ARTIST 2
Network of Excellence

IST-004527 ARTIST2:
Embedded Systems Design

Activity Progress Report for Year 2

JPRA-NoE Integration

# Adaptive Real-Time, HRT and Control

Clusters:

**Control for Embedded Systems**

**Adaptive Real-Time**

**Real-Time Components**

Activity Leader:

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http://www.control.lth.se/user/karlerik

*Policy Objective (abstract)*

*The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity an flexibility in embedded systems*

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# 1. Overview of the Activity

## *1.1 ARTIST2 Participants: Expertise and Roles*

Professor Karl-Henrik Johansson – KTH (Sweden)
*Provides expertise in applying control techniques to communication networks, including sensor networks.*

Associate Professor Anders Robertsson – LUND (Sweden)
*Provides expertise in performance control of server systems.*

Professor Karl-Erik Årzén – LUND (Sweden)
*Provides expertise on embedded control systems and feedback-based scheduling of control systems.*

Professor Alfons Crespo – UPVLC (Spain)
*Provides expertise on embedded computing.*

Professor Martin Törngren – KTH (Sweden)
*Provides expertise in architectural design and automotive embedded system applications involving dynamic configuration.*

Professor Pedro Albertos – UPVLC (Spain)
*Provides expertise on embedded control.*

Professor: Giorgio Buttazzo – (SSSA, Pisa)
*Provides expertise on adaptive RT techniques*

Professor Albert Benveniste – (INRIA)
*Provides expertise on embedded real-time systems and components.*

Professor Gerhard Fohler – (Univ Kaisersluatern)
*Provides expertise on flexible scheduling.*

Professor Werner Damm – (OFFIS)
*Provides expertise on embedded systems.*

Dr Pau Marti – (UPC)
*Provides expertise on embedded control.*

Prof. Vladimir Kucera – (CTU)
*Provides expertise in real-time control*

Dr Zdenek Hanzalek – (CTU)
*Provides expertise in real-time embedded control and scheduling.*

Professor Hermann Kopetz (TU Vienna)
*Provides expertise on time-triggered formalisms.*

Professor Luis Almeida - (University of Aveiro)
*Provides expertise on communication platforms.*

Professor Juan Antonio de la Puente - (UP Madrid)
*Provides expertise on target application platform and scheduling.*

Professor Eduardo Tovar - (Polytechnic Institute of Porto)
*Provides expertise on distributed systems and middleware.*

## 1.2 Affiliated Participants: Expertise and Roles

Dr Johan Eker – Ericsson (Sweden)
*Provides expertise on reservation-based scheduling in mobile terminals.*

Professor Lui Sha - University of Illinois (US)
*Provides expertise on error control of software systems.*

Professor Tarek Abdelzaher - University of Illinois (US)
*Provides expertise on feedback scheduling.*

## 1.3 Starting Date, and Expected Ending Date

Starting date = 1 Sept 2004. Since the overall status of the activity is to enhance the state of the art in applying control techniques to real-time control and computing systems the activity will run over the entire life-time of the network, and most likely also continue after the termination of Artist2.

## 1.4 Baseline

The situation at the beginning of this activity, i.e., at the start of ARTIST2 was the following. A number of projects already allowed some structuring and interaction, e.g., FLEXCON (Swedish national project) *Flexible Embedded Control Systems* involving Lund and Mälardalen), OCERA (European project) *Open Components for Embedded Real-Time Applications*, involving Pavia, UPVLC and CTU, RECSYS (European project) *Real-Time Embedded Control of Mobile Systems with Distributed Sensing* involving KTH, ARTIST (European Accompanying Measure) *Advanced Real-Time Systems* involving a majority of the partners, and FIRST (European project) *Flexible Integrated Real-Time Systems Technology* involving Pavia (Pisa) and Mälardalen.

There also existed strong links between the core partners and the affiliated partners, e.g., between Lund and Ericsson, between Lund, Virginia and Illinois, and between UPC and Mälardalen.

## 1.5 Problem Tackled in Year2

The work within the activity has been arranged in two parallel tracks. In the first track the integration between the Control cluster and the ART cluster has continued. This has been done in the form of a number of joint research activities, see Section 2.2. A planning meeting involving six participants was held in Pisa on March 10, 2006. A joint summer school has also been organized between these two clusters (The first European Laboratory on Real-Time and Control for Embedded Systems, Pisa, 10-14 July 2007), see http://www.artist-embedded.org/FP6/ARTIST2Events/Events/RT-Control/

In the second track the Control cluster and the RT Components cluster collaborate through joint organization of industrial workshops. The first of these events, devoted to the interaction between control and embedded electronics in automotive industry, was jointly organized by this activity and the network activity Forums with Specific Industrial Sectors that is coordinated by the RT Components cluster. The conclusions from this meeting are summarized in the activity report of the Forums with Specific Industrial Sectors activity. This form of collaboration between these two clusters was fruitful and the goal is to continue this also during Y3.

## *1.6 Comments From Previous Review*

### *1.6.1 Reviewers' Comments*

The reviewers' comments regarding last years deliverables from the cluster were as follows: *Four deliverables were due from this cluster at the end of Y1:*

- *Deliv-JPIA-a-Control-Y1*
- *Deliv-JPRA-NoE Integration-c-Y1 (this cluster's contribution as planned in the DoW.)*
- *Deliv-JPRA - Cluster Integration – Control for Embedded - a -Y1*
- *Deliv-JPRA - Cluster Integration – Control for Embedded - b -Y1*

*The deliverables were of uniformly excellent quality. The deliverable documents themselvesdescribed the problem to be addressed, the current state of the art, what was achieved using ARTIST2 funds in the past year, and natural integrative next steps for the coming 12/18 months. Where Roadmaps (or other collateral documents) were developed as part of a particular task, such documents were succinctly summarized in the deliverable, with pointers to the more complete document for the interested reader.*

The specific comments related to this activity were as follows: *This task is focused on the integration of research in the control, adaptive real-time and hard realtime clusters with respect to different computational models for embedded control systems and the use of control techniques to provide flexibility in embedded systems. The primary work items for Y1 was continuation of a number of pre-existing collaborations between members of the different clusters, holding an initial kick-off meeting (outcomes summarized in the deliverable) to initiate the NoE-wide integration activities, and holding a workshop at LUND focused on Control for Embedded Systems to which members of the ART and HRT clusters were invited. A summary of the outcomes of that workshop is provided as one of the accompanying documents to D18, discussed below.*

### *1.6.2 How These Have Been Addressed*

Since the reviewer's were very positive we have tried to continue along the same lines as previous year. A dedicated effort has been made to increase the collaboration with the RT Components cluster and that has proved successful.

# 2. Summary of Activity Progress

## *2.1 Previous Work*

### *2.1.1 Work achieved in the first 6 months of Y1*

- Kick-off meeting held
- UPVLC (Crespo) has evaluated the performance of the scheduling policies related to offer a constant bandwith behaviour. In conjuntion with SSSA (Lipari), a new version of the CBS called IRIS was developed. This new algorithm was implemented and evaluated in a real-time environment providing both hard and soft real-time constraints. The IRIS algorithm was implemented in RTLinux and included in the distribution of the OCERA project.
- Collaboration between Mälardalen (Fohler) and LUND (Cervin) about the combination of the jitter margin index and flexible scheduling methods.
- CTU studied holistic scheduling methods and analyzed a case study using the MAST tool (Cantabria).
- Karl-Erik Årzén contributed to the Artist2 workshop on diagnosis in Vienna, Dec 20-21, organized by the HRT cluster

### *2.1.2 Work achieved in months 6-12 of Y1*

- The Lund Workshop was held. The interaction between the control cluster, the participants from the ART cluster and the US affiliated partners was very valuable
- In order to add flexibility to the real-time applications UPVLC has developed a nanokernel called Xtratum. XtratuM is a thin layer of software that provides a simple and convenient API to access interrupt mechanims and timer devices. Xtratum permits the execution of environments/applications spatial and temporal isolated. Xtratum has been developed under the OCERA project.
- Collaboration between LUND (Cervin) and Pavia (Buttazzo) about the use of the Shark real-time kernel as a shared platform for implementing control applications.
- Collaboration between LUND (Cervin) and Ericsson (Eker) on distributed versions of the control server model
- A collaboration between UPC (Marti), Mälardalen (Fohler) and LUND on feedback scheduling of control system has been initiated
- CTU has built up several demonstrators for communication components based on the OCERA architecture (UPVLC, SSSA, CTU) including fish breeding control and supervision system (process control application), remote programming of mobile robot (robotics and supervision), human machine interface for autogiro (data acquisition and visualization), robotic arm demonstrator (servocontrol).
- Interaction between CTU and Aveiro (Almeida) on deadline constrained scheduling on FPGAs and multicast traffic optimization.

## 2.2 Current Results

### 2.2.1 Technical Achievements / Outcomes / Difficulties encountered

**Achievement: Organization of Workshop**

The workshop **Interaction between control and embedded electronics in automotive industry** was jointly organized by the RT Components and the Control clusters in Innsbrück, March 23. It was co-locacted with the Beyond AUTOSAR meeting organized by the network activity "Forums with Specific Industrial Sectors". Three invited presentations were given by Stefan Kowalevski (RWTH Aachen), Karl-Erik Årzén (Lund University), and Carlos Canudas de Wit (LAG Grenoble) followed by a panel discussion. A more detailed description of the content and focus of the presentations is given in the activity report of the "Forums with Specific Industrial Sectors" activity. Several conclusions can be drawn:

- There is a permanent misunderstanding between control & software engineers in the automotive industry
- Regarding the relative merits of ET/TT, control design aspects provide complementary views, not considered in the embedded design community. For example, in general a long but constant controller input-ouput latency is worse from a control performance point of view than a shorter but time-varying latency, also if the former constant latency is taken into account in the control design.
- The control systems in automotive systems are often structured in a multi-layer or multi-cascade fashion. This further increases the need to minimize the input output latency and puts special requirements on component-based architectures. For example, it is important to organize the computations in such a way that first only the parts of the controller components that are needed for the generation of the component outputs are calculated and then, afterwards, the parts of the components that are responsible for updating the state of the controller components are calculated. This is someting that is well-known within the field of process automation, but for some reason has not yet spread to, e.g., the automotive systems area
- In an automotive system there is only a limited amount of sensors and actuators. Both the sensors and actuators are typically used by several control systems or control functions. In an integrated system it is important to make it possible for several functions to use the same physical sensors and actuators, rather than, e.g., use several sesnors to measure the same physical entity, something which is not uncommon in federated architectures. Hence sensor and actuator component should have a special role in a component-based automotive system.
- Today, the structure of the control systems in an automotive system is to a large degree derived from the constraints of the federated system architecture. In an integrated system new possibilities for structuring the control systems open up. Hence, it would be worthwhile to take a completely new look upon how the overall control system for a car ought to be structured, including powertrain control, chassis control, safety systems, etc.

**Output from Achievement: Organization of Workshop**

A joint ARTIST2 paper summarizing the conclusions from the Beyond AUTOSAR workshop is under completion.

**Difficulties with Achievement: Organization of Workshop**

A problem with the organization of industrial workshop is to get the right people to attend. This meeting was held in connection with an industry-specific meeting that itself draw a lot of attendees. Another problem is to attract multi-disciplinary people to a relatively small area such as the interaction between control and computing. Therefore the co-location of this meeting with the Beyond AUTOSAR meeting was a large advantage. We will try to use this structure also in the future, e.g., in connection with the planned workshop aimed at the aerospace industry.

**Achievement: Joint Research Activities Involving the ART and the Control Cluster**

The joint research initiatives that were started during Y1 have continued. These include

- Anton Cervin (Lund) and Giorgio Buttazzo (Pisa) have worked on a comparison of jitter reduction techniques for control tasks. When implementing a controller in a multitasking operating system, there is a risk that the control loop will experience delay and jitter due to preemption from other tasks. Several jitter control methods have been proposed in the literature, and they all have different strengths and weaknesses with respect to timing and control performance. In this work, we have compared and evaluated four different task models: the Standard Task Model (STM), Reducing Jitter by Task Splitting (RJTS), Reducing Jitter by Advancing Deadlines (RJAD), and Reducing Jitter by Non Preemptive Execution (RJNP). It is found that RJTS is good for jitter reduction, but introduces a long delay which gives sluggish control performance. RJAD works well for reducing both jitter and delay, and gives good control performance in most cases. RJNP reduces input-output jitter to a minimum but may cause some tasks to miss their deadlines. A conference publication describing this joint work is under preparation and a technical report is available [3].
- Lund (Cervin) and Pisa (Bini) are working on optimal period selection for multiple controllers under fixed-priority scheduling. Traditionally, when scheduling controllers, it has been assumed that the deadline of each control task is less than or equal to its period. Under fixed-priority (FP) scheduling, this typically implies that the processor cannot be fully utilized. In this work, we have explored what control performance is possible to gain by moving outside the FP schedulability bound. Utilizing a simple upper bound on the response time of a task, the input-output delay can be bounded. Combining this bound with an approximate expression for the control performance (as a function of the rate and the delay of the controller), the optimal task periods can be found by solving a constrained optimization problem. For certain simple cases, exact analytical solutions can be found. A publication describing this joint work is under preparation.
- UPC (Marti, Selga) and Lund (Henriksson, Cervin) have worked on feedback-based scheduling of linear controllers with varying disturbance intensities. In previous work from Lund on feedback scheduling of linear controller tasks, it has been assumed that the amount of disturbances entering the control loops is constant over time. In [1] the inital states of the controlled plants are taken into account by the feedback scheduler by including the inital state in the cost function. The motivation for this is that a plant with a large error should receive more resources in order to better cope with the disturbance. However, in all but extreme cases it is the expected future disturbances that completely dominate the cost function. In this work, we have explored how one can obtain a more reactive feedback scheduler by estimating the amount of noise in the various control loops. We have also extended the cost functions to take a

constant delay (obtained using Control Servers) into account. The project has included a PhD student visit from UPC to Lund: Rosa Castañe spent 5 months (from August 2005 to December 2005) in Lund. In addition, several working meetings have taken place during 2006, in Pisa, March 2006 and Dresden, June 2006.

- Lund (Cervin) and Mälardalen/Univ Kasierslautern (Moris, Isovic, Fohler) have continued the work on flexible scheduling of controllers based on the jitter margin. The work combines two previously developed tools and techniques for flexible real-time systems: the jitter margin and the slot-shifting algorithm. Using the jitter margin, it is possible to guarantee a level of a performance of a controller, given bound on the worst-case input-output jitter. On the other hand, the slot-shifting technique can be used to allow sporadic tasks to execute at the cost of more jitter for the periodic tasks. In this work, an off-line design method based on simulated annealing has been devloped that tries to find an optimal schedule such that all control tasks meet their performance specifications, while at the same time allowing as many sporadic tasks as possible to execute. The work has resulted in the Master Thesis [2] which recently received the price for the best Swedish Master Thesis in the field of Real-tIme and Embedded systems during 2005-2006.
- Several of the groups have focused their activities on the SHARK kernel and the TrueTime tools as common platforms for feedback-based scheduling work. In Lund a project has started in which the suitability of using SHARK in control laboratories will be investigated. UPC has modified the Truetime simulator to better study new feedback scheduling theoretical results [4]. UPC has also added new features to Shark to allow easy implementation of feedback scheduling [5].
- A strong research connection is currently being established between CTU and UPCLC in the Control cluster and UCantabria, Pisa, UPC, and UYork in the ART cluster. This is funded through the FRESCOR project. Here several activities are currently being initiated, e.g., the implementation of contract-based kernels for embedded systems. Both CTU and UPVLC also participated in the ARTIST2 requirements workshop (Paris June 16 2006).

**Output from Achievement: Joint Research Activities Involving the ART and the Control Cluster**

See the publication list in Section 2.2.2. A complete list of publications produced by the Control cluster, with downloads available for most of the papers, is available here: http://www.md.kth.se/RTC/ARTIST2/publications.html

**Difficulties with Achievement: Joint Research Activities Involving the ART and the Control Cluster**

No special difficulties have been encountered. A general difficulty is the small means that are available for controlling the research within a network of excellence. Although a center of excellence can derive roadmap it is extremely difficult to ensure that the actual research work that is performed follows the lines of this roadmap. In this particular case, however, it happens to be the case.

**Achievement: Joint Summer School**

The summer school Firrst European Laboratory on Real-Time and Control for Embedded Systems was organized in Pisa, Italy, July 10-14, 2006. The number of participants were 40. http://www.artist-embedded.org/FP6/ARTIST2Events/Events/RT-Control/

**Output from Achievement: Summer School**

A report summarizing the summer school is available on the cluster material page, http://www.md.kth.se/RTC/ARTIST2/publications.html

**Difficulties with Achievement: Summer School**

Setting up the control devices for the practical experiments took the major effort in the preparation of the course and was underestimated at the time of the proposal. Sensory acquisition interfaces and servomotor control boards had to be developed and tested for each robot device and the total cost required for this phase was significantly higher than the allocated budget.

### *2.2.2 Publications Resulting from these Achievements*

[1] Rosa Castañé, Pau Martí, Manel Velasco, Anton Cervin, Dan Henriksson. Resource Management for Control Tasks Based on the Transient Dynamics of Closed-Loop Systems. In *Proceedings of the 18th Euromicro Conference on Real-Time Systems,* Dresden, Germany, July 2006.

[2] Moris Habib Behnam. Flexible Scheduling for Real Time Control Systems based on Jitter Margin. M.Sc Thesis. Mälardalen University 2005 (Best Sweidh Master Thesis in Real-Time Systems during 2005)

[3] Giorgio Buttazzo and Anton Cervin, "Analysis and Evaluation of Jitter Control Methods" Technical Report, Scuola Superiore S. Anna, RETIS-TR06-01, August 2006.

[4] Josep Guardia, Pau Marti, Manel Velasco and Rosa Castane. "Enabling Feedback Scheduling in TrueTime", UPC, Research report ESAII-RR-06-05, March 2006

[5] Josep Guardia, Pau Marti, Manel Velasco . "Feedback Scheduling in S.Ha.R.K: a First Approach", Research report ESAII-RR-06-13, July 2006

[7] Giorgio Buttazzo, Manel Velasco, and Pau Marti, "Quality-of-Control Management in Overloaded Real-Time Systems", to appear on IEEE Transactions on Computers.

[8] Giorgio Buttazzo, "Achieving Scalability in Real-Time Systems", IEEE Computer, Vol. 39, No. 5, pp. 54-59, May 2006.

[9] Mauro Marinoni and Giorgio Buttazzo, "Adaptive DVS Management through Elastic Scheduling", Proceedings of the 10th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2005), Catania, Italy, September 2005.

[10] Šůcha, P. - Hanzálek, Z.: Scheduling of Tasks with Precedence Delays and Relative Deadlines - Framework for Time-optimal Dynamic Reconfiguration of FPGAs, 20th IEEE International Parallel & Distributed Processing Symposium, WPDRTS, Island of Rhodes, Greece, April, 2006.

[11] Šůcha, P., Hanzálek, Z., Heřmánek, A., Schier, J.: Scheduling of Iterative Algorithms with Matrix Operations for Efficient FPGA Design - Implementation of Finite Interval Constant Modulus Algorithm, The Journal of VLSI Signal Processing, Springer, accepted for publication.

[12] Jad El-khoury. PhD thesis. A Model Management and Integration Platform for

Mechatronics Product Development. ISBN: 91-7178-268-0, Serie: Trita-MMK, ISSN 1400-1179; 2006:03, Department of Machine Design, KTH, May 2006.

[13] Ola Larses. PhD thesis. Architecting and Modeling Automotive Embedded Systems. Dept. of Machine Design, Royal Institute of Technology, Stockholm. TRITA – MMK 2005:31, ISSN 1400-1179, ISRN/KTH/MMK/R-05/31-SE, Nov. 2005

### *2.2.3 Keynotes, Workshops, Tutorials*

**Invited Presentation :** Karl-Erik Årzén, Anders Robertsson, Dan Henriksson, Mikael Johansson, Håkan. Hjalmarsson, Karl Henrik Johansson. Conclusions from the European Roadmap on Control of Computing Systems. In *First International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks,* Vancouver, Canada, April 2006 http://www.controlofsystems.org/febid2006/

**Keynote :** Karl-Erik Årzén. Implementering av reglersystem: utmaningar och forskningsinriktningar (Control System Implementation: Challenges and Research Directions). In Reglermötet 2006 (Swedish Control Conference), Stockhlm, June 2006. (http://www.s3.kth.se/control/reglermote/ )

**Invited Partcipant:** Karl-Erik Årzén participated in the Joint EU-US Workshop on Large ICT-Based Infrastructures and Interdependencies: Control, Safety, Security, and Dependability in Wahsington D.C representing ARTIST2.

**Invited Lecture** by Martin Törngren (KTH)at the ARTES summer school (www.artes.uu.se): "Automotive Embedded Systems – research challenges", Aug. 24, 2006

**Invited Lecture** by Martin Törngren (KTH) at Mecel (a Swedish subsidiary of Delphi) : "Cost-efficient and systematic verification of embedded control systems", June 14, 2006
Performed at the occasion of starting a new national project between Mecel and KTH.

**Invited Lecture** by Martin Törngren (KTH) at ENEA: "Automotive Embedded Systems; characteristics, trends and challenges", May 17, 2006

**Invited Lecture** by Martin Törngren (KTH) at PLM Forum 2006: "Challenges for PLM of Mechatronic Systems", Stockholm, May 10, 2006. A forum arranged by Technia AB.

**Invited panellists** at the ARTIST2 workshop: Beyond Autosar, Innsbruck, March 24, 2006 (Karl-Erik Årzén, Werner Offis, Martin Törngren)

**Invited participant**: Zdenek Hanzalek (CTU) participated in the ARTIST2 Workshop on Requirements for Flexible Scheduling in Complex Embedded Systems, Paris (Massy), 16 June 2006 http://www.artist-embedded.org/FP6/ARTIST2Events/Events/flex_sched/

**Workshop:** Interaction between control and embedded electronics in automotive industry Integrated with ARTIST2 Beyond AUTOSAR workshop (http://www.artist-embedded.org/FP6/ARTIST2Events/Events/Innsbruck06/ ) and Modellierung 2006 Innsbrück, Austria – March 23, 2005

# 3. Future Work and Evolution

## *3.1 Problem to be Tackled over the next 18 months (Sept 2006 – Feb 2008)*

The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity and flexibility in embedded systems. Each of the clusters have matching internal cluster activities, e.g., in the Control for Embedded Systems the corresponding cluster activities are Real-time techniques in control system implementations and Control in real-time computing. The activities within the cluster can be characterized as follows. There are strong joint research activities between the ART cluster and the Control cluster. These activities will be continued also during the next 18 months. The interaction with the RT-Components cluster is mainly performed through jointly organized workshops with industry. This approach will be continued also during the next 18 months.

The research problems to be tackled during the next 18 months involves both the use of control-techniques in resource scheduling for embedded systems and scheduling techniques and computational models for embedded control applications. These two lines are also combined in the form of feedback-based scheduling of embedded control systems. The explicit research problems that will be pursued is to a large extent dependent on the particular goals of the research projects that provide the direct funding for the activities. It is, however, quite clear that there will be work on feedback-scheduling of control tasks, event-based control, further use of SHARK and TrueTime as experimental and simulation platforms for the joint work, and mechanisms for handling overruns within this activity.

The aim for the industrial workshop is to organize a follow-up workshop on embedded control issues within a particular industrial branch. It is likely that the workshop will be co-organized with the Industrial Workshop network activity and that the particular branch will be the aerospace industry. A likely point in time for this workshop will be during the Spring 2007. A report summarizing the conclusions of the workshop will be produced.

During Early Spring 2007 a followup workshop to the Lund workshop on Control for Embedded Systems will be held. This time the workshop will be given at University of Illinois, Urbana-Champage with Tarek Abdelzaher and Lui Sha as the hosts. The format will be the same as last year, i.e. mainly invited participants and a lot of room for discussions. Tentative persons to be invited from outside the ARTIST2 community are John Doyle, Richard Murray, Mark Spong, Tariq Basar, Prasad Kumar, Williams Sanders, Klara Nahrstedt, Karl Åström, Dawn Tilbury and Joe Hellerstein. A report summarizing the conclusions of the workshop will be generated.

## *3.2 Current and Future Milestones*

Year1: Setting the technical background and assess the needs *(Achieved 100%)*

Year2: Demonstrate that applications of diverse type can be specified in terms of resource-aware tasks (*Achieved 80 %)*

*The work within the activity has focused on two application types only: multimedia applications and real-time control. Wintin these two broad application areas, several types of application have, however, been studied. These two application types are also the ones that are most natural for these techniques.*

**Update Milestone for Year3:**

- **Demonstrate that scheduling algorithms can be made adaptive by means of control schemes**
- **The organization of a new industrial workshop along the lines of the workshop organized jointly with the Beyond AUTOSAR activity**
- **The organization of a follow-up research workshop to the Lund Workshop on Control for Embedded Systems held in June 2005. The workshop is currently planned for Jan-Feb 2007**

## *3.3 Indicators for Integration*

Joint research work visible through joint publications, mobility of team members among the teams, joint transfer of results to industry, and jointly organized workshops and sessions. Some examples are work by Lund, Pisa and Univ Kaiserslautern on flexible and adaptive scheduling, work by UPC and Lund on feedback-based scheduling of control systems, joint workshop organization among INRIA, OFFIS and Lund, joint embedded systems curriculum development by numerous ARTIST2 partners, and joint development of summer school material by Pisa, Lund, Evidence and Avero.

The results obtained by combining the forces of the hard real-time, adaptive real-time and embedded control communities within ARTIST2 will make a strong contribution to the advancement of the state-of-the-art in this field.

## *3.4 Main Funding*

The main sources of funding for this work are:

- Nationally funded projects. For the Swedish partners these include FLEXCON, SAVE, SAVE++ and various projects funded by the Swedish Research Council. For the partners from other countries the situation is similar.
- EU projects. The following are examples of currently running EU projects that to some extent cover these acivities: RUNES, SOCRADES, ATESST, DYSCAS, CEMACS, and FRESCOR.

The FRESCOR EU project is a particularly good example of the strong interaction between the clusters involved in this activity. The project is aimed at developing a framework that integrates advanced flexible scheduling techniques directly into an embedded systems design methodology, covering all the levels involved in the implementation, from the OS primitives, through the middleware, up to the application level. This will be centred on a new contract model that will specify which are the application requirements with respect to the flexible use of the schedulable resources in the system, and also what are the resources that must be guaranteed if an application component is to be installed into the system, and how the system can distribute any spare capacity that it has, to achieve the highest usage of the available resources. Univ of Cantabria is coordinating this research while designing the architecture and contract model. UPV is in charge of the execution platforms dealing namely with Linux and appropriate RT executives. CTU is in charge of network support and distribution while focusing on wireless networks and reconfigurable FPGAs. Univ of York is responsible for analysis techniques, Pisa is working on adaptive QoS management, and TU Kaiserslautern is in charge of requirements analysis.

### *3.5 Internal Reviewers for this Deliverable*

Zdenek Hanzalek, CTU, Alfons Crespo, UPVLC