ARTIST 2

Network of Excellence

IST-004527 ARTIST2:
Embedded Systems Design

Cluster Progress Report for Year 2

Cluster:

Real-Time Components

Cluster Leader:

Dr. Albert Benveniste (INRIA)

http://www.irisa.fr/distribcom/benveniste/

Policy Objective (abstract)

The development of a general framework for component-based engineering of complex heterogeneous embedded systems is a grand challenge, which the cluster addresses by

- developing a proposal for a UML-based standardised modelling language for RT Embedded Systems,
- integrating tool support for modeling systems and predicting their properties,
- conducting a series of workshops, where industrial problems and developments, as well new research topics relevant for component-based engineering of complex heterogeneous embedded systems are given in-depth treatment.

Table of Contents

1. Overview

Real-Time Components (RTC) is a cluster resulting from the merge of the former two clusters on Hard Real-Time (HRT) and Components. This merge has been effective since October 2005.

Accordingly, the new organization for the RTC cluster is:

- **Platform: Components Platform for Component Modelling and Verification** (this was the platform-related activity of the former Components cluster, it continues as such). Responsible is Susanne Graf, from VERIMAG.
- **Cluster integration: Development of UML for Real-Time Embedded Systems** (this was the standard-related activity of the former Components cluster, it continues as such). Responsible is Sébastien Gérard, from CEA.
- **NoE integration: Forums with specific industrial sectors**. This is a totally new activity. Its scope encompasses all research topics of the former clusters HRT and Components (diagnosis, semantic platform, heterogeneity, interfaces and composition, ET&TT, and, more generally, what is relevant to the concept of Real-Time Components). This activity consists of in-depth meetings and forums with engineers from industry. This activity is jointly managed by Alberto Sangiovanni-Vincentelli from PARADES and Albert Benveniste from INRIA.
- **NoE integration: Seeding new research directions**. This is a totally new activity. Its scope encompasses all research topics of the former clusters HRT and Components (diagnosis, semantic platform, heterogeneity, interfaces and composition, ET&TT, and, more generally, what is relevant to the concept of Real-Time Components). This activity consists of in-depth meetings among researchers. This is jointly managed by Bengt Jonsson from Uppsala and Albert Benveniste from INRIA.

Each of the above 4 activities is reported in a separate Activity Deliverable. This cluster deliverable gives an overall condensed view of activities in the cluster as a whole.

1.1 High-Level Objectives

The initial objectives of the different activities in the cluster were as follows.

- **Platform: Components Platform for Component Modelling and Verification**: to obtain initial versions of tool integrations for the component modelling and verification platform. *A number of new connections between modelling formalisms and validation tools have been developed and two very important projects for the platform have been launched, the French platform project OpenEmBeDD and the IP SPEEDS.*
- **Cluster integration: Development of UML for Real-Time Embedded Systems**: to prepare an initial submission to the OMG standard for the UML profile for Modeling and Analysis of Real-Time and Embedded Systems (MARTE). *This submission is approaching maturity, and is scheduled for completion at the end of 2006.*
- **NoE integration: Forums with specific industrial sectors**: to conduct a meeting with industrial participation on embedded electronics in the automotive industry. *The meeting "Beyond Autosar" was conducted in March 2006, and a publication, reporting on the findings of this meeting, is in preparation.*
- **NoE integration: Seeding new research directions**: to organize a *research* seeding meeting on the topic "Classification and study of Models of Computation and Communication (MoCC) and resulting Conceptual Model for Embedded Systems" Co-

organizers Paul Caspi (VERIMAG) and Hermann Kopetz (TU Vienna). *This meeting has been scheduled for November 2006, in Zürich at ETH; the preparation of the meeting requires in depth thinking regarding conceptual models for distributed embedded systems, which is reported in the corresponding activity deliverable.*

More detail can be found in the corresponding activity deliverables. In this cluster deliverable, we present an overall view of research activities in the cluster that relate to the to its general research topics.

1.2 Industrial Sectors

The cluster activities are relevant for industrial sectors in which a major challenge is the need for mastering system integration of complex heterogeneous embedded systems. Several activities focus particularly on the automotive and aeronautics sectors.

- **Aeronautics:** This sector is faced with the challenge of Integrated Modular Avionics (IMA), which drastically changes the OEM/supplier relations. Integration will occur at the level of functions, not any more at the level of packaged hardware modules and devices. Therefore, constructors are faced with the need of mastering system integration at all levels of the design process (from requirements to hardware). This move will drastically impact how certification will be performed in the future.
- **Automobile:** The move is similar to that in aeronautics, the changes being in fact much more rapid and drastic – within a few years, the OEM/supplier chain will be entirely reconfigured. Added value, for constructors, will move to completely different components of the car, namely those mostly contributing to building the “concept” and “personality” of each different car. Sharing platforms with competitors is now the trend, as shown by the **Autosar**[1] initiative.

Both the above sectors are currently driving the innovation in the area of system level integration of complex heterogeneous embedded systems, for the following reasons:

- Complex hardware systems or System on Chip (SoC) design does not involve the same degree of heterogeneity since plant and physical process for control are not part of the problem.
- Research related to real-time components in the area of *automation* is still mostly academic, with the industrial move being hampered by the lack of agreed formal bases for the IEC 61131-3[2] and IEC 61499[3] standards for distributed control systems.
- Regarding the area of large information systems (such as military systems, air traffic control systems, telecommunication network systems…), the main focus is on component based software development in general, with a lesser emphasis on real-time aspects.

Both the model- and the component-based development approaches allow integration problems to be handled in the earlier phases of system design. Component properties that have global system impact, notably properties of timing and resource consumption, can be specified in interfaces in such a way that global resource usage can be predicted a priori, avoiding hard problems in system integration. The research goals of the cluster address these challenges.

[1] http://www.autosar.org

[2] http://en.wikipedia.org/IEC_61131-3

[3] http://en.wikipedia.org/IEC_61499

- Wider adoption of model-based approaches will be supported by standards for modelling of Real-Time Embedded Systems, as well as by the availability of tool chains for design, transformation and analysis that are based on such standards. These issues are addressed in the activities on *Components Platform for Component Modelling and Verification* and *Development of UML for Real-Time Embedded Systems.*
- Composition of models developed for different parts and viewpoints needs techniques for dealing with heterogeneity in design flows. This includes mixing different styles of scheduling policies (e.g., Event-Triggered and Time-Triggered), as well as mixing different Models of Computation. These issues are addressed in the activities on *Forums with specific industrial sectors* and *Seeding new research directions.* The results of these activities will in turn help to improve future model transformation and analysis tools.

Further technical discussions are needed in order to understand how these problems can be handled in the context of industrial system development.

1.3 Main Research Trends

To meet the research goals of the cluster, the following research trends within the scope of the RTC cluster have emerged as being of particular importance:

- Developing a proposal for a UML-based profile, which defines model constructs for modelling and analysing of real-time and embedded systems. Special focus is put on representing resources, timing, RT/E qualities of service, communication modes, execution modes, component model.
- Integrating tool support for different development activities, including at least tools to model systems, and to analyse and predict system properties.
- Specifying and determining extra-functional properties of components and component-based systems, in particular timing, performance, QoS, memory, power and other resource consumption. Particular problems include capturing the dependency on the characteristics of the underlying platform in a modular way, and specifying many different extra-functional properties simultaneously in a both modular and consistent manner.
- Handling heterogeneous system descriptions combining in a mathematical sound way the above functional and extra-functional properties as well as system design aspects produced by different teams at different stages of systems development. This is essential in allowing for a seamless transmission of the different design aspects (safety analysis, functional design, architecture dimensioning for performance, etc) between the different teams.

An emerging research is the field of mobile embedded systems in new domains like pervasive computing but also in traditional domains like automation and process control. The time has come to integrate existing knowledge in the field of real-time systems, dependable systems, modelling and component design into the paradigm of mobile embedded systems. ARTIST2 will consider this trend in the activity on *Seeding new Research Directions.*

2. State of the Integration in Europe

2.1 Other Research Teams

Modelling and design of Component based embedded systems is a field which draws on contributions from many different communities, including the general software engineering community. For embedded systems, focus is also placed on non-functional aspects of systems. Some teams are developing techniques and implementing related software tools to model, specify, and reason about timing and QoS properties (ARTIST2 teams include Aalborg, Cantabria, CEA, EPFL, INRIA, Munich, OFFIS, Twente, Timisoara, Uppsala, VERIMAG, and others – it is not possible to include a complete list). Some teams perform this work in the context of a standard modelling language, typically UML, to support a model driven development process. (Cantabria, CEA, MdH, OFFIS; TU/E, IRISA, VERIMAG – again, a complete list is not possible). ARTIST2 teams are very representative for the work done in Europe and worldwide for model-based development to embedded systems; there are also other prominent teams, e.g., in Braunschweig, Munich and Vanderbilt, with whom we have contacts.

The problem of specifying and reasoning about QoS properties of embedded systems recur in many other contexts in embedded system design, e.g., in scheduling, hardware modelling, systems architecture, etc. It is therefore of interest to avoid duplication of work and distil essential principles for the treatment of timing and other QoS properties in component-based systems. Important and original work is ongoing on this topic for example at ETHZ, where interface models for timed systems have been proposed, thus allowing for a component based approach to schedulability analysis.

A grand challenge for embedded system design is the development of theories and tools for design of heterogeneous systems. The CHESS project of NSF[4] has this in its objectives[5]. CHESS collects major US teams from key universities[6]. Several tools are developed in the context of CHESS that address heterogeneity (e.g., Ptolemy II and Metropolis). Note that some participants to CHESS are also involved in ARTIST2. Proposals for encompassing theories are, on the other hand, jointly developed by teams from INRIA, PARADES, and VERIMAG, in the context of ARTIST2.

2.2 Interaction of the Cluster with Other Communities

2.2.1 Involvement in ARTEMIS and promotion of the area

Several RTC Cluster partners, including OFFIS, PARADES, VERIMAG; and TU Vienna, are actively involved in ARTEMIS, an initiative to form a European technology platform on embedded systems supporting the needs for various industrial and academic embedded application domains, such as the automotive, avionics, but also the real-time requirements of consumer electronics. The interaction with ARTEMIS is expected to influence the work within ARTIST2 positively towards establishing a well-defined conceptual fundament that is useful for academia and industry.

[4] http://chess.eecs.berkeley.edu/ : Center for Hybrid and Embedded Software Systems

[5] http://chess.eecs.berkeley.edu/charter.htm

[6] http://chess.eecs.berkeley.edu/people/project_personnel/

VERIMAG and EPFL jointly produced a position paper [HS06], which summarizes some current trends in embedded systems design and point out some of their characteristics, such as the chasm between analytical and computational models, and the gap between safety-critical and best-effort engineering practices. The work calls for a coherent scientific foundation for embedded systems design, and discusses a few key demands on such a foundation: the need for encompassing several manifestations of heterogeneity, and the need for constructivity in design. This paper argues that the development of a satisfactory Embedded Systems Design Science provides a timely challenge and opportunity for reinvigorating computer science.

2.2.2 Interaction with other ARTIST2 Clusters

Since heterogeneity, as well as component-based modelling and analysis naturally involves different aspects of design, then different sub-communities of embedded systems area are interested in this subject, e.g., control, real-time, and hardware. Therefore, RTC topics are a crossing point for several ARTIST2 clusters, in particular RTC, Adaptive Real-Time, Execution Platforms, Control for Embedded Systems, and Verification and Testing. We provide examples of interactions with these clusters.

- **Execution Platforms:** Partners of the RTC cluster (INRIA, OFFIS, Timisoara, Uppsala, VERIMAG) participated in the workshop on “Distributed Embedded Systems”, organized at the Lorentz Center in Leiden, Nov. 21-24, 2005, by Ed Deprettere and Lothar Thiele (http://www.lc.leidenuniv.nl/lc/web/2005/177/info.php3?wsid=177) with large participation from the Execution Platforms cluster (Braunschweig, ETHZ, Linköping) This workshop focussed on comparison and classification of techniques for compositional response-time and performance analysis. In particular, a set of benchmark examples were defined with the aim of evaluating and comparing methods including the real-time calculus, holistic methods, Symta/S, and timed automata**.**
- **Control:** Several RTC partners (INRIA, PARADES) are prominent members also in the control community (and some of them are members of the HyCON NoE). Partners of the control cluster were important contributors to the opening day of the workshop **Beyond Autosar**, which was dedicated to the interaction of distributed embedded software and control**.**
- **Adaptive Real Time:** INRIA, CEA, and Cantabria are interacting with other ARTIST2 teams from the Adaptive Real-Time cluster under the NoE Integration activity QoS Aware Components (leader: Alejandro Alonso). This activity has been organized around a global meeting in Paris (May 30, 2006) and a joint concept map definition (in progress). J. Medina (Cantabria) was invited to the workshop "Requirements for Flexible Scheduling in Complex Embedded Systems". This workshop was organized by the ARTIST2 Adaptive Real Time Cluster in June 2006, in Massy, France. He presented a number of issues about the requirements for scheduling services in the component-based framework envisioned for the FRESCOR project.
- **Verification and Analysis:** Several projects, such as the French platform project OpenEmbedd, the German AVACS project and the IP Speeds, have started whose goals is to connect (1) teams working on modelling and model transformation techniques and semantic frameworks and (2) teams working on verification algorithms. Teams that are heavily involved in this effort include INRIA, PARADES, VERIMAG, Saarbrücken, CEA, and OFFIS.

2.2.3 *Interaction with the Standardization community*

The RTC cluster is, through CEA, Cantabria, and Thales, the driving force in the work of developing a profile of the Unified Modeling Language (UML™) for MARTE (Modelling and Analysing of Real-Time and Embedded systems). As part of an OMG activity, the work on MARTE is done in the context of a specific consortium consisting exclusively of OMG members, viz. the ProMarte consortium (www.promarte.org). A presentation of the ARTIST2 NoE was given by J. Medina (Cantabria) in the last OMG technical meeting in Boston, June 27th, 2006, scheduled by S.Gerard (CEA). Due to the interest of the audience, a next presentation has been scheduled for the next OMG meeting in Anaheim (September 25-29, 2006). This dissemination activity may eventually lead to further contacts and collaborations between ARTIST2 and specific OMG industrial participants.

VERIMAG and CEA have been the initiators of the MARTES workshop (www.martes.org) on model-driven development and real-time and embedded systems as a follow-up event on the successful workshop series on Real time embedded systems SIVOES and SVERTS. MARTES has been hold in October 2005 as a satellite event of the MODELS conference. The workshop attracted a number of interesting submissions and participants. The results of the workshop, as well as 2 best papers have been published in an LNCS volume.

Presently, we are actively preparing the second edition, to be held on October 2 or 3, 2006 in Genova, Italy in conjunction with the 9th International Conference on Model Driven Engineering Languages and Systems, MoDELS/UML 2006.

2.2.4 *Interaction with the automotive industry*

Specific effort has been dedicated to interacting with the automotive industry. This effort was made possible thanks to prior personal strong ties that some key participants (including: Werner Damm (OFFIS), Martin Törngren (KTH), Rolf Ernst (U. Braunschweig)) and affiliates (including: Stefan Kowalewski (RWTH Aachen)) of ARTIST2 had with the Autosar consortium. RTC cluster felt that it was important that the research community around ARTIST2 was made aware of the scientific and technical issues raised by the Autosar approach. Recall that the automotive industry is one of the two driving sectors for drastic changes to embedded systems design methods, and is certainly *the* sector where changes have been deepest and quickest.

Albert Benveniste (INRIA) and Werner Damm (OFFIS) jointly organized the *ARTIST2 Workshop* ***Beyond Autosar***[7], held in Innsbruck on March 23-24 2006. The workshop discussed in particular issues related to timing in the Autosar model (the so-called *timing model* of Autosar). More generally, the workshop helped making the academic community aware of the research issues raised by this approach from automotive industry. A more detailed report is in preparation, under the head of Werner Damm, where the issues discussed at the meeting will be reported and explained.

2.2.5 *Interaction with OverseasTeams.*

We strive to interact with relevant overseas teams in work on central ARTIST2 topics. We keep close ties with the CHESS project of NSF[8]. CHESS collects major US teams from key universities[9]. Also, close ties exist with teams working on the area of *Discrete Event Systems*

[7] http://www.artist-embedded.org/FP6/ARTIST2Events/Events/Innsbruck06/

[8] http://chess.eecs.berkeley.edu/ : Center for Hybrid and Embedded Software Systems

[9] http://chess.eecs.berkeley.edu/people/project_personnel/

originating from control, as well as the teams working on *Hybrid Systems*[10] and *Communication and Control*[11]. On the topic of software components, the INRIA Triskell team (Jean-Marc Jézéquel) has established strong research ties with Robert France's team (Colorado State University, USA), with mutual visits of several weeks. Robert France will spend 6 months at INRIA. Mälardalen (I. Crnkovic) has strongly established collaboration with SEI (Kurt Wallnau) and Monash University (Heinz Schmidt, affiliated ARTIST2 partner).

The work on standardization in OMG is done in strong collaboration with Carleton University Canada (Dorina Petriu and Murray Woodside).

A good cooperation contact has been established with Iman Poernomo (King's College, UK) on the topic of timed components and the management of stochastic properties of these components. Future cooperation will organized around a PhD work that is starting at King's College. This PhD work will extend the specification languages for time properties of the INRIA team with King's College work on stochastic descriptions of modes. The aim is to merge King's college and INRIA tool chains.

2.2.6 Organization of summer schools

The RTC cluster has been strong drivers in the organization of summer schools

- The ARTIST2 Summer School on Component & Modelling, Testing & Verification, and Statical Analysis of Embedded Systems, was held at Nässlingen, outside Stockholm Sept 29 - Oct 2, 2005, jointly organized by the RTC, Verification, and Compilers clusters, with over 60 students.

  http://www.artist-embedded.org/FP6/ARTIST2Events/SummerSchools/Artist05.html

- The Summer School on Model Driven Development for Real-time and Embedded Systems (www.mdd4dres.info) in Sept. 2006 in Brest. This is the third edition of this summer school which focuses on model-driven related issues in the context of real-time and embedded systems development.

The next edition of the ARTIST2 Summer School will be held in February 2007, in Trento, Italy.

2.2.7 Organization of conferences, workshops, summer schools

The RTC cluster has been co-organizing the following conferences and workshops (for more details: see the deliverable on *Spreading Excellence.*

- *Beyond Autosar*[12], organized in the framework of activity *Forums with industrial sectors.*
- An ARTIST2 workshop on *Model of Computation and Communication for embedded systems*[13] will be organized in Nov. 2006 in the framework of activity *Seeding new Research Directions.*
- CEA and VERIMAG are main organizers of the series of Workshop, MARTES (www.martes.org). This series of workshop is the result of a merge between two previous series of workshops, SIVOES and SVERTS organised respectively by CEA and VERIMAG. The concerns of MARTES workshops are related to domain-specific

[10] http://hscc06.csl.sri.com/ is the conference of this domain

[11] See the control conference CDC'2005 http://www.esi2.us.es/~cdcecc05/ where a –plenary has been devoted to this topic.

[12] http://www.artist-embedded.org/FP6/ARTIST2Events/Events/Innsbruck06/

[13] http://www.artist-embedded.org/FP6/ARTIST2Events/Events/MoCC

aspects in the modelling, analysis and validation of distributed, embedded and/or real-time systems. Experiment feedbacks relating to Model Driven Development, Model Driven Engineering and Model Integrated Computing usages are considered. The first edition has been co-located with the Models/UML conference in Montego Bay, Jamaica, Oct. 4, 2005. The second edition will happen collocated with Models'2006, in October 2006, in Genova (Italia).

- VERIMAG is the initiator of a series of workshops dedicated to synchronous languages (SLAP - http://www-verimag.imag.fr/SYNCHRONE/SLAP06/). The workshop topics are synchronous model of computation, synchronous languages and programming formalisms, compiling techniques, formal verification, test and validation of programs, case-studies, education, etc.
- VERIMAG has organised as a Satellite event of HCCS 2006 in Santa Barbara, the workshop TCC on "Topics in Computation and Control" (http://hscc06.csl.sri.com/computation-control.htm) which was intended to give an opportunity for researchers working in hybrid and embedded systems and other domains at the intersection of computation and control to give lengthier survey/tutorial presentation, not bounded necessarily to the last incremental technical results that they proved before the submission deadline of a conference.
- VERIMAG is also a co-initiator and co-organiser of the symposium on Formal Methods for Components and Objects FMCO (http://fmco.liacs.nl/fmco06.html) the aim of which is to bring together researchers and practioners in the areas of software engineering and formal methods to discuss the concepts of reusability and modifiability in component-based and object-oriented software systems The 4th issue has been organised in November 2005 in Amsterdam, and the next one is being organised in November 2006.

2.3 Main Aims for Integration and Building Excellence through ARTIST2

2.3.1 To develop a common foundation for building of heterogeneous systems

Integration results from promoting and developing this research area in the following ways:

- Since heterogeneity by essence involves different aspects of design, then different sub-communities of embedded systems area are interested in this subject, e.g., control, real-time, and hardware.
- Therefore, this subject is a crossing point for several ARTIST2 clusters, in particular RTC, Execution Platforms, and Control for Embedded Systems. In fact, these clusters have been participating to the RTC events where this topic was discussed.

Excellence is revealed by the tight links the RTC community has with the leading teams in the US, e.g., belonging to the above mentioned CHESS project.

2.3.2 To develop and disseminate a more coherent view on handling timing and QoS properties in component-based systems for RTES

In view of the need to develop a widely adopted technology for component-based development of embedded systems, it is vital to strive for convergence between European research teams working on this topic. ARTIST2 aims at providing generic solutions to the key technical problems in this endeavour, and to achieve convergence by means of collaboration between research teams, as well as in-depth contacts with industry in order to understand industrial

requirements on this problems and to point out possible technical solutions (as has been the objective of, e.g., the workshop *Beyond Autosar*).

2.3.3 To contribute such a view in UML standardization of RTES aspects

Integration results from in one hand promoting research results of European laboratories in the future UML standard for Real-Time and Embedded systems and in other hand from making the link between the European industry needs in this domain (e.g. Thales) and the standard itself.

Excellence is revealed by the links the RTC community has with the US and Canadian leading teams also working in the ProMarte consortium, whereas with the tool vendors such as IBM and Telelogic, also part of the ProMarte consortium.

2.3.4 To synchronize European efforts on modelling and development tools

Work towards the integration of modelling and validation technology implemented in different presently isolated tools so as to provide stronger validation support for modelling languages used in practise is the aim of the platform activity of the cluster. This aim is shared by a number of national and European collaborative projects initiated by the participants of the cluster. The effort also achieves other important effects: it harmonizes concepts developed by different groups to avoid fragmentation, it achieves greater impact both scientifically and towards industry in that the combined efforts of several research teams are combined into an overall demonstrator.

2.3.5 To tighten the links between the academic community and driving industrial sectors such as automobile and avionics

Better integration between the academic community and the above mentioned driving industrial sectors has resulted from the meeting *Beyond Autosar.* A similar action line is planed for 2007 regarding the avionics and aeronautics industrial sector, with IMA (Integrated Modular Avionics) as main target.

These ties are also extremely important for improving excellence of the European academic community in the area of real-time embedded systems. Improved excellence will result from getting a better understanding of the technical issues raised by these industrial contexts. Symmetrically, excellence will improve if some feedback, from academia to industry, is found of some value by our industrial partners.

References

[HS06] Thomas A. Henzinger and Joseph Sifakis, "The embedded systems design challenge, Proceedings of the 14th International Symposium on Formal Methods (FM), Lecture Notes in Computer Science, Springer, 2006.

3. Overall Technical View

3.1 Brief State of the Art

The development of a general framework for component-based development of heterogeneous embedded systems is a grand challenge which spans several research topics. A central goal is to support model-based development by progress on formalisms for modeling components, systems and architectures, progress on mappings between and combination of modeling formalisms, techniques for guaranteeing composability of models and components, and techniques for generation of target specific code. A common goal of these topics is to pave the way for better design tools for model- and component-based development.

There are currently design tools, in which systems are designed by putting together pieces that could be termed components. Examples are MetaH[14], Ptolemy[15], and Metropolis[16]. The functions of these tools are in some sense analogous to, e.g., MATLAB/Simulink. The advantage is that they support a variety of design notations, thereby supporting heterogeneous system design in a syntactic sense. However, “components” can be assembled only in the supporting tool, meaning that different systems and components must all be developed in the same environment (tool) to stay compatible. Another class of tools include environments adopting the “synchronous approach”, such as SCADE or Esterel Studio, which also include tightly integrated and powerful verification tools at the expense of sacrificing the ability to analyze heterogeneous models. For wider adoption of model driven development, it would be desirable with equally powerful tools with verification support in tools for modelling languages adopting the “asynchronous approach” or even a mixture of modeling approaches. Current tools for asynchronous modeling in UML-based formalisms (Artisan, Rhapsody, RoseRT, TAU) have a weaker verification support than e.g., SCADE or Esterel Studio, and there is also a lack of standardized formalisms for modeling real-time embedded systems.

UML emerged in recent years as a modelling standard for software, including also software for embedded systems for which specific UML profiles have been developed. Since several years, the Object Management Group (OMG) has adopted the UML Profile for Schedulability, Performance, and Time (SPT) to model real-time concerns [MHD04]. However, the SPT profile has several shortcomings, and there is a need for modifications to comply with the evolution of other OMG standards, and to have a profile with a broader scope. This has resulted in a Request For Proposals (RFP) for a new UML Profile named MARTE (Modeling and Analysis of Real-Time and Embedded systems, which should address issues such as compliance with the UML Profile for Quality of Service and Fault Tolerance (QoS & FT), specification of not only real-time constraints but also other embedded QoS characteristics such as memory and power consumption, modelling and analysis of component-based architectures, and the capability to model systems in different modelling paradigms (asynchronous, synchronous, and timed).

The situation concerning tools to analyse systems modelled in UML is not satisfactory. There exist a number of tools for the analysis and verification of functional and timing properties of system models, such as as the Kronos and IF tools (developed at VERIMAG), Uppaal (developed at Aalborg and Uppsala), Hytech (developed at Cornell and Berkeley), the Metropolis tool (developed at PARADES and Berkeley) and several others. The effort made in some recent projects, such as OMEGA, has lead to some encouraging results concerning

[14] http://www.htc.honeywell.com/metah

[15] http://www.ptolemy.eecs.berkeley.edu

[16] http://www.gigascale.org/metropolis

validation of UML designs [GBC05,GOO06]. The newly started SPEEDS project gathers as core members academic partners with an important back ground in validation and modelling (INRIA, OFFIS, PARADES, and VERIMAG), industrial partners developing software modelling and development environments (Esterel Technologies, Telelogic, TNI, and Extessy) as well as important users from the embedded systems domain (such as Airbus, Daimler-Chrysler, Saab, and Bosch). The aim of this project is to improve the current situation with respect to verification and validation.

As stated above, a crucial issue for component-based embedded systems is *heterogeneity* of component models. This heterogeneity concerns different execution models (synchronous, asynchronous, vs. timed), communication models (synchronous vs. asynchronous), as well as different scheduling paradigms. To allow designing heterogeneous embedded systems from diverse types of components, we must develop a coherent ***theory for building complex heterogeneous systems*** which addresses, e.g., the issues of composability and compositionality, and allow predicting and optimizing functional and non-functional properties of the designed systems. Such a comprehensive theory is missing today, thereby making it difficult to understand how to build systems that combine, e.g., synchronously and asynchronously executing components and reason about non-functional properties. First steps have been performed by the group (comprising RTC partners) consisting of A. Benveniste and B. Caillaud (INRIA), L. Carloni (Columbia University, New York), P. Caspi (VERIMAG), A. Sangiovanni-Vincentelli (PARADES and U.C. Berkeley), and S. Tripakis (VERIMAG and Berkeley Candence Labs.) with the work on *Tag Systems,* where systems executions are seen as partially ordered sets of events labelled with *tags* to capture the different aspects of design, both functional and extra-functional (series of papers at Emsoft conferences every year since 2002).

Another crucial issue is to guarantee composability of components by techniques for **component interfaces,** in particular for **non-functional properties.** This involves modelling, specification, prediction, tool support of such properties. It is widely recognized that such technology should be based on a *rich component model* (this concept used in [BBB+00]), which allows to model, specify, and predict timing, QoS, and resources properties of components and of systems composed from components. The *OFFIS* team has developed the Rich Component Model concept for embedded systems design into a framework that allows specifying and verifying functional and non-functional requirements, as well as their horizontal, vertical, and inter-viewpoint composition at different abstraction levels [DVMJ05]. This will allow to boost the level of re-use in electronic control unit design, while the proposed framework covers the complete development cycle, that is from high-level specification models to design models, allowing informed decisions to be made for the implementation phase.

Currently available support for non-functional properties in component interfaces include specialized technologies, exemplified by the *Rubus* component model [IN02], that have been developed for particular embedded systems domains. These provide some limited support for handling QoS and resource usage, but only in rather limited situations. To improve this situation, it would be desirable to be able to use the rich flora of existing techniques for specification and analysis of QoS properties. To specify timing properties, different variants of timed automata can be used, as in, e.g., the *Omega* component model [DJPV05], which has a semantics in terms of the IF language, supported by timed automata. For other types of properties, e.g., relating to queuing and performance, models based on queueing networks, Markov chains, etc. have been used. These approaches offer a precise mechanism for specifying and analysing QoS properties. A potential problem is that analysis may not always scale to systems with large numbers of components. For instance, standard schedulability analysis for simple fixed priority scheduled systems typically scales better to large numbers of components than does analysis of systems whose components are specified in detail by timed automata.

Designing components for reuse calls for a system of program annotations rich enough to ensure that the components will interact in a coherent manner when connected together. The dynamic information about the interactions of the component with its environment combines expectations of the component about its environment with guarantees offered in return by the component to its environment. L. de Alfaro and T. Henzinger introduced for that purpose *Interface Automata*, viewed as enriched type systems (the so-called *Behavioral Type Systems*), which capture the temporal aspects of software component interaction. A component refines another component if it imposes less constraint about the environment and offers more guarantee in return. We obtain in this way a compositional semantics due to the fact that a component can be replaced with a more refined version in any environment compatible with the original component: The refined version may offer more services but both are equivalent in restriction to the set of services of the original component; this situation is reminiscent to the sub-class polymorphism in object-oriented programming. A first extension of this work to timing properties is the work of *timed interfaces* (de Alfaro, Henzinger, Stoelinga) [dAHS02].

References

[BBB+00] F. Bachmann, L. Bass, C. Buhman, S. Comella-Dorda, F. Long, J. Robert, R. Seacord, and K. Wallnau. Technical Concepts of Component-Based Software Engineering, Volume II. Technical Report CMU/SEI-2000-TR-008, Software Engineering Institute, Carnegie-Mellon University, May 2000.

[DJPV05] Werner Damm, Bernhard Josko, Amir Pnueli, Angelika Votintseva A discrete-time UML semantics for concurrency and communication in safety-critical applications. In *Science of Computer Programming*, 2005

[DVMJ05] W. Damm, A. Votintseva, A. Metzner, B. Josko, T. Peikenkamp und E. Böde. Boosting Re-use of Embedded Automotive Applications through Rich Components. In: FIT 2005 - Foundations of Interface Technologies 2005.

[dAHS02] L. de Alfaro, T.A. Henzinger, M. Stoelinga. Timed Interfaces, in Proc. EMSOFT 2002. LNCS 2491, pp. 108-122.

[IN02] D. Isovic and C. Norström. Components in real-time systems. In Proc. RTCSA 2002, 8th International Conference on Real-Time Computing Systems and Applications, Tokyo, Japan, March 2002.

[MHD04] J. L. Medina, M. G. Harbour and J. M. Drake: The “UML Profile for Schedulability, Performance and Time” in the Schedulability Analysis and Modeling of Real-Time Distributed Systems. SIVOES-SPT Workshop. Toronto (Canada). May, 2004.

3.2 Ongoing Work in the Partner Institutions

In this section, we describe work in partners’ institutions that relate to the topics of *Developing Standardized Modeling Formalisms, Tool integration, Component interfaces for non-functional aspects,* and *support for heterogeneous system design.*

3.2.1 Developing Standardized Modeling Formalisms

As described in Section 3.1, UML currently has several shortcomings as a formalisms for modeling real-time embedded systems. To overcome them, ARTIST2 works along several research directions **(1)** to broaden the scope and applicability of UML for real-time embedded systems, and create a UML profile for MARTE, **(2)** to provide more uniform support for *executable* models in UML, **(3)** to develop support for modeling of heterogeneous systems in a way that complies with several standards, notably UML and SysML.

(1) A major effort is devoted to defining the UML profile for MARTE. The effort involves *CEA, Cantabria,* and *Carleton University* Canada (Dorina Petriu and Murray Woodside), with significant input from *INRIA* and *VERIMAG.* This effort is lead by *CEA*, with S. Gérard (CEA) leading the ProMarte consortium (www. promarte.org) [OMG'05] in the context of ARTIST2, and also in the CARROLL-Protes project (www.carroll-research.org). J. Medina (Cantabria) has been on a longer visit at CEA. This collaboration has resulted in work on the general structure of the MARTE profile [EDMG05], followed by results on how to link previous work of Cantabria on schedulability analysis (in the MAST framework) with performance analysis issues in an integrated way [EDG+05], as a basis for the work on MARTE. A paper about the new elements for schedulability analysis in the prospective MARTE standard [EMDG06] is being submitted. *VERIMAG* has contributed views and discussion of how MARTE should consider central concepts that have been developed in the OMEGA project [OGL06] [OGY05]. INRIA has contributed to MARTE with its background from synchronous languages.

In the concrete work on developing the MARTE profile, *CEA* has specifically been involved in writing three main chapters of the document: the Non-Functional Property Framework, the Hardware Execution Platform Model and the Software Execution Platform Model, whereas *Cantabria* is contributing to the chapters on Schedulability Analysis and Real-Time Features. The following bullets descrite technical details of this work.

- The Non-Functional Property (NFP) framework is especially focused on formalizing a set of modeling UML constructs to specify non-functional information in a precise way. It provides an abstract syntax and a grammar for specifying the values of NFPs. It defines a set of NFP data types commonly used in the real-time and embedded system domain, such as Duration, Data Transmission Rate, Data Size, and Power. Additionally, there is a capability of defining new user-specific units in terms of existing base units.
- The Hardware Execution Resource Model is composed of two views, a *logical view* that classifies hardware resources depending on their functional properties, and a *physical view* that concentrates on their physical properties. These two views are complementary, even if they provide two different abstractions of HW.
- The Software Execution Resource Model is intended to define in MARTE the ability to describe a mutli-tasking execution model based on an RTOS-like software execution platform. Since it is presumably out of the scope of MARTE to define a new standard for RTOS APIs, it has been decided to provide in MARTE the ability to define in a unified way RTOS-like software execution platform through the definition of a specific UML profile: the SEPM (Software Execution Platform Model) sub-profile. Additionally, the MARTE will contain as appendices specific UML model libraries to support three commonly used standard RTOS APIs: Posix (Issue 6 IEEE std 1003.1), OSEK/VDX (OS 2.2.2), and Arinc (653-1).

(2) Work on providing a uniform basis for an execution semantics has been performed by the CEA, INRIA and Thales teams. They are contributing to the elaboration of a new standard: *Executable UML foundation* [MFJ05] that will help harmonizing other standards. Its objective is to enable a chain of tools that support the construction, verification, translation, and execution of computationally complete executable models.

(3) Work in the project IP-SPEEDS, by partners INRIA, OFFIS, PARADES, and VERIMAG, has involved development on a system level UML/SysML compliant framework for heterogeneous components. This framework will be supported by work on different tool chains in collaborations between partners within the context of IP-SPEEDS and within the activity *Plaform for Component Modeling and Verification.*

3.2.2 Tool integration

Partners of the RTC cluster are collaborating on the development of several, partly overlapping and interconnected, tool chains for modelling and analysis of component-based embedded systems. These tool chains will provide tool support for modeling languages, some of whose development is described in Section 3.2.1, by mapping them to intermediate semantic formalisms, some of which are developed as described in Section 3.2.4, for which analysis support exists or is being developed.

In the context of the French National project OpenEmbeDD (http://openembedd.inria.fr), which includes the ARTIST2 Partners CEA, France Telecom, INRIA, Thales, and VERIMAG, work has started on mappings from the user level formalisms SDL and the MARTE UML profile (see Section 3.2.1) to the semantic framework of BIP under development at VERIMAG (see Section 3.2.4).

In the French national project Persiform (http://www-persiform.imag.fr), which includes the ARTIST2 Partners France Telecom, INRIA, and VERIMAG, aiming at performance evaluation for both functional and design specifications of component-based services to be integrated into service platforms, work has progressed to a complete transformation chain from a UML profile based on activity diagrams, satisfying the requirements of the designers and the performance engineers, to the performance evaluation platform SES Workbench (http://www.mmsolutions.com/english/workbench.htm) via several intermediate forms which will be connected to functional analysis tools in the coming year.

The *INRIA team* has developed a tool chain for timed software components, using tools and technology from several teams of the RTC cluster. Timed tree logic is used to specify and reason about the component services and their composition. The component implementation process uses a two-step method: designers construct an abstract implementation using timed automata, which is checked against the specification using the IF and Kronos tools from *VERIMAG*. A model driven approach is then applied to build a platform dependent implementation. The concrete implementation is generated by model transformations using tools from *INRIA Triskell team*. The target architecture is the Giotto platform designed by the *EPFL* team. The tool chain covers the life cycle of timed components from the service specification in timed tree logic down to algorithms coded in Java and executed on a Giotto runtime. To sum up, this tool chain involves three RTC cluster teams.

The *Uppsala* team has developed a new version of the TIMES tool for schedulability analysis and code generation based on the Eclipse environment, integrated with UML component modeling, and incorporating a virtual machine for the execution of automata-based component models.

3.2.3 Component interfaces for non-functional aspects.

Work in ARTIST2 is pursued along different lines. One line of work is a framework for simultaneous expression of many different non-functional properties. The aim is to develop the concept of *rich component models* into a mature framework for system design, and is pursued within IP-SPEEDS by RTC partners INRIA, OFFIS, PARADES, and VERIMAG, who are currently developing a meta-model for rich components. This includes defining a notion of component for which different *viewpoints* (functional, times, safety, etc) can be synchronized, and different viewpoints for different components can be formally composed. It will comply with existing or de-facto standards, including the Autosar real-time component model, UML 2.0 (in particular SysML profile) [DVMJ05, Da06]. The work in SPEEDS also involves a new theory of *interfaces* is being developed, allowing for cross-viewpoint assume-guarantee reasoning. This piece of work undertaken within the SPEEDS project is a clear byproduct of previous and current work developed in the ARTIST2 community.

Another line of work is more focussed on timing properties. There are several related ongoing efforts. On is the effort of *Timisoara, ETHZ,* and *Uppsala*, on developing scalable techniques for specifying timing properties by combining features of the real-time calculus (developed at ETHZ), classical schedulability analysis, and timed-automata techniques (implemented, e.g., in Uppaal) [FPY06]. The goal is to combine advantages of the different paradigms for specification and analysis of timing properties: that of timed-automata based specification and analysis, the kind of timing analysis typically performed in e.g., fixed-priority schedulability analysis of real-time system, and the real-time calculus approach. A synchronization point for this effort was the workshop "Distributed Embedded Systems" at the Lorentz Center in Leiden in Nov. 2005 with participation from several RTC cluster members, where different approaches were reviewed and tested on benchmark examples. During February 2006, Marius Minea (Timisoara) visited Uppsala for technical collaboration. Timisoara conducted research along several directions for modeling and analyzing multiprocessor embedded systems using a calculus that would allow the compositional computation of resource availability and response times to events. One potential approach involved finding a closed-form solution for a restricted form of systems composed of tasks characterized by period, deadline and jitter; however, after analysis this was deemed too complex for realistic system descriptions. To make use of the existing algorithms in the Uppaal and TIMES tools [FPY06] (developed by the Uppsala team), a diploma project at Timisoara implemented a translation from a dedicated description language for multiprocessor tasks into Uppaal models using timed automata, constructed according to predefined patterns. Initial results showed that Uppaal can handle systems involving a few processors and several tasks for each; however, more specialized analyses rather than those using the full power of timed automata will be needed for handling more complex. Uppsala has developed a translation between the real-time calculus of ETHZ and timed automata formalism, which is currently being implemented in Uppaal. Initial attempts have encountered complexity problems, and the effort has required significant optimization work. In parallel, results on analysis of component-based systems with asynchronous communication channels have been obtained by the Uppsala team. Preliminary results are reported in [KY06].

Another effort, which uses techniques from classical schedulability analysis to develop a formalism for component interfaces has been further pursued by the *EPFL* team by developing an assume-guarantee interface algebra for real-time components [HM06]. In this formalism a component implements a set of task sequences that share a resource. A component interface consists of an arrival rate function and a latency for each task sequence, and a capacity function for the shared resource. The interface specifies that the component guarantees certain task latencies depending on assumptions about task arrival rates and allocated resource capacities. The algebra defines compatibility and refinement relations on interfaces. Interface compatibility can be checked on partial designs, even when some component interfaces are yet unknown. In this case interface composition computes as new assumptions the weakest constraints on the unknown components that are necessary to satisfy the specified guarantees. Interface refinement is defined in a way that ensures that compatible interfaces can be refined and implemented independently. The algebra thus formalizes an interface-based design methodology that supports both the incremental addition of new components and the independent stepwise refinement of existing components. The flexibility and efficiency of the framework has been demonstrated through simulation experiments.

A third effort, which also uses techniques from schedulability analysis is conducted by *Cantabria* and *Thales* in the newly started project FRESCOR: Framework for Real- time Embedded Systems based on COntRacts (www.frescor.org, IST-034026), which aims to produce a framework for handling timing requirements with a focus on reconfigurable architectures. The project has a large participation by teams working on scheduling and adaptive real-time techniques. Other efforts, that continue Cantabria's former work in the research scope of this cluster, promotes a modelling methodology for the analysis of

component-based embedded systems [LMD06] [MLD06]. Within the context of the SAVE Swedish national project, the Uppsala and Mälardalen teams are developing *SaveCCM* (the SaveComp component model) [ÅCF+06]. *SaveCCM* can be seen as a slight extension of the *Rubus* component model. Timing properties of a system of components can be analyzed using fixed-priority analysis techniques, using e.g., the MAST schedulability modeling and analysis environment developed by the Univ. of Cantabria. The SaveCCM component model is given a formal semantics based on timed automata [CHP05]. The *SaveCCM* component model has been employed in industrial case studies, e.g., at CC Systems.

EPFL and PARADES have collaborated to adapt techniques for specifying component interfaces for the development of a structured coordination language for specifying the interaction of real-time tasks has been developed [GHI+06]. Task communication happens through shared variables called communicators, which can be read and written only at specified time instances. Sensors and actuators are special kinds of communicators. The read and write times of communicators determine the release times and deadlines of tasks. Tasks may also depend on each other, be refined into sets of tasks, and be changed through mode switches. The language is a hierarchical extension of Giotto, and has been inspired by and used in the automotive domain.

Dortmund and Uppsala are collaborating to develop automata learning techniques for automatically deriving behavioural models of components from legacy code or observations of system behavior. Part of the work concerns extending these techniques to derive timed models (reported in [GJP06]). Potential applications are to derive (timed or untimed) models of environments of component-based system for modelling and analysis. As a basis for experimentation, Dortmund has developed *LearnLib* [BRS06], a library for automata learning, which a flexible modular structure that can be configured to exploit specific properties of applications, in order to make automata learning scalable to realistic settings. During spring and summer 2005, Therese Berg (Uppsala) visited Dortmund in order to collaborate on extending the functionality of LearnLib with facilities to better handle parameterized alphabets, reported in [BJR06]. During July-August 2006, Harald Raffelt (Dortmund) visited Uppsala, with the primary goal of using LearnLib to derive a model of an industrial protocol developed by an industrial partner of Uppsala.

3.2.4 Supporting Design of Heterogeneous Systems

Work has progressed on the problem of combining models in different paradigms. In the framework of the ARTIST2 network of excellence, INRIA, PARADES, and VERIMAG have developed a systematic method to formally model heterogeneous reactive systems [BCCC04]. The motivation is twofold. On the one hand, heterogeneous models are encountered throughout the design flow for embedded systems: use of UML notations, of Simulink-Stateflow, of synchronous languages. On the other hand, execution architectures for deployment generally follow a *model of computation* that is different from that of the modeling tools. For example, whereas the Time-Triggered Architecture (TTA) of the Vienna team (H. Kopetz) strictly obeys the synchronous model, this is no longer the case for other commonly used infrastructures (field buses, CAN, ARINC, etc.). In 2002–2003, we analyzed the Loosely Time-Triggered Architecture (LTTA), which is in use at Airbus. In previous years, we addressed the issue of heterogeneity, thanks to the so-called *tag system* model originally due to Edward Lee and Alberto Sangiovanni-Vincentelli (Berkeley and PARADES). We have simplified and tailored this model to our needs The new version covers not only synchronous and asynchronous models, timed and untimed models, and their free combination, but also is able to model causality dependence relations, such as those induced by data- and control-flow dependencies. We have formally defined what it means to migrate from one model to another. We have formally defined what heterogeneous parallel composition means, *e.g.*, what P||Q means, for P synchronous and Q asynchronous. We have formally defined what it means to

preserve semantics, *e.g.*, when migrating from a synchronous to a *globally asynchronous, locally synchronous* design (GALS). We have characterized, by algebraic means, those designs that preserve semantics when deployed on an infrastructure which *model of computation* differs. In 2005, we presented an operational view of tag systems, where we focus on tag machines as mathematical artefacts that act as finitary generators of tag systems. Properties of tag machines have been investigated. Results on homogeneous compositionality are detailed in [BCCS-V05]

In another direction, Benoît Caillaud and Dumitru Potop-Butucaru (VERIMAG, then INRIA, team Aoste) have developed a theory for the correct deployment of synchronous designs over globally asynchronous, locally synchronous (GALS) architectures. This work introduces the notion of weak endochrony, at a macro-step level, which extends to a synchronous setting the classical theory of Mazurkiewicz traces [PCB05]. In [PC05] a micro-step model for the representation of asynchronous implementations of synchronous specifications is introduced. The model covers classical implementations, where a notion of global synchronization is preserved by means of signaling, and globally asynchronous, locally synchronous (GALS) implementations where the global clock is removed. This model offers a more refined framework for reasoning about essential correctness properties of an implementation: the preservation of semantics and the absence of deadlocks.

The BIP (Behavior, Interaction, Priority) framework for modeling heterogeneous real-time components [S05] [BBS06] [GS05] which integrates results obtained at *VERIMAG* over the past 5 years has been implemented in a tool allowing the efficient execution of specifications.. BIP is a central semantic-level formalism that is connected to several modeling formalisms and validation tools in the work of *Plaform for Component Modeling and Verification,* but is also an effort to enable integration of heterogeneous systems. Work on the integration of existing validation techniques, implemented in the IF platform, is ongoing. A mapping from BIP to Think/Fractal is being implemented jointly with *FTR&D* for achieving code generation for BIP descriptions. Several industrial case studies have been modelled using BIP, including an Adaptive QoS controller for a video encoder, a planner for autonomous robots and we started to work on a model of sensor networks (together with FT R&D) for fine grained energy consumption analysis.

Stavros Tripakis and Paul Caspi of VERIMAG actively collaborated with INRIA and PARADES in developing researches on heterogeneous systems modelling and in automatic code generation from high level synchronous models on several platforms, notably asynchronous preemptive ones [TSSC05].

The effort on support for heterogeneous systems also involves addressing issues in systems architecture. TU Vienna is working on a next-generation embedded architecture for Systems-on-a-Chip (SoCs) that provides a predictable integrated execution environment for the component-based design of many different types of embedded applications (e.g., consumer, avionics, automotive, industrial). The architecture is inspired by the research priorities that have been identified in the ARTEMIS Strategic Research Agenda (SRA), such as composability, networking, robustness/security, diagnosis, resource management, and evolvability. The network interface will be based on the Time-Triggered Ethernet (TTE) protocol that supports the coexistence of hard real-time communication and standard Ethernet messages [KAGS05, OPK05]. Although based on a time-triggered communication system with static schedules, the architecture shall provide means for dynamic reconfiguration taking into account communication, computation, and power requirements of the hosted application subsystems. The communication system will be interfaced through a generic architecture interface which satisfies the requirements of multiple different application domains and provide encapsulation mechanisms that allow the integration of subsystems with mixed-criticality levels.

As a contribution to the design of systems architectures, the *OFFIS* team has developed an approach to design space exploration within the development of distributed embedded real-time systems. The mapping of software parts onto suitable hardware parts is a crucial issue of optimization towards efficient and inexpensive implementations. The optimization process is restricted by the set of requirements the implementation has to meet, e.g. real-time requirements like end-to-end deadlines. We focus on an optimal design space exploration approach for distributed real-time applications which is based on specially tailored satisfiability testing. Architectural as well as task and message parameters are encoded in terms of arithmetic inequations over integers. An extended SAT checker modulo scheduling theory is used in a binary search scheme in order to achieve optimal allocations of tasks and messages to architectural elements. The usage of satisfiability checking modulo scheduling theory allows for treating a rich set of different scheduling paradigms used within one heterogeneous system and, therefore, enables us to even optimize complex architectural network topologies. While this technique is able to optimize systems of formidable size with regard to real-time requirements, the possibility to easily extend the optimization task by adding requirements for different view points (memory consumption, pre-defined allocations, etc.) by introducing new sets of arithmetic inequalities opens a wide range of applications for design space exploration of complex multi-objective driven systems implementation [MH05, MFHS06], The approach will be used and extended within the new IP SPEEDS.

References

[ÅCF+06] Mikael Åkerholm, Jan Carlson, Johan Fredriksson, Hans Hansson, John Håkansson, Anders Möller, Paul Pettersson, Massimo Tivoli, The SAVE approach to component-based development of vehicular systems, Journal of Systems and Software, Elsevier, to be published

[BBS06] A. Basu, M. Bozga, J. Sifakis Modeling Heterogeneous Real-time Components in BIP, invited keynote speech at SEFM 2006, Pune, LNCS, 2006

[BCCC04] A. Benveniste, B. Caillaud, L. Carloni, P. Caspi, A. Sangiovanni-Vincentelli. Heterogeneous Reactive Systems Modeling: Capturing Causality and the Correctness of Loosely Time-Triggered Architectures (LTTA), in: Proceedings of the Fourth ACM International Conference on Embedded Software, EMSOFT'04, ACM Press, September 2004, vol. September, available from http://doi.acm.org/10.1145/1017753.1017790.

[BCCS-V05] A. Benveniste, B. Caillaud, L. P. Carloni, A. L. Sangiovanni-Vincentelli. Tag Machines, in: Proceedings of the fifth ACM International Conference on Embedded Software (Emsoft), Jersey City, NJ, USA, ACM Press, September 2005, p. 255–263, available from http://doi.acm.org/10.1145/1086228.1086276.

[BJR06] Therese Berg, Bengt Jonsson, Harald Raffelt: Regular Inference for State Machines with Parameters. In Proc. FASE 2006, Vienna, Austria, March 27-28, 2006, LNCS 3922 Springer 2006, pp 107-121

[BRS06] Therese Berg, Harald Raffelt and Bernhard Steffen. LearnLib: A Library for Automata Learning and Experimentation" in Proc. FMICS05 (Tenth International Workshop on Formal Methods for Industrial Critical Systems), September 5-6, Lissabon, Portugal, ACM Press, pp. 62-71,

[BCGMM-06] Marius Bozga, Pierre Combes, Susanne Graf, Wei Monin, Nicolas Moteau, Qualification d'architectures fontionnelles. In Notere'06 2006

[CHP05] J. Carlsson, J. Håkansson, P. Pettersson. SaveCCM: An analyzable component model for real-time systems. Proc. Int. Workshop on Formal Aspects of Component Software, Oct. 2005.

[Da06] W. Damm. Component based design of embedded automotive systems. In: Proceedings, AAET 2006, Automatisierungs-, Assistenzsysteme und eingebettete Systeme für Transportmittel 2006.

[DHO06] W. Damm, H. Hungar, E. Olderog. Verification of cooperating traffic agents. International Journal of Control 79 (5). 2006.

[DVMJ05] W. Damm, A. Votintseva, A. Metzner, B. Josko, T. Peikenkamp und E. Böde. Boosting Re-use of Embedded Automotive Applications through Rich Components. In: FIT 2005 - Foundations of Interface Technologies 2005.

[EDG+05] Huáscar Espinoza, Hubert Dubois, Sébastien Gérard, Julio L. Medina Pasaje, Dorina C. Petriu, C. Murray Woodside: Annotating UML Models with Non-functional Properties for Quantitative Analysis. MoDELS Satellite Events 2005, Lecture Notes in Computer Science, Springer, p. 79-90.

[EDMG05] Huáscar Espinoza, Hubert Dubois, Julio L. Medina, Sébastien Gérard. A General Structure for the Analysis Framework of the UML MARTE Profile. In Proc. Workshop MARTES: Modeling and Analysis of Real-Time and Embedded Systems, Satellite event of MoDELS 2005. Montego Bay - Jamaica. 4 october 2005

[EMDG06] Huáscar Espinoza, Julio L. Medina, Hubert Dubois, Sébastien Gérard. A UML-Based Modeling Standard for Quantitative Analysis of Real-Time Systems. CEA/LIST/DTSI/SOL/LLSP Internal Report.

[FMPY06] Elena Fersman, Leonid Mokrushin, Paul Pettersson, Wang Yi. Schedulability analysis of fixed-priority systems using timed automata. *Theor. Comput. Sci.* 354(2): 301-317 (2006)

[GHI+06] Arkadeb Ghosal, Thomas A. Henzinger, Daniel Iercan, Christoph M. Kirsch, and Alberto Sangiovanni-Vincentelli, A hierarchical coordination language for interacting real-time tasks, Proceedings of the Sixth Annual Conference on Embedded Software (EMSOFT), ACM Press, 2006.

[GGMSM06] Gregor Gössler, Susanne Graf, Mila Majster-Cederbaum, M. Martens, Joseph Sifakis, Ensuring Properties of Interaction Systems by Construction, Seminar in Honor of Reinhard Wilhelm's 60th Birthday, Dagstuhl 2006, to appear in LNCS

[GJP06] O. Grinchtein, Bengt Jonsson, P. Pettersson: Inference of Event-Recording Automata Using Timed Decision Trees. In Proc. CONCUR 2006, Bonn, Aug. 2006, LNCS 4137, pp 435-449.

[GP06] Susanne Graf, Andreas Prinz. "Time in Abstract State Machines". To appear in Fundamentae Informaticae, special issue of ASM 2005.

[GS05] G. Gössler, J. Sifakis. "Composition for Component-Based Modeling", Science of Computer Programming, vol. 55, pp. 161--183 (2005)

[HM06] Thomas A. Henzinger and Slobodan Matic. An interface algebra for real-time components. *Proc. 12th Annual Real-Time and Embedded Technology and Applications Symposium (RTAS),* IEEE Computer Society Press, 2006.

[HM06a] N. Halbwachs and L. Mandel. Simulation and verification of asynchronous systems by means of a synchronous model. Sixth International Conference on Application of Concurrency to System Design, ACSD 2006. Turku, Finland, June 2006

[HS06] Thomas A. Henzinger and Joseph Sifakis, "The embedded systems design challenge, Proceedings of the 14th International Symposium on Formal Methods (FM), Lecture Notes in Computer Science, Springer, 2006.

[KAGS05] Hermann Kopetz, Astrit Ademaj, Petr Grillinger and Klaus Steinhammer, The Time-Triggered Ethernet (TTE) Design, in Proceedings of the 8th IEEE International Symposium on Object-oriented Real-time distributed Computing (ISORC), Seattle, Washington, 2005

[KC-06] Ch. Kossentini and P. Caspi: Approximation, Sampling and Voting in Hybrid Computing Systems. In HSCC06, Sta Barbara, March 2006.

[KY06] Pavel Krcál and Wang Yi, Communicating Timed Automata: The More Synchronous, the More Difficult to Verify., in *Proc. CAV 20026*: 249-262

[LMD06] P. Lopez, J.L. Medina, J.M. Drake. Real-Time Modelling of Distributed Component-based Applications. Proccedings of the 2006 32nd Euromicro Conference on Software Engineering and Advanced Applications (EUROMICRO-SEAA'06). IEEE Computer Society Press, august 2006.

[MFJ05] Pierre-Alain Muller, Franck Fleurey, and Jean-Marc Jézéquel. -- Weaving executability into object-oriented meta-languages. -- In S. Kent L. Briand, editor, *Proceedings of MODELS/UML'2005*, volume 3713 of *LNCS* pages 264--278, Montego Bay, Jamaica, October 2005. Springer.

[MFHS06] A. Metzner, M. Fränzle, C. Herde und I. Stierand. An Optimal Approach to the Task Allocation Problem on Hierarchical Architectures. In: Proceedings of the 20th IEEE International Parallel and Distributed Processing Symposium. IEEE Computer Society, April 25-29 ,2006 Rhodes Island, Greece

[MH05] A. Metzner und C. Herde. RTSAT - Scheduling Tasks in Distributed Real-Time Systems by Enhanced Satisifiability Checking. In: Proceedings of the IEEE Real-Time Systems Symposium, Work in Progress Session. December 5-8, 2005 Miami, Florida, USA

[MLD06] M. Medina, P. Lopez, J.M. Drake. Towards a UML Profile for Real-Time Modelling of Component-Based Distributed Embedded Systems. Proceedings of the FDL'06 - Forum on Specification & Design Languages, Darmstadt - Germany, Sept. 19-22, 2006 ISSN: 1636-9874.

[OGL06] Iulian Ober, Susanne Graf, David Lesens: Modeling and Validation of a Software Architecture for the Ariane-5 Launcher. FMOODS 2006: 48-62

[OGY05] Iulian Ober, Susanne Graf, Yuri Yushtein. "Timing analysis and validation of the embedded MARS bus manager". In Intl Workshop on Modeling and Analysis of Real Time Embedded Systems, MARTES 2005, with MoDELS 2005, October 2005

[OMG'05] ProMarte consortium, Joint UML Profile for MARTE Initial Submission, realtime/05-11-01, November 2005, available at: http://www.omg.org/cgi-bin/doc?realtime/05-11-01 .

[OPK05] Roman Obermaisser, Philipp Peti and Hermann Kopetz, Virtual Networks in an Integrated Time-Triggered Architecture, in Proceedings of the 10th IEEE International Workshop on Object-Oriented Real-Time Dependable Systems, Sedona, AZ, USA, 2005.

[PDR2005] G. Pinto, W. Damm und S. Ratschan. Guaranteed termination in the verification of LTL properties of non-linear robust hybrid systems. In: In ATVA Automated Technology for Verification and Analysis 2005. Taipei, Taiwan, October 4-7, 2005, LNCS 3707

[PCB05] D. Potop-Butucaru, B. Caillaud, A. Benveniste. Concurrency in Synchronous Systems, in: Formal Methods in System Design, To appear, 2005, available from http://www.irisa.fr/s4/download/papers/potopFMSD2005.pdf.

[PC05] D. Potop-Butucaru, B. Caillaud. Correct-by-construction asynchronous implementation of modular synchronous specifications, in: Proceedings of the Fifth International Conference on Application of Concurrency to System Design, ACSD 2005, 2005, available from http://www.irisa.fr/s4/download/papers/Potop-acsd2005.pdf.

[RFS+05] Raghu Reddy, Robert France, Sudipto Ghosh, Franck Fleurey and Benoît Baudry, Model Composition - A Signature-Based Approach, in proceedings of Aspect Oriented Modeling (AOM) Workshop, Montego Bay, October 2005.

[SBD06] S.Saudrais, O. Barais and L. Duchien, Using Model-Driven Engineering to generate QoS Monitors from a formal specification, AQSerM: Advances in Quality of Service Management workshop, EDOC, Hong Kong, October 2006.

[S05] Joseph Sifakis "A Framework for Component-based Construction", 3rd IEEE International Conference on Software Engineering and Formal Methods (SEFM05), Keynote talk, September 7-9, 2005, Koblenz, pp 293-300.

[TSSC05] S. Tripakis , C. Sofronis , N. Scaife , P. Caspi. "Semantics-preserving and memory-efficient implementation of inter-task communication on static-priority or EDF schedulers", Proceedings of the 5th ACM international conference on Embedded software, pp. 353-360, September 18-22, 2005, Jersey City, NJ, USA.

3.3 Interaction and Building Excellence between Partners

The main concrete interaction between partners takes place by discussions at workshops, meetings and conferences, by mutual visits, and by collaboration in research projects.

Workshops organized by the cluster, or with significant cluster participation are used for discussions on central research topics. Such discussions have occurred, e.g., at Models/UML (Oct. 2005), the ARTIST2 plenary meeting (Sept. 2005), the workshop on “Distributed Embedded Systems” (Leiden, Nov. 2005), FMCO (Formal Methods for Components and Objects) (Amsterdam, Nov. 2005), and the workshop “Beyond Autosar” (Innsbruck, March 2006).

Interaction also occurs through direct mutual visits. J. Medina (Cantabria) has been on a longer visit at CEA in working on the MARTES submission. Marius Minea (Timisoara) has visited Uppsala on two occasions for collaboration on timing analysis in component-based systems. Harald Raffelt (Dortmund) has visited Uppsala in Summer 2006 for the work on deriving component models.

Important interaction and collaborative work happens in collaborative research projects with participation of several cluster partners. Examples of such projects are SPEEDS where INRIA, OFFIS, PARADES and VERIMAG are focusing on modelling frameworks and methodology and system level validation techniques. The results of the project will be integrated in commercial development platforms and academic analysis tools connected to them. SPEEDS will build upon work of previous projects, in particular WOODDES, SAFEAIR, NexTTA and OMEGA. In the SAVE project, Uppsala and Mälardalen are collaborating on component models in the Swedish National project SAVE [ÅCF+06]. Other projects with an analogous role include OpenEmBeDD and Persiforme.

References being joint publications in the period

[ÅCF+06] Mikael Åkerholm, Jan Carlson, Johan Fredriksson, Hans Hansson, John Håkansson, Anders Möller, Paul Pettersson, Massimo Tivoli, The SAVE approach to component-based development of vehicular systems, Journal of Systems and Software, Elsevier, to be published

[BJR06] Therese Berg, Bengt Jonsson, Harald Raffelt: Regular Inference for State Machines with Parameters. In Proc. FASE 2006, Vienna, Austria, March 27-28, 2006, LNCS 3922 Springer 2006, pp 107-121

[BRS06] Therese Berg, Harald Raffelt and Bernhard Steffen. LearnLib: A Library for Automata Learning and Experimentation" in Proc. FMICS05 (Tenth International Workshop on Formal Methods for Industrial Critical Systems), September 5-6, Lissabon, Portugal, ACM Press, pp. 62-71,

[BCCS-V05] A. Benveniste, B. Caillaud, L. P. Carloni, A. L. Sangiovanni-Vincentelli. Tag Machines, in: Proceedings of the fifth ACM International Conference on Embedded Software (Emsoft), Jersey City, NJ, USA, ACM Press, September 2005, p. 255–263, available at http://doi.acm.org/10.1145/1086228.1086276.

[BCGMM-06] Marius Bozga, Pierre Combes, Susanne Graf, Wei Monin, Nicolas Moteau, Qualification d'architectures fontionnelles. In Notere'06 2006

[EDG+05] Huáscar Espinoza, Hubert Dubois, Sébastien Gérard, Julio L. Medina Pasaje, Dorina C. Petriu, C. Murray Woodside: Annotating UML Models with Non-functional Properties for Quantitative Analysis. MoDELS Satellite Events 2005, Lecture Notes in Computer Science, Springer, p. 79-90.

[EDMG05] Huáscar Espinoza, Hubert Dubois, Julio L. Medina, Sébastien Gérard. A General Structure for the Analysis Framework of the UML MARTE Profile. In Proc. Workshop MARTES: Modeling and Analysis of Real-Time and Embedded Systems, Satellite event of MoDELS 2005. Montego Bay - Jamaica. 4 october 2005

[EMDG06] Huáscar Espinoza, Julio L. Medina, Hubert Dubois, Sébastien Gérard. A UML-Based Modeling Standard for Quantitative Analysis of Real-Time Systems. CEA/LIST/DTSI/SOL/LLSP Internal Report.

[GHI+06] Arkadeb Ghosal, Thomas A. Henzinger, Daniel Iercan, Christoph M. Kirsch, and Alberto Sangiovanni-Vincentelli, A hierarchical coordination language for interacting real-time tasks, Proceedings of the Sixth Annual Conference on Embedded Software (EMSOFT), ACM Press, 2006.

[GGMSM06] Gregor Gössler, Susanne Graf, Mila Majster-Cederbaum, M. Martens, Joseph Sifakis, Ensuring Properties of Interaction Systems by Construction, Seminar in Honor of Reinhard Wilhelm's 60th Birthday, Dagstuhl 2006, to appear in LNCS

[GS05] G. Gössler, J. Sifakis. "Composition for Component-Based Modeling", Science of Computer Programming, vol. 55, pp. 161--183 (2005)

[HS06] Thomas A. Henzinger and Joseph Sifakis, "The embedded systems design challenge, Proceedings of the 14th International Symposium on Formal Methods (FM), Lecture Notes in Computer Science, Springer, 2006.

[OGL06] Iulian Ober, Susanne Graf, David Lesens: Modeling and Validation of a Software Architecture for the Ariane-5 Launcher. FMOODS 2006: 48-62

[OMG'05] ProMarte consortium, Joint UML Profile for MARTE Initial Submission, realtime/05-11-01, Nov. 2005, available at: http://www.omg.org/cgi-bin/doc?realtime/05-11-01 .

4. Overall Assessment and Vision for the Cluster

4.1 Assessment

As explained in Section 1, a decision has been made to merge the two clusters Hard real-Time and Components, to properly manage redundancies and improve synergies. We feel that this objective has been reached in large part:

- The more general activities of the former clusters were closely related in their topics. They have been fused and restructured into the two novel activities *Forums with industrial sectors* and *Seeding new Research Directions,* thus emphasizing on what is delivered specifically by the cluster rather than on general themes.
- This restructuring has allowed to better present what is actually done within the cluster and at the same time favors specific ARTIST2 related activities rather than general ones.
- There are research directions within the scope of the cluster that involve large implementation and tool building efforts, which can only be carried in the context of larger projects with more funding. The ARTIST2 specific activities nicely complement such efforts by considering conceptual questions, and fostering discussions and dissemination for a larger group of researchers and industrials. In fact, we feel that the type of open meetings organized under the umbrella of the two new activities are a better vehicle for European integration in the area of the cluster than would be “regular” cluster meetings.
- This restructuring has had some little inconvenience, though. Since general management and organizational cluster meetings have been less numerous, less opportunities have been given to the *UML for Real-Time systems* activity to feed the cluster with information related to UML. In order to provide to ARTIST2 partners a detailed view of the MARTE standard, CEA plans to organized a specific ARTIST2 meeting on MARTE in order to give to ARTIST2 partners the opportunity to influence the standard and raise issues that can be taken into account during the next phase of the MARTE standardization (i.e., after the vote on the MARTE standard, which is now scheduled for December 2006).
- The idea of connecting more closely the *Platform* activity of the cluster to other, larger, activity platforms ongoing at cluster on *Verification and Testing* was mentioned. Going into more detail regarding the respective nature of these two platform activities revealed that they focus on different aspects. The focus of the tools of the *Platform for Verification and Testing* is the validation technologies themselves and their possible combinations and most of the concerned tools work on semantic level formalisms with restricted expressivity. The “component platform” focuses on the connection of modelling tools and validation tools with relatively rich input formalisms. Notice also that some of the validation tools connected the platform, for example the IF toolset and Times, are also part of the validation platform. Also the tools developed for the validation of security protocols and those supporting certification activities have been planned to be part of both platforms. However, there is still important work to be done on the verification engines themselves, and this work has been considered prioritory over the interconnection with modelling languages.

Overall, we believe that the move which was made was right, despite the slight inconveniences that resulted. We feel it right to give stronger emphasis on ARTIST2 specific activities such as the two new ones and we propose keeping this policy for the future.

4.2 Vision and Long Term Goals

The different RTC activities have different roles regarding vision and long term goals:

- The need for a good and effective connection between UML-RT related standardisation bodies and the active academic community will remain. This is the role currently played by the activity *Development of UML for Real-Time Embedded Systems.* This role should remain fulfilled even after the end of ARTIST2.
- Presently, all the tools included in the platform activity are built with the common aim to enhance the analysis and validation capacity of model-based design. This requires the connection of existing validation tools to the modelling environments used for the development of embedded systems, and the development of appropriate semantic level formalism from which code generation can be envisaged. For making the different translation steps easier, model transformation techniques are enhanced or new ones developed. An important side-effect of this activity should be to find out which modeling constructs at user level are amenable to translation into a semantic level formalism for which effective analysis can be provided. It thus serves as a unifying testbed for the work in the activity on standardization, and the work on semantic foundations for heterogeneous system design. The outcome of the platform activity should allow to evaluate the feasibility by means of some complete tool chains. Another important aim of the platform activities is to contribute techniques allowing to make easier the adaptation of existing techniques to new modeling environments, as there will never be a unique modelling framework.
- The vision and long term goals of the two new activities on *Forums with industrial sectors* and *Seeding new research directions* are different from the former ones. At some period of time, the corresponding contact points between different communities (industry/academia or between different research communities) are needed – for example in the form of these ARTIST2-RTC workshops. When the need has been satisfied, there is no reason to maintain such activities unless novel reasons appear. Accordingly, we have a more opportunistic vision of the future of the two new RTC activities. As long as the need for such contact points will remain, we believe that the format we have invented for them at RTC is interesting. As long as the problems of component-based development are perceived as important by industry, containing large unsettled research problems, we believe that the need for this type of meetings will persist. These activities will also continue to inspire work on heterogeneous system development and interfaces in component-based systems.

4.3 Future Work and Evolution

We only summarize the main points here. Details can be found in the progress reports of the four activities.

4.3.1 Technical Description

Future plans for the respective activities include:

- **Platform: Components Platform for Component Modelling and Verification**. In the next 18 month period, the concerned tool chains will be enlarged by means of new model transformations, and by bringing the modeling standards closer together. A major part of the work will be performed within the projects OpenEmBeDD and IP SPEEDS. A major role for ARTIST2 is to harmonize semantics between different tool chains, using the expertise of all ARTIST2 partners, and to connect the platform work with standardization activities.

- **Cluster integration: Development of UML for Real-Time Embedded Systems** Plans for the next 18 months include to finalize the work on the first version of the MARTE standard, and to obtain feedback from other ARTIST2 teams.
- **NoE integration: Forums with specific industrial sectors**. The sequence of meetings in different industrial sectors will continue by considering the avionics domain, and subsequently (whether this will happen already in the next 18 months is not determined) in the consumer electronics domain.
- **NoE integration: Seeding new research directions**. The meeting of this period, on *Models of Computation and Communications (MoCC)* will be conducted in fall 2006, followed by a meeting on new research challenges for *Mobile Embedded Systems.* Collaborative research work on the central research topics in the area will continue.

4.3.2 Current and Future Milestones

The initial objectives of the different activities in the cluster were as follows.

- **Platform: Components Platform for Component Modelling and Verification**: *to obtain initial versions of tool integrations for the component modelling and verification platform*. During Year 2, initial subsets of two of the three planned tool chains have been built, and two very important projects for the platform have been launched, the French platform project OpenEmBeDD and the IP SPEEDS, planning to construct more complete versions of these tool chains.
- **Cluster integration: Development of UML for Real-Time Embedded Systems**: *to prepare an initial submission to the OMG standard for the UML profile for Modeling and Analysis of Real-Time and Embedded Systems (MARTE).* This submission is approaching maturity, and is scheduled for completion at the end of 2006.
- **NoE integration: Forums with specific industrial sectors**: *to conduct a meeting with industrial participation on embedded electronics in the automotive industry*. The meeting “Beyond Autosar” was conducted in March 2006, and a publication, reporting on the findings of this meeting, is in preparation.
- **NoE integration: Seeding new research directions**: *to conduct a research meeting on conceptual models for distributed embedded systems*. This meeting has been scheduled for November 2006, in Zürich at ETH; the preparation of the meeting requires in depth thinking regarding conceptual models for distributed embedded systems, which is reported in the corresponding activity deliverable.

Milestones for the next 18 month period are as follows.

- **Platform: Components Platform for Component Modelling and Verification**: During Year 3, the existing initial tool chains will be strengthened so as to be able to connect some of the analysis and validation tools to UML modelling tools, in order to realize tools chains to analyze user-level models.
- **Cluster integration: Development of UML for Real-Time Embedded Systems**: During Year 3, the development work for a proposal for a UML profile for MARTE will be finalized. At least one meeting will be conducted to debrief the current version of the proposal, and to obtain feedback from ARTIST2 partners and industry.
- **NoE integration: Forums with specific industrial sectors**: the main milestone for this period is to prepare a meeting on *The challenges raised by Integrated Modular Avionics (IMA).* The approach for this meeting will be similar to the one followed for the *Beyond Autosar* meeting, namely: we shall invite a panel of engineers from aeronautics industry, who are involved different areas of systems design (from early systems design

down to flight control). We shall try to understand the move in OEM/supplier chain, the impact of IMA on systems architectures, and the research directions that would result. A subsequent milestone could be a similar meeting in the sector of consumer electronics; corresponding goals are not defined yet.

- **NoE integration: Seeding new research directions**: A meeting on *Models of Computation and Communications (MoCC) in Embedded Systems* will be held in Zurich hosted by EHTZ on November 16th-17th 2006 and co-organised by L. Thiele, A. Benveniste and P. Caspi. This is a very fundamental meeting aimed at understanding the role of computing and communication paradigms in designing embedded systems. Studies on MoCC are the foundations of developments regarding heterogeneity, a topic that was identified as central to embedded systems in the ARTIST roadmap. A meeting on *Basic Concepts in Mobile Embedded Systems* will be organized by the Vienna team in December 2006. The collaborative work on central research topics for the activity (heterogeneity, components and interfaces, model-based development) will continue, supported by relevant workshops and project meetings.

5. Cluster Participants

5.1 Core Partners

Team Leader **Co-responsible for activity on "seeding new research directions"**	
	Albert Benveniste http://www.irisa.fr/distribcom/benveniste/
Technical role(s) within ARTIST2	Former ARTIST2-Hard Real Time cluster leader. Now Real Time Components cluster leader. Co-leader of activities *Forums with industrials* and *Seeding new work directions.* Co-organizer of meeting *Beyond AUTOSAR.*
Research interests	Research interests include: embedded systems, synchronous languages, heterogeneous systems; large distributed systems, telecommunication network and service management, true-concurrency theory; automatic control, system identification and diagnosis, application to vibration mechanics.
Role in leading conferences/journals/etc in the area	Member of the Editorial Board of the *Proceedings of the IEEE,* Associated Editor at Large of the *IEEE Transactions on Automatic Control*; PC member of several conferences including EMSOFT.
Notable past projects	SACRES, Solutions for Safety Critical Embedded Systems, IST project 1996-1999 SAFEAIR (IST-1999-10913, 2000-2002). Avionics Systems Development Environment http://www.safeair2.org/safeair/index.htm SPEEDS (ongoing IP) MAGDA RNRT project (1998-2001). Models and algorithms for distributed fault management in telecommunications networks.

	MAGDA2 RNRT project (2002-2003). Models and algorithms for end-to-end distributed fault management in telecommunications networks. SWAN RNRT project (2003-2006). Self-Aware Management in networks and Web services. Eureka projects in vibration mechanics • SINOPSYS (1997-1999). In-operation modal analysis and monitoring. • FliTE (2001-2004). Automated input/output and output-only modal identification and monitoring with application to aeronautics including flutter onset monitoring. • FliTE2 (2005-2008). Industrial transfer of Flite results, aeroelastic flutter monitoring.
Awards / Decorations	1990 CNRS Silver Medal; 1991 IEEE Fellow

Team Leader **Co-responsible for activity on "seeding new research directions"**	
	Bengt Jonsson http://user.it.uu.se/~bengt/
Technical role(s) within ARTIST2	Participant in discussions, contributions regarding compositionality, modelling, analysis of timing properties, tool building (TIMES)
Research interests	Research interests include: embedded systems, semantics, verification, modelling, specification, testing of distributed and embedded systems
Role in leading conferences/journals/etc in the area	PC member of several conferences including EMSOFT.
Notable past projects	ASTEC, Competence Center for Software Technology, 1995-2005. http://www.astec.uu.se/ Regular model checking (www.regularmodelchecking.com)

Team Leader	
	Paul Caspi (VERIMAG) http://www-verimag.imag.fr/~caspi/
Technical role(s) within ARTIST2	Participant in the Real-time and Component Cluster, in particular the activity “Seeding new research directions”
Research interests	Model-based development, synchronous languages, models for heterogeneous systems
Role in leading conferences/journals/etc in the area	PC member of ACSD 2005, RTAS 2006, WESE2006
Notable past projects	IST RISE: Reliable Innovative Software for Embedded Systems (2002-2005) IST Next-TTA: High Confidence Architecture for Distributed Control Applications (2001-2004) IST Crisys (terminated in 2001) IST SafeAir (terminated in 2001)

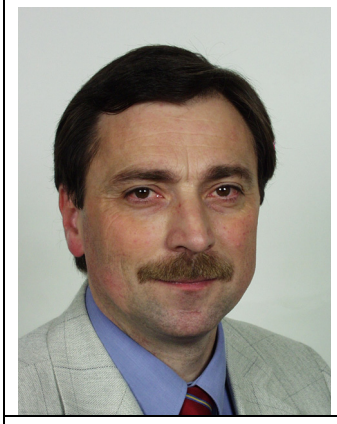
Team Leader **Responsible for JPIA-Platform Platform for Component Modelling and Verification**	
	Susanne Graf (VERIMAG) http://www-verimag.imag.fr/~graf/
Technical role(s) within ARTIST2	Participant in the Real-time and Component Cluster Responsible for JPIA-Platform Platform for Component Modelling and Verification
Research interests	Formal modeling and analysis of reactive and timed systems.
Role in leading conferences/journals/etc in the area	PC member of CAV 2005, MODELS 2006, FMICS 2006, FMCAD 2006, TACAS 2007 PC chair of ATVA 2006 Board of European Association of Software Systems and Technologies, EASST Animation of ASERT, the group on Embedded Systems ASERT within the CNRS virtual lab ASR
Notable past projects	IST INTERVAL - Consistent timing extensions for Telecom standards SDL, MSC and TTCN IST OMEGA - Correct Development of Real-time Embedded Systems Formal verification of embedded systems based on UML http://www-omega.imag.fr/ IP ASSERT SPEEDS - Speculative and Exploratory Design in Systems Engineering Provide a semantics based modelling methods with analysing techniques to support the construction of complex embedded systems by composing heterogeneous subsystems together with a speculative tool-supported design process.

Scientific Coordinator of the ARTIST2 NoE	
	Joseph Sifakis (Director of VERIMAG) http://www-verimag.imag.fr/~sifakis/
Technical role(s) within ARTIST2	Scientific Coordinator Participant in the Real-time and Component Cluster Participant in JPIA-Platform Platform for Component Modelling and Verification
Research interests	Component based design, QoS Control, Modeling and Validation
Role in leading conferences/journals/etc in the area	EmSoft'06 : Executive Committee (http://www.it.uu.se/conf/EMSOFT06/) Date'07 : Chair of the Embedded Software Track, and member of the Executive Committee (http://www.date-conference.com/) Editorial boards: • Formal Methods in System Design (http://www.springerlink.com/content/1572-8102/) Software Tools for Technology Transfer (http://sttt.cs.uni-dortmund.de/)
Notable past projects	• ARTEMIS ETP (http: www.artemis-office.org/) • ARTIST FP5 (http://www.artist-embedded.org/ARTIST_FP5_PublicReport.pdf) • EmSoC regional initiative • IST OMEGA (http://www-omega.imag.fr/) • IST ADVANCE (http://www.liafa.jussieu.fr/~haberm/ADVANCE/main.html) • RTP SECC (http://www.systemes-critiques.org/SECC/) • RNTL Espresso (http://www.inria.org/recherche/equipes/espresso.en.html) • Nano network
Awards / Decorations	CNRS Silver Medal in 2001

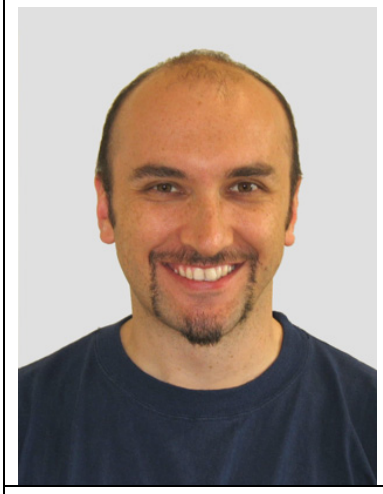
Team Leader **Participant in the activity "Forums with Specific Industrial Sectors"** **Participant in the activity "Seeding New Research Directions"**	
	Prof. Dr. Werner Damm (OFFIS) http://www.offis.de
Technical role(s) within ARTIST2	Bring in Expertise in embedded system modelling and validation. Deep involvement in cooperation with the automotive industry. Co-organizer of the Workshop "Beyond Autosar"
Research interests	Embedded system modelling and validation, formal verification, semantic foundation, safety analysis
Role in leading conferences/journals/etc in the area	Program Committee Member CAV2006 Co-Program Chair CAV2007 Member of the Editorial Board "Formal Methods in System Design" Member of the ARTEMIS Innovation Working Group Coordinator of the SafeTRANS cluster
Notable projects	OMEGA - Correct Development of Real-time Embedded Systems Formal verification of embedded systems based on UML http://www-omega.imag.fr/ AVACS - Automatic Verification and Analysis of Complex Systems This project addresses the rigorous mathematical analysis of models of complex safety critical computerized systems. http://www.avacs.org/ SPEEDS - Speculative and Exploratory Design in Systems Engineering Provide a semantics based modelling methods with analysing techniques to support the construction of complex embedded systems by composing heterogeneous subsystems together with a speculative tool-supported design process.

Team Leader **Participant in the activity on "Development of UML for Real-Time Embedded Systems"**	
	Dr. Sébastien Gérard, CEA
Technical role(s) within ARTIST2	Leader of the standardization effort for the UML Profile for Modelling and Analysis of Real-Time and Embedded Systems: MARTE (prospective standard of the OMG)
Research interests	Modeling for RT/E Systems, code generation, RT/E analysis such as WCET and schedulability analysis.
Role in leading conferences/journals/etc in the area	Member of the Editor Board of our Springer Journal on Software and Systems Modeling (SoSyM) Co-organizer of the Summer School MDD for DRES (www.mdd4dres.info) Co-organizer of the workshop series MARTES (www.martes.org) Member of the ISORC 2007 PC
Notable past projects	WOODDES (IST project) A UML profile for Automotive industry http://wooddes.intranet.gr/ EAST-AEE (ITEA project) An Architecture Description Language for Automotive: EAST-ADL

Team Leader **Participant in the activity on "Development of UML for Real-Time Embedded Systems"**	
	Dr. Jean-Marc Jézéquel, full professor of computer science at the university of Rennes 1, France
Technical role(s) within ARTIST2	Leader of the Triskell INRIA team http://www.irisa.fr/triskell/
Research interests	Model driven software engineering based on object oriented technologies for telecommunications and embedded systems.
Role in leading conferences/journals/etc in the area	Associate editor of the Journal of Software and System modelling, of the Journal of Object technology; conference chair of SPLC-Europe 2005, UML2002, chair of steering committee of UML2004, PC member of UML2006, CBSE2006, SPLC2006
Notable past projects	QCCS (IST project) Quality Controlled Component Based Software http://www.qccs.org FAMILIES (ITEA project) FAct-based Maturity through Institutionalisation Lessons-learned and Involved Exploration of System-family engineering http://www.esi.es/Families/

	Prof. Dr. Bernhard Josko (OFFIS) http://www.offis.de/
Technical role(s) within ARTIST2	Participating in several activities bringing in the expertise on real-time UML verification
Research interests	Modelling and analysis of embedded systems, formal verification, real-time UML, SysML
Notable projects	OMEGA - Correct Development of Real-time Embedded Systems Formal verification of embedded systems based on UML http://www-omega.imag.fr/ EASIS – Electronic Architecture and System Engineering for Integrated Safety Systems Within WP System Dependability provide formal verification guidelines http://www.easis.org SPEEDS - Speculative and Exploratory Design in Systems Engineering Provide a semantics based modelling methods with analysing techniques to support the construction of complex embedded systems by composing heterogeneous subsystems together with a speculative tool-supported design process.

	Prof. Dr. Hermann Kopetz Real-Time Systems Group Institute of Computer >Engineering Vienna University of Technology http://www.vmars.tuwien.ac.at
Technical role(s) within ARTIST2	Team Leader TU Vienna
Research interests	expertise in fault-tolerant systems architecture and inventor of the TTA concept
Role in leading conferences/journals/etc in the area of fault-tolerant real-time systems	Chairman of the IFIP WG 10.4 on Dependable Computing and Fault-Tolerance DSN steering committee member
Notable past projects	DECOS - Dependable Embedded Components and Systems Develop the basic enabling technology to move from a federated distributed architecture to an integrated distributed architecture. http://www.decos.at TTEthernet – Time-Triggered Ethernet Establishing of a time-triggered (TT) Ethernet with predictable temporal performance and strong fault-isolation for safety-critical real-time control systems and multimedia systems. NEXT TTA Enhance the structure, functionality and dependability of the time-triggered architecture (TTA) to meet the cost structure of the automotive industry, while satisfying the rigourous safety requirements of the aerospace industry. http://www.vmars.tuwien.ac.at/projects/nexttta/ DSoS - Dependable Systems of Systems Develop significantly improved means for composing a dependable "system of systems" (SoS) from a set of largely autonomous component computer systems. http://research.cs.ncl.ac.uk/cabernet/www.laas.research.ec.org/dsos/
Awards / Decorations	Fellow of the IEEE

	Dr. Wilfried Elmenreich Real-Time Systems Group Institute of Computer >Engineering Vienna University of Technology http://www.vmars.tuwien.ac.at
Technical role(s) within ARTIST2	Team Member TU Vienna
Research interests	expertise in sensor networks, sensor fusion and smart transducer interfaces
Role in leading conferences/journals/etc in the area of fault-tolerant real-time systems	Organizer of the annual Workshop on Intelligent Solutions in Embedded Systems (WISES)
Notable past projects	DSoS - Dependable Systems of Systems Develop significantly improved means for composing a dependable "system of systems" (SoS) from a set of largely autonomous component computer systems. http://research.cs.ncl.ac.uk/cabernet/www.laas.research.ec.org/dsos/ CoMa Concepts and methods for the configuration and maintenance of the time-triggered fieldbus system TTP/A. TTSB – Time-Triggered Sensor Bus Elaborate the concepts for a modern and cost-effective fieldbus with deterministic real-time behavior.

Team Leader **Participant in the activity on "Development of UML for Real-Time Embedded Systems"**	
	Dr; Julio Medina , University of Cantabria
Technical role(s) within ARTIST2	Schedulability Analysis and Component-Based solutions inside the standardization effort for the UML Profile for Modelling and Analysis of Real-Time and Embedded Systems: MARTE (prospective standard of the OMG)
Research interests	Real-Time Systems, Object Oriented and Component-based Modelling, Real-Time Distributed Systems, Unified Modelling Language (UML), Flexible scheduling strategies, Real-Time Programming and Operating Systems, Rate Monotonic Analysis (RMA) and Schedulability Analysis
Role in leading conferences/journals/etc in the area	Member of the PC of RTAS 07 Area B: Development, Verification, and Debug Tools for Real-Time and Embedded Systems
Notable past projects	FIRST THREAD

Team Leader **Participant in the activity on "Seeding New Research Directions" and "Forums with Specific Industrial Sectors"**	
	Prof. Thomas Henzinger, EPFL http://mtc.epfl.ch/~tah
Research interests	Formal modeling and analysis of reactive, timed, and hybrid systems. Design and implementation of hard real-time systems.
Role in leading conferences/journals/etc in the area	Chair, advisory board, ACM Conference on Embedded Software. Associate editor, ACM Transactions on Embedded Computing Systems.
Notable past projects	HyTech, a model checker for hybrid systems. mtc.epfl.ch/software-tools/hytech Mocha, a design and verification framework for reactive modules. mtc.epfl.ch/software-tools/mocha Giotto, a programming language for control applications. mtc.epfl.ch/software-tools/giotto Blast, a software verifier. mtc.epfl.ch/software-tools/blast
Awards / Decorations	Fellow, IEEE. Member, Academia Europaea. Member, German Academy of Sciences (Leopoldina).

Team Leader	
	Pierre Combes (FTR&D) http://rd.francetelecom.com/fr/groupe/rd/index.html
Technical role(s) within ARTIST2	Participant in the Real-time and Component Cluster, in particular the activity "JPIA-Platform Platform for Component Modelling and Verification"
Research interests	Formal modelling and verification, performance analysis
Role in leading conferences/journals/etc in the area	PC member of ERTS, Notere, CFIP, MceTech, ICSEA
Notable past projects	IST OMEGA

5.2 Affiliated Industrial Partners

More complete lists of affiliated industrial partners appear in the activity deliverables. Here is only one of them.

Team leader	
	Dr David LESENS (Astrium Space Transportation) http://www.eads.net
Technical role(s) within ARTIST2	Provide case study to specificy industrial needs and evaluate produced technologies
Research interests	Development of critical real-time embedded software Model Driven Engineering Validation & Verification Automatic Code Generation, Automatic Test Generation
Role in leading conferences/journals/etc in the area	

Notable past projects	ASSERT (EU project, coordinator ESA) • Proof Based System Engineering • Model Driven Approach French cluster of competitiveness SYSTEM@TIC (Ile de France) • Gateway from system models to software models • Framework fot fault tolerant systems Automatic Code Generation research project (ESA project) From Matlab/Simulink and SCADE model OMEGA research project UML for real time critical software
Awards / Decorations	
Further Information	

5.3 Affiliated Academic Partners

Team Leader **Participant in the activity on "Seeding new research directions"**	
	Dr. Marius Minea, Institute e-Austria Timisoara http://www.ieat.ro http://www.cs.upt.ro/~marius
Technical role(s) within ARTIST2	Affiliated partner IeAT has expertise in formal verification (model checking), especially for real-time systems, and compositional reasoning including assume-guarantee techniques. Within the cluster, the partner is working on: - abstraction and compositional reasoning techniques for real-time models. Starting from models such as timed automata, the goal is to generate more abstract timed interfaces that can be used to reduce - modeling and performance analysis of embedded systems consisting of tasks with given timing parameters (period, deadline, jitter). Using analysis techniques borrowed from network calculus and timed automata, the challenge is to computer performance characteristics such as availability and response time in a modular fashion starting from individual components.
Research interests	formal verification (model checking), compositional and assume-guarantee reasoning, real-time and embedded systems, model-based testing, verification of security protocols
Notable past projects	Verification of telecommunications code written in SDL Model-based testing and automated test generation with Rational Test RealTime (with Siemens VDO Automotive)

	Prof. Ivica Crnkovic Mälardalen University Department of Computer Science and Electromics http://www.idt.mdh.se/~icc
Technical role(s) within ARTIST2	Affiliated partner, active in real-time components. Member of group building RT component model SaveCCM. Initiator of cooperation with Swedish Industry, cooperation with Mohash University, Australia, and SEI(Carnegie Mellon University, US
Research interests	Component-based software engineering, Development processes
Role in leading conferences/journals/etc in the area	Co-chair of technical committee for Euromicro Software Engineering and Advance Applications conference (SEAA) , General Chair of Euromicro SEAA 2006, Program chair 2007 Member of Steering committee of ACM SIGSOFT Symposium of Component-based Software Engineering, General chair 2006, Program Chair 2004. General Chair of ACM SIGSOFT European Software Engineering Conference and the ACM SIGSOFT Symposium on the Foundations of Software Engineering Co-Editor – Journal of Systems and Software – special editions in Component-based Software Engineering, 2007, 2005, 2003
Notable past projects	SAVE and SAVE++ – Design of safety critical vehicular systems, funded by Swedish foundation for Strategic Research, http://www.mrtc.mdh.se/SAVE/ FLEXCON - Flexible Embedded Control Systems, , funded by Swedish foundation for Strategic Research, http://www.control.lth.se/FLEXCON/ CBSE Network - Component-Based Software Engineering Network
Awards / Decorations	Industrial Software Engineering, donation from ABB for professorship