility of static scheduled systems.
4. Real-Time Networks
   This part introduces the basic concepts of real-time communication networks, focusing on real-time message scheduling, event/time-triggered communication, communication control and synchronization issues. It also presents some common application service models and some case studies of standard communication protocols. It concludes presenting new trends in wireless networks, sensor webs, and internet connection.

5. QoS management
   This part introduces the problem of resource management for QoS control in centralized systems and distributed systems. Existing solutions are presented for both cases. Middleware architectures for distributed real-time systems are also presented, with particular emphasis on RMI, RT-Java, and RT-RMI.

4.5.k. ESSES: European Summer School on Embedded Systems (July 14th – Oct 17th 2003)

The European Summer School on Embedded Systems (ESSES) (http://archi.snu.ac.kr/symin/esses/index.html) was organized by Hans Hansson (Malardalen University, member of Artist), Sang Lyul Min (Seoul National University), and Kang G. Shin (University of Michigan).

The school brought together 19 top students from Korea, and 56 from Europe.

The summer school provides a forum for Ph.D students and early-career researchers in low-power, embedded, and real-time research areas to learn up-to-date research from masters in the three strongly inter-related research areas and to foster their own research network.

The school is also funded by the ARTES Network for Real-Time Research and Graduate Education in Sweden (http://www.artes.uu.se/index.html), BK21 Korea Advanced Institute of Science and Technology (http://bk21.kaist.ac.kr/), Malardalen Real-Time Research Center (http://www.mrtc.mdh.se/).

It brings together an impressive set of lecturers from Europe, Asia, and the USA.

Extended abstracts of the lecture notes will be published as a volume in the Springer-Verlag LNCS series.

Programme

Period 1: LOW POWER SYSTEMS)

Introduction and Overview

Dynamic Voltage Scheduling (DVS)

Low-Power I/O Systems

Operating System Support for Low Power

Period 2: Embedded Systems

Introduction and Overview

Embedded System Programming and Compilation

Embedded System Simulation

Operating System and Middleware for Embedded Systems

Period 3: Real-time systems

Introduction and Overview

Synchronous Language Paradigm in Real-time Systems

Real-time Scheduling

Formal Methods in Real-time Systems

Participants

Anders B. Christiansen	Aalborg, Denmark
Anders Brödlös Olsen	Aalborg, Denmark
Jan Jacob Jessen	Aalborg, Denmark
Jens Alsted	Aalborg, Denmark
John Knudsen	Aalborg, Denmark
Tue Brems Olsesen	Aalborg, Denmark
Yannick le Moullec	Aalborg, Denmark
Francisco Borges Carreiro	Aveiro, Portugal
Joaquim Ferreira	Aveiro, Portugal
Mario Cahla	Aveiro, Portugal
Björn Andersson	Chalmers, Sweden
Cecilia Ekelin	Chalmers, Sweden
AnnMarie Ericsson	Högskolan i Halmstad
Nuno Pereira	ISEP, Portugal
Gil-Su Kim (Korea Univ.)	Korea Univ.
Sang-Yong Lee (Korea Univ.)	Korea Univ.
Nguyen-Thai Ngyuen-Phan	KTH, Sweden
Darius Virzonis	KUT Panevėžys Institute (Lithuania)
Jonas Elmqvist	Linköping, Sweden
Mehdi Amirijoo	Linköping, Sweden
Viacheslav Izosimov	Linköping, Sweden
Andreas Löfgren	MdH, Sweden
Goran Mustapic	MdH, Sweden
Joel Huselius	MdH, Sweden
Mohammed El Shobaki	MdH, Sweden
Raimo Haukilahti	MdH, Sweden
Sigrid Eldh	MdH, Sweden
Tomas Lennvall	MdH, Sweden
Anders Pettersson	MdH, Sweden
Andres Moller	MdH, Sweden
Damir Isovic	MdH, Sweden
Johan Fredriksson	MdH, Sweden
Radu Dobrin	MdH, Sweden
Thomas Nolte	MdH, Sweden

Paolo Gai	Pisa, Italy
Dongkun Shin	SNU, Korea
Ganghee Lee	SNU, Korea
Hyung Gyu Lee	SNU, Korea
Jaesoo Lee	SNU, Korea
JiHyuck Yun	SNU, Korea
Jin-Hyuk Yoon	SNU, Korea
Junu Kim	SNU, Korea
Juyup Lee	SNU, Korea
KeeSung Han	SNU, Korea
Kyungtae Kang	SNU, Korea
Minho Kim	SNU, Korea
Nam-Joon Kim	SNU, Korea
Sheayun Lee	SNU, Korea
Sooyeon Kim	SNU, Korea
Wonchul Lee	SNU, Korea
Woon seok Kim	SNU, Korea
Youngmin Yi	SNU, Korea
Martin Pohlak	TU Dresden, Germany
Cedric Meuter	ULB Bruxelles, Belgium
Laurent Doven	ULB Bruxelles, Belgium
Wolfgang Werner Freund	Uni Dortmund, Germany
Jork Loeser	Uni Dresden, Germany
Daniel Lohmann	Uni Erlangen, Germany
Harvey Tuch	Uni NSW, Australia
Vasughi Sundramoorthy	Uni Twente, NL
Ferdy Hanssen	Univ. Twente
Fuhzi Wang	Univ.Birmingham, UK
Håkan Zeffer	UU, Sweden
Martin Karlsson	UU, Sweden
Mayank Saksena	UU, Sweden
Olga Grinchstein	UU, Sweden
Therese Berg	UU, Sweden
Anders Hessel	UU, Sweden

Andreas Ermedahl	MdH, Sweden
Siarhei Yermalayeu	Philips Research, NL
Davide Cantini	Pisa, Italy
Luca Marzario	Pisa, Italy

Annika Karlsson	UU, Sweden
John Håkansson	UU, Sweden
Konstantinos Bletsas	York, UK

4.5.I. EmSys Summer School (June 20th – July 2nd, 2003)

The EmSys Summer School (http://www.softwareresearch.net/site/other/EmSys03/) was a 3-day event June 30th - July 2nd 2003 in Salzburg, organized by Prof. Dr. Wolfgang Pree (CS, University of Salzburg) and Dr. Christoph Kirsch (EECS, University of California at Berkeley).

Programme

Monday, June 30th

Real-Time Programming (Niklaus Wirth, Christoph Kirsch)

Time-Triggered approach (Hermann Kopetz)

Tuesday, July 1st

Lab: from control models to real-time code using Giotto, (Wolfgang Pree, Christoph Kirsch)

Modeling and Components (Bran Selic, Bertrand Meyer)

Wednesday, July 2nd

Keynote presentations from prominent members of the embedded systems research community:

- Prof. Dr. Hermann Kopetz (TU Vienna)
- Prof. Dr. Bertrand Meyer (ETH Zurich)
- Prof. Dr. Heikki Saikkonen (Nokia Research, Helsinki)
- Prof. Dr. Joseph Sifakis (Director of Verimag, Grenoble)
- Dr. Bran Selic (Rational/IBM)
- Dr. Alkis Konstantellos (EU-IST) requested

4.6. Sponsoring for External International Conferences / Schools

In addition to direct organisation of events (see sections 2, 3 and 4), Artist FP5 has provided sponsoring for international conferences and schools that were not organized exclusively by Artist FP5 partners. Nonetheless, Artist FP5 partners are generally involved in their organisation, in some capacity.

These events have also helped to further the overall Artist FP5 aims.

- **Conference on EU-Korea Collaboration in Embedded Systems**
  20th April 2005, Lotte Hotel (Sogong-dong), Emerald Room
  Organised by Delegation of the EU Commission Seoul & Ministry of Information and Communication. In Collaboration with the Federation of Korean Information Industries, Korea Embedded Software Industry Council & ETRI

- **ECRTS / OSPERT 2005 - Operating Systems Platforms for Embedded RT**
  July 5th, 2005
  http://feanor.sssup.it/%7Elipari/OSPERT.html

- **MEMOCODE'05**
  July 11-14, 2005
  http://memocode.irisa.fr/2005/
  The goal of MEMOCODE 2004, the second in a series of international conferences, was to gather together researchers and software and hardware practitioners to explore ways in which software and hardware design can exploit research results in formal methods. These topics include formal specification languages, formal models, model checking, theorem proving, specification-based testing, compositional methods, methodologies based on formal methods, and rigorous approaches (e.g., refinement) to transforming a hardware or software specification into a reliable, efficient implementation.

- **Laser Summer School on Software Engineering**
  Sept 11-17, 2005
  http://se.inf.ethz.ch/laser/2005/
  The 2005 LASER school brings together six of the best experts in the field of concurrent and real-time systems. Each will present a series of six lectures on his or her latest research efforts. The six speakers are: Laura Dillon (Michigan State University), Bertrand Meyer (ETH Zürich/Eiffel Software), Jay Misra (University of Texas at Austin), Amir Pnueli (Technion), Wolfgang Pree (University of Salzburg), Joseph Sifakis (Verimag).

- **ASWSD - Automotive Software Workshop - San Diego**
  January 10-12, 2004 http://aswsd.ucsd.edu/2004/
  The goal for the workshop is to bring together experts from industry and academia, who work on highly complex, distributed, reactive software systems related to the automotive domain, and to discuss and further the understanding of the following focus areas:

- **SCOPES 2005**
  Sept. 29 - Oct. 1, 2005
  http://www.scopesconf.org/
  A key goal of the workshop was to provide an interactive atmosphere, including special discussion sessions. The workshop is open to all interested participants active in embedded systems. By holding the conference in Dallas, the workshop attracted significant numbers of attendees from the research and application communities of both industry and academia.

4.7. International Collaboration Working Groups

The purpose of the Artist International Collaboration working groups was to work on action lines in which strong synergy between international teams would have the greatest benefit. We have set up the common understanding and background on which we can progressively base collaborative actions and joint projects. To this end, we have:

- Identified relevant topics of common interest.
- Set up international Collaboration Working groups for selected topics - these gathered a small number of key persons from the EC, USA, and/or Korea.
- Each group has worked together to produce a white paper on the corresponding topic, presented at the International Collaboration Day 2003, October 11th in Philadelphia (near EmSoft'03).

4.7.a. WG1 : Timing Validation

Led by Reinhard Wilhelm - Saarland University

Motivation

Hard Real-Time Systems need reliable guarantees for their timeliness. These must be derived by an analysis of the Hardware/Software System by provably correct methods. The single-task WCET problem seems to be solved, even on modern processor architectures.

However, the general problem posed by industrial practice, namely analyzing arbitrary task systems to be executed on top of (distributed) real-time operating systems and implemented using middleware components is an open problem of high relevance to industrial practice, but of a complexity, which is greater by at least one order of magnitude.

Results

Viable methodologies for analyzing task sets - to be run on top of real-time operating systems:

- Supporting (limited) pre-emption
- Distributed over a heterogeneous processor network
- Implemented using appropriate middleware
- Using a clever cache-locking strategy, or the proof that this problem is infeasible

Guidelines for the design of: 1) embedded processors; 2) middleware with highly predictable behaviour.

Presentation and White Paper

Abstract:
The determination of upper bounds on execution times, commonly called Worst-Case Execution Times (WCETs), is highly relevant for hard real-time systems and rather complex, if the underlying processor architecture has components such as caches, pipelines, branch prediction, and other speculative devices.
This White Paper reports about requirements for WCET tools we have collected from industrial users and describes several available WCET tools and research prototypes.

The white paper and presentation slides are also available on-line:

Presentation: http://www.artist-embedded.org/PastEvents/ICD_2003/Trends/Dave%20Whalley.pdf

White Paper: http://www.artist-embedded.org/IntlCollab/2003/WCET_whitePaper.pdf

Participants

WCET Tool Providers

AbsInt Angewandte Informatik GmbH Reinhard Wilhelm **Chalmers University of Technology** Per Stenstroem **Florida State University** Dave Whalley	**IRISA, Rennes (France)** Isabelle Puaut **Mälardalen University** Hans Hansson Jan Gustafsson Bjoern Lisper **North Carolina State University** Frank Mueller	**Paderborn University** Peter Altenbernd Friedhelm Stappert **Saarland University** Reinhard Wilhelm Stephan Thesing Marc Langenbach **TU Braunschweig** Rolf Ernst	**TU Vienna** Peter Puschner **University of York** Guillem Bernat Ian Bate **Uppsala University** Jakob Engblom

Participating integrators are: **Esterel Technologies**, **TimeSys Corporation**, **TNI Valiosys**

4.7.b. WG2 : Adaptive Real-Time Systems for Dynamic Applications

Led by Giorgio Buttazzo - University of Pavia

Motivation

Most current real-time applications (e.g., multimedia and robotics systems) are less critical and more dynamic than classical hard real-time systems. In such cases, efficiency in resource utilization is as important as predictability, especially in embedded systems, where resources are limited. Adaptivity is also required to cope with significant environmental changes. Two novel important issues that also need to be investigated for mobile embedded devices include energy-aware computing and security.

Results

The major goal of the proposed research is to identify the weakest points in today's real-time platforms that limit the development of real-time embedded systems that are predictable, efficient, adaptive, resource-aware, and secure. By interacting with leading research groups and industrial companies involved in RT system development, we expect to understand what is missing in the current approach and what should be provided to achieve the desired characteristics listed above.

To achieve this goal, we will mainly focus on different aspects, including kernel mechanisms, operating systems interfaces, network protocols, middleware, and programming languages.

The current state-of-the-art solutions will also be analyzed and assessed in terms of runtime overhead, implementation complexity, and implications on standard OS interfaces.

White Paper

Abstract :
Resource Reservation (RR) is a class of real-time schedulers, proposed by the research community for hard and soft real-time systems, which are receiving considerable attention from industry. With this white paper, we would like to trigger a broad discussion between the academic and the industrial world on the use of RR techniques in standard operating systems. After presenting the major reasons for using RR ("why"), we present

a set of propositions on "what" and "how" should be provided, which pinpoint the demands on operating systems and the research issues that remain to be addressed.

White Paper: http://www.artist-embedded.org/IntlCollab/2003/ARTOSS-RR.pdf

Artist Participants

Giorgio Buttazzo	Univ. of Pavia	Italy
Alan Burns	Univ. of York	UK
Giuseppe Lipari	Scuola S.Anna of Pisa	Italy
Luis Almeida	Univ. of Aveiro	Portugal
Michael Gonzalez	Univ. of Cantabria	Spain
Gerhard Fohler	Malardalen University	Sweden
Marisol García-Valls	Univ. Carlos III de Madrid	Spain

External Participants

Joseph Loyall	BBN Technologies	USA
Ragunathan Rajkumar	Carnegie Mellon University	USA
Heung-Nam Kim	ETRI	Korea
Doo-Hyun Kim	ETRI	Korea
Paolo Gai	Evidence	USA
Lui Sha	University of Illinois at Urbana	USA
Doug Schmidt	UC Irvine	USA
Moon Hae Kim	Konkuk University	Korea
Kevin Jeffay	University of North Carolina at Chapel Hill	USA
Sjir van Loo	Philips Research	Netherlands
Liesbeth Steffens	Philips Research	Netherlands
Al Mok	University of Texas at Austin	USA

4.7.c. WG3 : Semantic Platform for Hard Real Time

Led by Albert Benveniste – INRIA

Motivation

Integrating the different tools used at the different stages of embedded systems design has been identified as one of the main bottlenecks nowadays. This has been the subject of several talks from industrials at the two ARTIST meetings of April and October 2002. The reason for this is the difficulty in getting proper tool integration at the semantic level, due to the different paradigms these tools rely upon.

Results

There is an ongoing cooperation involving European and US groups, which has the topic of Semantic Platform as one of its objectives, namely the COLUMBUS European project. This project proposes to develop both fundamental studies related to the above topic. In addition, since several participants of COLUMBUS are already tightly coupled with marketed tools and their vendors, it is expected that major effective results from the research will benefit to products, and therefore industry. We propose to regard the Semantic Platform activity of the COLUMBUS project as an ARTIST working group for Action 1 on Hard Real-Time.

Presentation and White Paper

Abstract:
Platform-based Design (PBD) is a relatively new methodology paradigm for the design of embedded systems. It has made significant inroads in the electronic industry (see for example the OMAP platform for cellular communication and the Nexperia Platform for multimedia). However, the concept means different things for different industrial sectors and for different design groups. An attempt at structuring this approach has been put forward by our research group. The basic aspects of the methodology are its meet-in-the- middle view of the design process where a combination of top-down and bottom-up processes define an approach that maximizes re-usability and verifiability while maintaining constraints on performance, cost and power consumption. We describe the general aspects of the methodology and we give three applications to show how this method can be applied in a number of different industrial domain of great interests such as wireless sensor networks, automotive controllers and electric motor drives. The point here is to show that it is possible to adopt a general design methodology for all embedded system applications thus forming the basis for a well structured discipline that yields repeatable results and save substantial amount of expensive resources.

In particular, the wireless sensor network domain presents several challenging problems, it is characterized by hard real-time constraints, it has to be fault tolerant and design-error free, and it has to react to a nondeterministic adversary environment. Ad hoc wireless sensor networks are designed for environmental monitoring application and we emphasize a methodology that favours re-use at all levels of abstraction.

We used the platform-based design paradigms to identify an abstraction layer for the applications that is implementation independent.

The goal is to design a sensor node which is able to reconfigure itself and to form a network without any need for expensive infrastructure.

The design of automotive control systems is becoming increasingly complex due to the increasing level of performances required by car manufactures and the tight constraints on cost and development time imposed by the market. In this report, we illustrate the application of an integrated control implementation design methodology, recently proposed by our group, to the development of the highest layers of abstraction in the design flow of an engine control system for motorcycles.

Finally we show that an appropriate subset of the layers of abstraction used for the automotive application can also be used for the design of electric drives. The essential gain in this domain is the possibility of designing for non idealities of the computing platform at the functional level thus allowing for early detection of errors and short time-to-market while satisfying tight performance constraints.

White Paper: http://www.columbus.gr/documents/public/WPPBD/Columbus_DPBD1_0.3_Cover.pdf

Presentation: http://www.artist-embedded.org/PastEvents/ICD_2003/Trends/Albert%20Benveniste.pdf

Artist Participants

Albert Benveniste	INRIA	France
Benoit Caillaud	INRIA	France
Paul Caspi	Verimag	France
Paul Le Guernic	INRIA	France
Alberto Sangiovanni-Vincentelli	PARADES	Italy

External Participants

Shankar Sastry	UC Berkeley	USA
Janos Stipanovits	Vanderbilt	USA
Edward Lee	UC Berkeley	USA

4.8. Joint International Projects

Artist FP5 partners have been instrumental in setting up and implementing joint projects with teams outside Europe, with both the USA and Asia. These are generally very difficult to set up, mainly due to the varying selection criteria (both halves of an international collaboration project need to be accepted, on compatible objectives and timelines), financial and technical reporting, and review process.

4.8.a. Collaboration with NSF Projects

Artist partners collaborate with NSF projects through specific international calls set up by the NSF (100k$/project).

There are existing collaboration projects between Verimag and Vanderbilt, TU Vienna and Berkeley, and others.

- **Hipeac - Rutgers & Princeton Universities**
  European main contacts: Mateao Valero (TU Catalonia)
  US main contacts: Liviu Iftode (Rutgers University), Margaret Martonosi (Princeton University)
  Collaboration has been very successful and mutually beneficial:
  - Student exchanges (3 month- visits) are essential to bootstrap a collaborative project
  - Technical workshop to bring together the collaborating teams
  - At least two years necessary to complete a significant project
  - Seek additional funding to continue the projects if promising
  - Collaborations with Rutgers and Hipeac/UPC, Barcelona and UPMC/LIP6, Paris are under way
  - Gilberto Contreras (Princeton PhD student) spending summer at U. Patras in Greece, working with Stefanos Kaxiras (Main effort: Heterogeneous parallelism using NDP's flow-oriented model, and Network provisioning)
  - Continuing telecollaboration with Gilberto Contreras
- **DECOS - University of California, Irvine / Vanderbilt University**
  European main contact: Hermann Kopetz / Roman Obermaisser (TU Vienna)
  US main contacts: Kane Kim (UC Irvine), Janos Sztipanovits (Vanderbilt University)
  Technical Topics of the DECOS/TADE (UC Irvine) Collaboration:
  - Formalization of the structure of the real-time distributed component named TMO and the linking interface specification of DECOS jobs
  - Collaborative work on the integration of event-triggered and time-triggered communication paradigms
  - Comparison of commercial off-the-shelf platforms (common hardware and operating systems) as used in TADE with the introduced integrated DECOS platform
  - Comparative studies of the TADE testbed and the DECOS test-bench, along with cooperative experiments
    - Performance measurements
    - Fault-injection experiments for evaluation of encapsulation of communication and computational resources
    - Validation of development tools

  Technical Topics of the DECOS/Vanderbilt Collaboration:
  - Model Integrated Computing for DECOS

- Case study: Meta-modeling of sensor DAS
- Interpreters for exporting information to other tools (compiler, scheduling tools, etc.)
- Model transformation tools support export to other model-based tools (e.g. MATLAB)

- **RUNES – UCB, Caltech, UCSD, ISIS**
  European main contact: András Tóth (Ericsson)
  UC Berkeley in RUNES Brings in extensive experience on open experimental software/hardware platforms for networked embedded systems technology.
  Caltech in RUNES brings in leading competences in autonomous mobile systems and information dynamics in complex inter-connected networks.
  UCSD in RUNES brings extensive experience in optimised radio technology, intimate knowledge in applications and design methodology.
  ISIS in RUNES brings the extensive, cutting edge competence and tools in Model Based Design Methodology.

- **ARTIST/ARTIST2 – Berkeley/Vanderbilt University**
  European main contacts: Joseph Sifakis (Verimag&Artist) / Hermann Kopetz (TU Vienna)
  US main contacts: Janos Sztipanovits (ISIS-Vanderbilt), Claire Tomlin (Stanford University & Chess-Berkeley), Mary Margaret Sprinkle (Chess-Berkeley: The Trust Project)
  Artist 2 / Vanderbilt collaboration:
  - - MIC-based modeling interface for IF;
  - - Semantic Unit specification for Time Automata
  - - Modeling Language Design Environment

  DECOS / Vandebilt collaboration:
  - MIC-based modeling environment for DECOS
  - Automotive Design Tool Chain
  - DESERT Applications

  UC Berkeley-Chess collaboration with IST programs
  - RUNES, EU-IST program in network embedded systems (Ericsson, KTH, Aachen, Brescia, Pisa, Patras, …)
  - Columbus (with Cambridge, l'Aquila, Rome, Patras, INRIA)
  - Hybridge, Hycon (with Cambridge, Patras, NLR, Eurocontrol, Brescia, KTH)
  - ARTIST, ARTIST2 (Grenoble, INRIA, ETH-Zurich)

4.8.b. Joint IST proposal with India

Contacts have also been set up with India, mainly through Indian universities, and TCS (Tata Consultancy Services) research lab, which organizes an international seminar in January 2006. Several Artist2 members have been invited.

4.9. Conclusions and Next Steps

Clearly, International Collaboration will continue beyond the end of Artist FP5 – in particular through the Artist2 NoE. We feel this is a significant achievement, given the low level of organised international collaboration that existed in the area before the start of the project.

The continuing goals for International Collaboration will be:

- Increased awareness on the state of the art in Europe.
- Participation of project partners in high-level joint technical meetings with US teams.
- Increased discussion across different research communities in Europe.
- Definition and launching of coordinated or joint projects with US teams.

The immediate events planned are described in detail here.

4.9.a. ARTIST - China Spring School (April 3rd-15th, 2006)

http://www.artist-embedded.org/FP6/ARTIST2Events/Events/ChinaSchool/

The school will be held April 3rd-15th, 2006, in Xi'an, China.

Objective

The School offers a 2-week course consisting of four tutorials on state-of-the-art techniques for the design and analysis of embedded systems given by leading scientific experts.

We aim to provide a forum for young professors, lecturers, researchers, postgraduates (advanced master and PhD students) working in the fields of modelling, design, implementation, validation and performance analysis of embedded systems as well as engineers from industry with practical background with the development of embedded systems.

Targeted Audience

The school is open for participation for everybody, however, some previous training and/or experience in fundamentals of computer science as well as knowledge of computer architecture is required. Participants will be selected according to their CVs submitted to the organization committee.

Interested Chinese PhD students (both Master and PhD), young professors and researchers with academic and/or professional backgrounds in disciplines relevant to school's themes should apply for participation. Fields of study appropriate for applicants include, but are not limited to: compiler/operating systems support for embedded systems (including real-time systems), hardware/software design for embedded systems, embedded system design methodology, middleware, formal methods, real-time scheduling.

4.9.b. Embedded Systems Week / EmSoft'06 Workshop: "Foundations and Applications of Component-based Design" (October 22-25, 2006)

http://www.artist-embedded.org/FP6/ARTIST2Events/Events/Components_EmSoft/

Artist2 will organize a major workshop in Seoul in the framework of the Embedded Systems week, October 22-25, 2006, in Seoul, South Korea.

The workshop will be comprised of invited and contributed presentations, as well as dedicated discussion sessions, ordered according to the topics given above.

Objectives and Scope

Discuss recent results on component-based design with emphasis on design frameworks for real-time systems encompassing heterogeneous composition and models of computation, especially frameworks for handling non-functional and resource constraints, design under conflicting dependability criteria, trade-offs between average performance and predictability.

The workshop aims to gather together researchers from computer science and electrical engineering and will seek a synthesis between the underlying paradigms and techniques. The focus is not only on fundamental results but also on their implementation in methods and tools and their concrete application in areas such as automotive, avionics, consumer electronics and automation.

The workshop will address specific challenges such as:

- Modular design strategies for embedded systems
  - composable analysis methods
  - rich component concepts
  - design methodologies
- Predictability and efficiency
  - exploitation of the trade-off
  - approaches to predictability vs. efficiency
  - from hardware platforms to software systems
- Design space exploration
- Application scenarios

4.9.c. Other Events Planned

Events further into the future are described summarily here:

- **ARTIST Summer School 2006**
  We will repeat the successful experience of the Artist2 2005 Summer School in Sweden, possibly in the same location and with the same organizers, or in Bertinoro. We will undoubtedly update the topics, but this is still under discussion.
- **Embedded Systems Week in Salzburg**
  (October 2007)
  The objective is to create the main scientific event on embedded systems worldwide.
- **MEMOCODE'06 Formal Methods and Models for Codesign**
  (July 27-29, 2006) http://memocode.irisa.fr/
  Third ACM-IEEE International Conference on July 27-29, 2006 -- Napa Valley, California
- **MARTES Modelling and Analysis of Real Time Embedded Systems**
  (October 2006)
- **Fundamental Challenges raised by Integrated Modular Avionics,**
  in fall 2006 or winter 2007.
- **Fundamental Challenges related to Real-Time Components raised by Consumer Electronics and Telecommunications**,
  Fall 2006 or winter 2007.
- **Conceptual Model for Distributed Embedded systems, and a taxonomy of MoCCs** (Models of computation and Communication), in spring or fall 2006
- **Workshop on system modelling for communication centric systems**,
  in the summer of 2006
- **Workshop on Dynamics and Models of Computer Software Systems**
  (June-August 2006)
- **Control over networks**
  (June 2006)
- **Adaptive RT, HRT and Control Workshop 1**
  (late Spring 2006)
- **Adaptive RT, HRT and Control Workshop 2**
  (late Fall 2006)
- **Workshop on the link between formal and computational models**
  (July 9-16, 2006, Venice, Italy)
- **System Modelling for Communication Centric Systems**
  (June/July 2006)
- **ECRTS 2006**
- **RTSS 2006**

5. Industrial Liaison

Within ARTIST, Industrial Liaison with industry occurs in several ways:

- **Individual contacts**
  between one or several members of the consortium, and one or several industrial partners, for a specific technical goal or area of investigation and development.
- **Participation in leading Industrial Projects**
  Artist partners have participated in a very large participated in leading industrial projects, IST Integrated Projects, the European Technology Platform: ARTEMIS, SPEEDS, SPICES, ASSERT, DECOS, RUNES, East-EEA, Autosar. Work in Artist helped to structure these.
- **Speakers at ARTIST Events**
  We are very fortunate to have a very large participation by industrial participants at ARTIST events: International Collaboration Days, external workshops, conferences or summer schools. These are described in detail in section 4. Industrial participants are active both as speakers and as attendees.
- **ARTIST2 Industrial Affiliated Partners**
  Formal participation by industrial partners in the Artist2 Network of Excellence proposal – either as full partners, or as Industrial or SME Affiliated partners. This is a long-term commitment to take part in the NoE's research activities, or as relays for spreading excellence.
- **ARTIST Industrial Advisory Board**
  This board is shared with the ARTIST2 Network of Excellence. The IAB has provided some very valuable input on the Artist roadmaps, before publication.

As shown in the sections below, Artist FP5 has been particularly successful in gaining useful and lasting interaction with industry. We feel this is a key component of our strategy for structuring European research on embedded systems design.

5.1. Contributions by Industrial Partners in Artist FP5

In implementing the ARTIST workplan, we have had direct participation from a number of industrial contacts. These include:

Industrial and SME Partners	Main contact
ABB Automation Technology	Göran Arinder
ABB Automation Technology Products AB/ Robotics	Christer Norström
ACE Associated Compiler Experts bv	Hans van Someren
Airbus *	François Pilarski
ARTiSAN Software	Alan Moore
BBN / GTE	Joe Loyall
BMW Group	Michael von der Beeck
Boeing	David Sharp
BullDAST s.r.l.	Dr. Monica Donno
DaimlerChrysler	Matthias Grochtmann
DaimlerChrysler AG	Thomas Thurner
DARPA +	John Bay
dSPACE Gmbh	Joachim Stroop
European Space Agency + *	Eric Conquet
Electricité de France (EDF)	Alain Ourghanlian
Enea Embedded Technology	Jan Lindblad
Eonic Solutions GmbH	Eric Verhulst
Ericsson Mobile Platforms AB	Johan Eker
Esterel Technologies	Bernard Dion
Evidence Srl	Paolo Gai
Ford Research Laboratory	Ken Butts
Free2Move	Per-Arne Wiberg
Hispano Suiza	Philippe Baufreton
Honeywell Labs (Minneapolis)	Tariq Samad
Honeywell Prague Laboratory	Vladimir Havlena
IAR Systems AB	Carl von Platen
Intecs Sistemi	Marco Casucci (CEO)
Israel Aircraft Industries	Dr. Michael Winokur
LifTech	António Garrido
Lockheed Martin	Jonathan Preston

Magneti Marelli	Walter Nesci
Micro I/O Serviços de Electrónica Lda	Fernando Santos
Nokia Denmark A/S	Peter Mårtensson
Philips Research Labs + *	Liesbeth Steffens Sjir van Loo
Renault	Samuel Boutin
Siemens Mobile Phones A/S	Sven Holme Sørensen
Snecma Moteurs / Hispano Suiza	Philippe Baufreton
Space Systems Finland Ltd.	Dr. Niklas Holsti
STMicroelectronics	Miguel Santana Roberto Zafalon
Thalès	Dominique Potier
TNI-Valiosys	Jean-Luc Lambert
Volkswagen AG	Fabian Wolf
Volvo Car Corporation	Jakob Axelsson
Volvo Technology Corporation	Magnus Hellring
+ Indicates companies having made several presentations at different Artist meetings * Indicates companies having actively participated in the technical work	

Contacts Gathered

Contacts from the Artist FP5 activities, described in the previous section, have been gathered into a large mailing list, now used with in the Artist2 NoE for the newsletter. This list of contacts contains over 3500 e-mail addresses.

5.2. Technical Publications

Within the Industrial Liaison workpackage, the following documents have been published by the Artist FP5 consortium. Although these represent specific points of strong interaction with industry, interaction between Artist and industrial partners is by no means limited to these areas.

5.2.a. ARTIST / OMG Interaction Report

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/ReviewsOct2005/Deliverables/ArtistFP5_Y3/W4.A2.Y2_Artist_OMG_Interaction.pdf

This document provides an overview of standards that are relevant to the ARTIST components working group. It is broadly split into two main sections: specification standards and implementation technology standards. The aim is to distinguish between standards for specification and modeling, such as UML, that define modeling concepts related to real-time modeling and components, and implementation standards, which are focused at realizing these concepts at the implementation level.

This section has been mainly written by CEA-List which representative member at OMG (Dr. Sébastien Gérard) is very involved at OMG for all the work which is related to modeling, component and real-time. Especially he is one very active member of the RTAD (Real-Time Analysis and Design) working group led by Alan Moore (Artisan Software) and Bran Selic (IBM) where he is currently leading the writing of the new incoming profile MARTE (the UML Profile for Modeling and Analysis of Real-Time and Embedded systems).

5.2.b. Components Meta-Model Report: Systems of heterogeneous components and their semantics in UML

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/ReviewsOct2005/Deliverables/ArtistFP5_Y3/W4.A2.Y2_ComponentsMetaModelReport.pdf

This report identifies some weaknesses of the existing UML component model and UML profiles for non functional properties and Quality of service, and sketches a component model consisting of user level.

A central idea in systems engineering is that complex systems are built by assembling components, or building blocks. Components are systems characterized by their interface, an abstraction that is adequate for composition and re-use. It is possible to get large components by “gluing” together simpler ones. “Gluing” can be considered as an operation on components.

Component-based frameworks and tools have been developed for general-purpose software, and some of them have very successful commercial implementations (.COM, .NET, EJB, etc.). A very important aspect of a component framework is it’s usefuleness for early validation at abstract level, which is, a part from syntactic checks, mostly neglected by these frameworks.

5.2.c. Proposal for RT-Posix Extensions / Modifications

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/ReviewsOct2005/Deliverables/ArtistFP5_Y3/W4.A3.N3.Y3_RTPosixExtensions.pdf

POSIX is the standardization of the UNIX operating system at the international level. It describes application program interfaces for the operating system services, with the aim of portability at the source code level. In addition to general-purpose services, it contains optional real-time services. Its reference: is IEEE Std 1003, ISO/IEC 9945-1, Portable Operating Systems Interface.

One of the most successful standards in the area or Real-Time Operating Systems (RTOS) is the realtime version of POSIX. Many major RTOS vendors claim some level of conformance to this standard.

During the lifetime of the ARTIST network participation in the POSIX standard has focused on the development and finalization two Standards Projects: the real-time and embedded profiles, and the device control API. Both of these project got input from ARTIST and were completed successfully.

Work has also focused on three new work items with proposals coming from ARTIST, which should become Standards Projects shortly: the application-defined scheduling API, the interrupt control API, and the scheduling allocation domain API.

5.2.d. Industrial Affiliates Input and Feedback

http://www.artist-embedded.org/FP6/ARTIST2Events/PastEvents/ReviewsOct2005/Deliverables/ArtistFP5_Y3/W4.A4.Y2.Y3_Industrial_Affiliates.pdf

This report describes the current strengths and weaknesses in the design of real-time embedded SoC and distributed embedded systems in terms of performance estimation, design space exploration and low power.

It also covers the influence and impact of the proposals in embedded systems education, roadmap activities and new directions in embedded systems engineering.