IST-214373 ArtistDesign
Network of Excellence
on Design for Embedded Systems

Progress Report for Year 1

Transversal Activity:
Design for Adaptivity

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Policy Objective (abstract)
An embedded hardware-software system is adaptive, if it can modify its behavior and/or architecture to changing requirements. Adaptivity is increasingly important as the complexity and autonomy of embedded systems increases. Adaptivity is a cross-cutting system characteristic that affects hardware and software as well as modeling, architecture, and run-time support. This deliverable summarizes the achievements of the activity during Y1 of ArtistDesign.

Versions

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1. Overview

1.1 High-Level Objectives

An embedded hardware-software system is adaptive, if it can modify its behavior and/or architecture to changing requirements. Adaptivity is increasingly important as the complexity and autonomy of embedded systems increases. Adaptivity is required both off-line at design-time and on-line at run-time. Off-line adaptivity is required to handle changing system specifications and to support platform-based or product-family based development. On-line adaptivity is required to be able to dynamically respond to changing conditions and contexts and through this improve performance and resource utilization. The changes can involve different types of resource requirements, changing system objectives, and changing external conditions.

Adaptivity is a cross-cutting system characteristic that affects both hardware and software. At the software-level adaptivity is mainly concerned with flexible and adaptive resource scheduling, e.g., CPU time scheduling. At the hardware-level adaptivity includes both adaptation of operation modes, e.g., supply voltage and clock frequency, processor instruction sets, and dynamic management of hardware resources, e.g., processing elements and memory.

The cross-cutting nature of adaptivity implies that it affects all aspects of embedded system design. The high-level objective of this thematic activity is therefore to integrate the efforts and combine the competences related to adaptivity in embedded systems within the four thematic clusters. The main way of achieving this is to create suitable interfaces, meeting points, and research contacts between the partners. Another important objective for this activity is to define the ontology for adaptivity in embedded systems, i.e., the relationship between adaptivity, reconfigurability, flexibility, sustainability, and robustness, and the relationship between adaptivity and predictability.

Although partners from all the four thematic clusters are part of this activity, it is partners from the Operating Systems and Network cluster that dominate. Hence, the majority of the partners are working on issues related to adaptive resource management, including CPU scheduling and QoS management; adaptive networking, and operating and middleware support for adaptivity. The use of feedback and control-theoretical approaches in order to achieve adaptivity is also studied by several partners. However, the activity also contains partners with interests in modeling of adaptive processes and applications, hardware (run-time) reconfigurability, and timing analysis support for adaptability.

The joint research within the cluster can be divided into three areas:

- **Adaptive resource scheduling**
  This area concerns adaptive scheduling in which schedules and task parameters are dynamically modified in order to prevent overload conditions and minimize some application-related cost function, e.g., control performance or energy consumption. The area include mechanisms for achieving adaptivity both on a task level and on a system level, adaptive resource reservations, QoS management, and control-based mechanisms for achieving adaptivity. The area applies to a wide range of resource types, although the majority of the work will be focused on CPU and communication bandwidth
- **Hardware-based adaptivity**
  This area concerns dynamic management of hardware resources (processing elements, memory, communication interconnect) to meet dynamic resource requests

from the software and to cater for different application domains both at design time and run time. It contains mechanisms for adaptation of hardware modes of operation.

Hardware-based adaptivity also includes modeling of adaptive processes and applications and hardware generation for such systems.

- **Adaptive networking**
  This area includes different mechanisms for supporting adaptivity in communication networks, excluding on-chip networks. It includes dynamic ad hoc routing mechanisms in sensor network applications, adaptivity in network protocols at various levels to cater for dynamically changing application demands, and application-aware networking.

1.2 Industrial Sectors

The use of adaptive resource management is of particular interest for soft real-time applications, e.g., multimedia applications within consumer electronics systems and in telecommunications. Consumer electronics products range from miniature cameras and MP3 players to advanced media servers and large displays. Mainly driven by Moore's law, the evolution in the CE industry is very fast. Utilizing available hardware and software resources in an optimal fashion is crucial both to save costs and to keep the competitive edge. Moreover, multimedia systems exhibit a highly dynamic behavior, since task execution times are often dependent on input data that are difficult to predict. As a consequence, these systems are prone to intermittent overload conditions that could degrade the performance in an unpredictable fashion.

The introduction of multicore platforms also in embedded applications creates new design challenges. A particular problem compared to uniprocessor platforms is the WCET analysis. Due to the shared memory access WCET analysis runs the risk of being very conservative. This will most likely hamper the application of hard real-time techniques based on static analysis. Hence, the market for more dynamic or adaptive resource management based on feedback from the true resource utilization and/or the application quality-of-service can be expected to increase in the future.

Also in industrial sectors where predictability is the main concern there is always a certain need for adaptivity. For example, companies like Boeing have expressed a need for active resource management and dynamic scheduling as well as to handle, during system execution, things that were not anticipated at design-time. The automotive industry also has expressed increasing needs to handle software upgrades in a robust way and flexible attachment of devices (e.g. PDA's, especially in the infotainment domain). In addition to resource management, this requires more stringent configuration management (be it on-line or support by off-line tools) that ensure that new configurations are compatible (both in a functional and non-functional sense).

1.3 Main Research Trends

Real-time systems constitute a notable share of today's embedded computers that needs special attention. The design of robust and fault-tolerant real-time systems is a highly active research area that has produced numerous approaches for evaluating and increasing system robustness against selected fault scenarios. These methodologies can be applied throughout the design process of an embedded system and yield systems that are highly robust against a selected set of disturbances in the field. Future embedded systems, however, will undergo an evolution in both hard- and software configuration during their lifetime. In the automotive industry, it is already common to update or add software components during the lifetime of a

product, producing a variety of software configurations in the field. To ensure functional and temporal correctness of all possible configurations, OEMs have to maintain a complex versioning database and perform exhaustive testing to cover the whole configuration landscape. This already constitutes a problem today, which will grow into a major challenge in the future.

Designing embedded systems robust and fault-tolerant will not ultimately solve this problem, as the evolution an embedded system goes through during its lifetime cannot be foreseen at design time. Hence, embedded systems need to be adaptive to changing conditions, in the sense that they need to be able to meet given requirements including safety, security, and performance, in the presence of uncertainty in its external environment or internal execution platform. Adaptivity can be seen as a means for enforcing predictability in the presence of uncertainty.

The uncertainty can be viewed as the difference between the average and the worst-case behavior of a system and its environment. The trend in embedded system is towards drastically increasing uncertainty due to, e.g., execution platforms with increasingly sophisticated HW/SW architectures (layering, caches, multiple cores, speculative execution etc), increased connectivity with complex and non-deterministic external environments, increased amount of difficult-to analyze software, and increased variability with respect to use cases.

One technique for achieving adaptivity in particular in software-based systems is feedback. In many embedded systems worst-case designs are unfeasible for several reasons. One of these is the over-provisioning of resources that this typically implies. Other reasons are uncertainties associated with worst-case resource utilization estimates and on-line changes in objectives, external conditions and use cases. In a feedback-based resource management system, the allocation of resources is based on a comparison of the actual resource utilization by, e.g., a set of activities or tasks, with the desired resource utilization. The difference is then used for deciding how the resources should be allocated to the different activities. The decision mechanism constitutes the feedback controller in the scheduling scheme. Feedback control makes it possible to deal with uncertainties and variations in a controlled way.

Feedback scheduling is primarily suited for soft real-time applications and adaptive real-time applications, where missing one or more deadlines does not jeopardize correct system behavior, but only causes performance degradation. For this type of systems, the goal is typically to meet some Quality of Service requirement. The adaptive class of real-time systems is a suitable description for a many practical applications. This includes different types of multimedia applications, but also many control and signal processing applications. An important research trend here is how to best model embedded computing system from a control perspective. Different model formalisms can be considered, from pure discrete event based models to fluid continuous-time approximative models.

The research trends related to adaptivity in embedded systems are numerous since adaptivity is crosscutting. In hardware-based oriented embedded systems there are work performed on modeling and hardware generation for adaptive processes and applications. Emerging architectures such as partially reconfigurable, either fine-grained or coarse-grained, FPGAs provide a huge potential for adaptivity in the area of embedded systems. Since many system functions are only executed at particular points of time they can share an adaptive component with other system functions, which can significantly reduce the design costs. However, adaptivity adds another dimension of complexity into system design since the system behavior changes during the course of adaptation. This imposes additional requirements on the design process, in particular system verification.

In the software-oriented part of embedded systems there is also a considerable work on computational models that allow for adaptivity, how adaptivity can be provided in component-based architectures, adaptive task models for scheduling, program language constructs

supporting adaptivity, and run-time support for adaptive resource management from operating systems, middleware, and communication networks. The resources in the latter case typically include clock cycles, memory, communication bandwidth, and energy, but could in general also include other resources which are allocated dynamically.

2. State of the Integration in Europe

2.1 Brief State of the Art

Since adaptivity affects all layers of system development and all the thematic areas in ArtistDesign it is quite difficult to provide a bried technical state of the art description. Here, we have focused on the industrial state of the art. For a description of the state of the art in research we refer to the respective thematic cluster reports.

Adaptive resource management is primarily of interest in consumer electronics, industrial automation, and telecommunications. Mobile cellular terminals today are getting more and more advanced and their source code consists of 5-15 million lines of, typically C, code involving a large number of parallel activities. For these applications, the use of adaptive resource management would allow to safely mix real-time and non real-time processes. The majority of the activities are related to multimedia streaming, where multiple video and audio streams are common. It is not uncommon to have a desired system utilization that is well beyond 100 %. Designing the system for the worst-case scenario is not exonomically justified. Hence, adaptivity is needed in order to be able to dynamically tradeoff the quality of the activities.

In telecommunication companies, the main current interest seems to be in exploring the use of the Linux OS and its real-time extensions. QoS mechanisms, virtualization and reservation-based scheduling, multi- and many-core platforms, and data-flow based programming models are also attracting substantial interest.

In the area of Industrial Automation, the continuous increment in processing power and memory capacity in local processors gives the opportunity to add new tasks into them, increasing system complexity in terms of supervision, diagnostics, presentation, communication, etc. Adaptive task scheduling that preserves the real-time constraints is a possible way to handle such situations and manage the complexity of the application.

Reconfigurable hardware systems are a technique that for a long time has not been able to compete either with software-based systems or with ASIC-based solutions. However, there are signs that that is about to change, especially for applications where the gains in performance over software-based system and the faster development cycle compared to ASICs are important.

The multi/many-core trend also narrows the gap between software and hardware-based implementation techniques. In both cases good models are needed for exploiting parallelism, both in the programming models and languages used and in the compilers and analysis tools. Ideally, it should be possible to execute the same application either on a FPGA with a high-level of parallelism or on a, e.g., quad-core, platform without having to change anything in the source.

2.2 Main Aims for Integration and Building Excellence through ArtistDesign

Adaptivity is a concern which cuts vertically across all levels of abstraction in embedded systems design, spanning from high-level requirements to implementation details on specific platforms. It therefore needs to be carried out in a synergistic manner, and is therefore the subject of a transversal activity involving all clusters of the NoE. In Artist2 adaptivity-related issues were spread out among different activities in different clusters. The main purpose of this

activity is to integrate research teams working on different aspects of adaptivity in embedded systems design.

2.3 Other Research Teams

The main teams in Europe on software-related adaptivity in embedded systems are part of ArtistDesign and this activity. In the more hardware-related area some of the leading teams in Europe belong to ArtistDesign but not all. The ones that are outside ArtistDesign mostly are part of the HiPEAC NoE (http://www.hipeac.net/members_new) which has separate clusters on reconfigurable computing, adaptive compilation and multi-core architectures. However several of the ArtistDesign partners also belong to HiPEAC, e.g., IMEC, CEA, Aachen, TU Braunschweig, UDortmund, and UBologna. Hardware-based adaptivity is also the focus of the ANDRES project (http://andres.offis.de/) in which OFFIS, TU Vienna, KTH, UCantabria and Thales participate. The same situation holds for the sensor network field. Several very strong European groups are not part of ArtistDesign, e.g., TU Berlin and SICS. The sensor network and cooperating object NoE in FP7 that runs in parallel with ArtistDesign is CONET (http://www.cooperating-objects.eu/). Organic computing systems which adapts dynamically to the current conditions of its environment through self-organization, self-configuration, self-optimization etc is the topic of the priority program 1183 funded by the German Science Foundation (DFG) (www.organic-computing.de/spp). Here several German teams participate.

Within US there is large amount of research on different aspects of adaptivity in embedded systems and on the use of control in embedded systems. Most of the software-based parts of this currently go under the label cyber-physical systems, an area where NSF recently has started a new programme. Strong research groups in the US include UIUC (Abdelzaher, Sha), Virginia (Son, Stankovic), CMU (Rajkumar), UNC (Baruah, Anderson). There are also interest in related topics from several control groups in the US, e.g., Berkeley (Sastry), UIUC (Dullerud, Basar), Caltech (Murray, Doyle), CMU (Krogh) just to name a few.

2.4 Interaction and Building Excellence between Partners

The interaction and work within this activity consist of individual and joint research projects (see Chapter 3), jointly organized meetings and workshops (see Chapter 3 and 5), jointly organized educational events (Chapter 3), and the development of a common shared wiki that will act as the repository for the work.

2.5 Interaction of the Transversal Activity with Other Communities

The partners of the activity interact with a several other research communities. These include the high-performance computing community, the sensor network community, and the control community at large and in particular the networked control community. The partners also interact with different industry branches, e.g., the automotive industry, e.g., through the DySCAS project, the microelectronics industry (through interactions with STMicroelectronics and NXP), the telecom industry (through Ericsson). The partners also have strong links to several US groups, e.g. UIUC, UNC and UVA, with Tarek Abdelzaher, Lui Sha and Sanjoy Baruah as affiliated international partners to ArtistDesign.

The partners also interact with the partners of the European projects that they participate in which do not belong to ArtistDesign. These include FRESCOR, ACTORS, HiPEAC, PREDATOR, COMBEST, MOSART, ANDRES, REALITY, DySCAS, CHAT and MOSART.

3. Summary of Activity Progress

The following summarizes the technical activities that are part of this activity. Certain parts have been omitted due to the fact that they already have been included in the Artist2 reporting or that they already are reported in the deliverables from the thematic clusters. It has been our attempt to reduce any overlap to the minimum. However, since all deliverables are generated in parallel it is still possible that there is a certain overlap. As an illustration of this; For KTH, the modeling and validation related to adaptivity is described in the corresponding activity deliverables. Here the focus is more on algorithms and architectures (supported by the modeling and validation work).

It should be emphasized that in the majority of the cases the actual research work described below has only marginally been funded by ArtistDesign. In most cases the funding comes from other national or European projects. The role of ArtistDesign is to provide the networking “glue” between these activities.

3.1 Technical Achievements

Modeling and analysis of adaptive systems (KTH et al)

Adaptivity is a common concept used in embedded system and custom hardware design for many years. Reconfigurable FPGAs, embedded software, configurable datapaths and parameterisable analog components are all familiar examples of adaptivity. We use the term to denote the general, abstract concept of changing the behaviour of a system at run-time which encompasses software, configurable or parameterisable digital and analog hardware.

KTH, together with partners from OFFIS, TU Vienna, Univeristy of Cantabria, THALES and DS2, has developed concepts for modelling adaptivity in an abstract way to make relevant and interesting properties of adaptive systems explicit. The type and level of adaptivity is an important design consideration in many systems and it should be possible for the designer to systematically explore the design space with adaptivity being one more design parameter just like performance, cost and power consumption. In order to provide a sound basis that captures adaptivity in a broad and general sense they have introduced adaptivity as an extension to a formal modelling framework. This allows to formally and systematically study adaptivity and its interesting properties and it establishes a clean and consistent conceptual basis for development of design analysis and exploration methods and tools.

Together with our partners, KTH has developed general concepts for formally modelling adaptive objects and applied them to dynamically reconfigurable systems. Based on these concepts, a performance analysis method and accompanying tools for reconfigurable systems has been developed. Moreover, a method to minimize power consumption for streaming applications on MPSoC platforms while meeting all real-time constraints has been developed.

See http://andres.offis.de/ for more details.

Symbolic Quality Control for Multimedia Applications (Verimag, ST Microelectronics)

Objectives: The objective here is to study and implement a fine grain quality control method for multimedia applications. The method takes as input application software composed of actions. The execution times of actions are unknown increasing functions of quality level parameters.

Main Results: The method allows the construction of a Controller which computes adequate action schedules and corresponding quality levels, so as to meet QoS requirements for a given platform. These include requirements for safety (action deadlines are met) as well optimality (maximization and smoothness of quality levels).

The Controller consists of a Quality Manager and a Scheduler. For each action, the Controller uses a quality management policy for choosing a schedule and quality levels meeting the QoS requirements. The schedule is selected amongst a set of optimal schedules computed by the Scheduler. A solid theoretical basis for designing and implementing the Controller has been provided.

Verimag proposes a symbolic quality management method using speed diagrams, a representation of the controlled system's dynamics. Instead of numerically computing a quality level for each action, the Quality Manager changes action quality levels based on the knowledge of constraints characterizing control relaxation regions. These are sets of states in which quality management for a given number of computation steps can be relaxed without degrading quality. Verimag also studies techniques for efficient computation of optimal schedules.

Experimental results including the implementation of the method and benchmarks for an MPEG4 video encoder are available. The benchmarks show drastic performance improvement for controlled quality with respect to constant quality. They also show that symbolic quality management allows significant reduction of the overhead with respect to numeric quality management. Finally, using optimal schedules can lead to considerable performance gains.

Current Work: Verimag and STMicroelectronics (no longer an Artist partner) are currently studying real-time implementations of the method, by using the BIP component framework.

Web: http://www-verimag.imag.fr/~sifakis/RealTimeJournal-Oct2008.pdf

Bandwidth Measurements (NXP Semiconductors)

Memory bandwidth is a scarce resource in our multi-media SoCs. One way to deal with this scarcity is run-time adaptation. As a first step towards runtime adaptation NXP Semiconductors has made a demonstrator that provides a runtime visualization of the memory bandwidth used by the competing agents on the SoC.

Dynamic changes of real-time parameters (ETHZ, SSSA)

There have been several meetings and a long terms student exchange between ETHZ and SSSA. In particular, PhD student Luca Santinelli is visiting ETHZ for 6 months in order to start joint research related to dynamic changes of real-time parameters. So far, ETHZ has been investigating the effect of changing task sets and real-time requirements while still guaranteeing real-constraints. The approach is based on the real-time calculus and lead to a publication at DATE 09: Reliable Mode Changes in Real-Time Systems with Fixed Priority or EDF Scheduling. Many application domains require adaptive real-time embedded systems that can change their functionality over time. In such systems it is not only necessary to guarantee timing constraints in every operating mode, but also during the transition between different modes. The approaches presented so far to address the problem of timing analysis over mode changes are restricted to fixed priority scheduling policies. Most of them are also bound to simple periodic event stream models. In this paper, we proposed a new method for the design and analysis of adaptive multi-mode systems that supports any event stream model and can handle EDF as well as fixed priority scheduling of tasks. We embedded the analysis method into a well-established modular performance analysis framework based on Real-Time Calculus and prove its applicability by analyzing a case study.

At the same time, Luca Santinelli from SSSA used the real-time calculus framework from ETHZ in order to model hierarchical scheduling methods. Both methods will be combined during the visit of Luca at ETHZ.

Integrating the Design Environments BIP and DOL (ETHZ, Verimag)

ETHZ and Verimag (Joseph Sifakis) started to integrate their design environments BIP and DOL on a semantic and tool level. There have been visits of PhD students and postdocs from ETHZ in Grenoble in order to clarify the corresponding semantic issues. In particular, BIP is based on a state-based model of components whereas DOL follows a stream-based operation principle. Work has started to model the stream-based DOL semantics in BIP and this way, to verify important system properties. As the state-based representation allows the modeling of adaptive system behavior, a major step to increase the expressivity of stream-based models has been possible. This activity just started and will be ongoing in year 2 of ArtistDesign.

Adaptive energy management in clusters of wireless sensor nodes (University Bologna, ETHZ)

In a distributed wireless sensor network, several nodes cooperate to the achievement of a global goal. The monitored environment is generally covered by multiple nodes deployed in the environment in order to guarantee redundancy and overlapping of the sensed area. In many scenarios each node is able to modulate and adjust the monitored area by varying the sensitivity of on-board sensors. Furthermore efficient energy policies can improve the performance and the autonomy of the network by exploiting the combination of several classes of devices with heterogeneous features.

Objectives: The objective of the work by UBologna and ETH-Z is to exploit distributed finite horizon control methods and multi-parametric programming to improve and optimize the performances of clusters of nodes in a wireless sensors mesh. Furthermore they extended the problem from the point of view of a single node to the hierarchical control of a cluster of nodes belonging to a large network.

Main Results: They have addressed run-time adaptivity to systems while using efficient run-time estimation methods combined with distributed finite horizon control methods. In particular they propose a model which run on the cluster-heads node and will decide the long-term objectives of each node, in order to ensure long-term sustainability of the energy harvesting from a cluster point of view by the collection of prediction and information from all the nodes.

Current work: Currently they are focusing on optimizing the hierarchical controller and have developed new control algorithms which tune the application parameters according to the time-varying amount of harvested energy. The application scenario is related to Vision Sensor Networks.

Design of an adaptive technique to enhance Real-Time support of IEEE 802.11e networks (University of Catania)

The IEEE 802.11e standard is a popular protocol for QoS support in wireless networks. The EDCA mechanism defines four Access Categories (ACs) to achieve differentiated QoS levels for the different types of traffic. For each AC there are a dedicated queue and different values for the back-off parameters. Recent literature showed the limitations of such a protocol when handling real-time industrial traffic. The main reason is that the fixed values imposed by the

standard could lead to a high number of collisions. An approach to overcome some of these limitations and improve the QoS support for real-time traffic has been proposed. The approach tries to reduce the number of collisions, so that the available bandwidth is used more efficiently by the real-time data traffic, especially in high traffic conditions. This is achieved through a dynamic adaptation of the back-off parameters CWmin and CWmax for the different Access Categories. Such an adaptive control is performed by a fuzzy-logic controller that takes into account both the throughput and frame retransmission count.

A reference architecture for self-configuring embedded systems (KTH, Volvo, Offis).
As part of the DySCAS research project, a framework and middleware architecture for the development of dynamically or self-configurable systems are being developed. By dynamic configuration we refer to the ability of a system to during run-time change the number of components (software/hardware), their connections and the properties which characterize their execution and communication. In contrast, in a traditional static configuration these parameters are determined during development time and mainly remain fixed during the operation of the system. The following use cases drive the work: Download of new software, attachment of external devices, and internal reconfiguration for performance or fault-tolerance purposes. It should be noted that the self-configuration is delimited to the application related software and hardware. The middleware supports dynamic configuration but is itself not reconfigurable during run-time. The work involves ArtistDesign partners KTH, Offis and Volvo (affiliated) and non ArtistDesign partners such as Enea, Bosch, Daimler and the Univ. of Greenwich. The work has with the assistance of ArtistDesign included interactions with Aveiro, CEA and LTH (partners of ArtistDesign). Currently, a functional architecture in terms of a component model definition, middleware components and interfaces have been developed and defined. Algorithms suitable for run-time configuration management, load balancing and quality of service have been developed. While the project mainly targets automotive applications (starting with telematics/infotainment domains), we believe that the architecture is general enough to be able to serve other applications as well. Automotive specifics include the consideration of standards (Autosar), safety critical functionality, integration with legacy systems and resource constraints. The architecture and algorithms have been evaluated in simulation and evaluation in terms of a reference implementation is under way. Modeling and validation as part of this framework is treated in the corresponding ArtistDesign activities.

See www.dyscas.org for more information.

Evaluation of feedback scheduling methods for real-time control tasks (UPC)
Feedback scheduling (FS) often refers to the problem of sampling period selection for real-time control tasks that compete for limited computing resources such as processor, network, or battery power. Its goal is to optimize the aggregated control performance achieved by all tasks by efficiently using the scarce resources. In this work representative existing FS methods are selected, their main features are identified, and a simple control performance evaluation is performed. The latter shows that a) jitter in job executions hide the true performance that can be achieved by the analyzed FS methods, b) after completely removing the degrading effects of jitters, the performance of each FS method dramatically changes, and c) the relative benefit provided by each method depends on the type of perturbations affecting the plants. A publication describing this work can be found at .
http://paginespersonals.upcnet.es/~pmc16/ifac08.pdf

Timing analysis of event-driven control systems (UPC)
In standard time-driven control systems, i.e. sampled-data control systems, the progression of time triggers the control updates. In event-driven control systems, the occurrence of discrete

events triggers the control updates. This preliminary works develops a graphical approach that permits to interpret the activation of discrete events generated by the progression of the system state with respect to the time they occur. In particular, for a class of linear event-driven control systems, this approach permits to determine the amplitude and frequency of the sampling intervals that event conditions generate. This opens the possibility of controlling these properties which determine the computational load imposed by event-driven controllers. A publication describing this work can be found at
http://paginespersonals.upcnet.es/~pmc16/hscc08.pdf

Distributed Online Performance Analysis (TU Braunschweig)

The compositional performance analysis model (as implemented in SymTA/S from TU Braunschweig and Symtavision) has been extended in order to allow distributed modeling and analysis of embedded systems. A novel distributed algorithm for control of the global analysis flow has been proposed. This enables run-time analysis of embedded systems, which can be used for e.g. access control. An implementation in C on top of a microkernel yields first results on memory footprint and runtime of embedded performance analysis.

Framework for Performance Control of Embedded Applications (TU Braunschweig)

A complementing framework to the embedded analysis engine has been developed. It enables access control and runtime-optimization of embedded systems. The key idea of this framework is that applications enter a performance contract based on descriptions (annotations) with the embedded system. This framework strictly separates modeling and execution aspects into two domains. The analysis engine is situated in the modeling or annotation domain enabling run-time feasibility tests of contracts as well as model-based optimization. The execution domain manages run-time aspects such as starting and stopping or migration of tasks as well as monitoring adherence to performance contracts. Here also a prototype implementation on top of a microkernel exists.

Networking support for flexible traffic scheduling (Aveiro, Mälardalen, UPVLC)

Aveiro, Mälardalen University and UPVLC jointly address the development of protocols and architectures to provide operational flexibility and composability in networked real-time systems. The technologies used focused mainly on Switched Ethernet.

Adaptation mechanisms for real-time wireless networking (Aveiro)

Aveiro also work on development of higher layer network protocols to enhance the resilience to interference in wireless real-time communication and to provide an estimation of relative localization based on the radio-frequency signal. The technologies used focused mainly on IEEE802.11 and IEEE802.15.4. Part of the work is done in cooperation with Zhejiang University in China.

Software metadata and System Scenarios (IMEC vzw, TU/e, DUTH, UCM)

Software Metadata is information extracted from embedded software applications, which is used to guide and assist automatic memory, bandwidth and computation optimizations. In the context of the transversal activity for Adaptivity, IMEC extended the software metadata framework in order to be able to support System Scenarios. Therefore, instead of using worst case software metadata information for the optimizations, multiple data sets are used according to the most frequent System Scenarios. This work was performed in cooperation

with the Software, Synthesis, Code Generation and Timing Analysis cluster, the Hardware platforms and MPSoC cluster and involved additional teams outside the ArtistDesign network. More details can be found in the corresponding cluster deliverables.
http://www2.imec.be/imec_com/mpsoc_runtime.php

Adaptive and Feedback-Based Resource Management in FRESCOR and ACTORS (York, SSSA, ULUND, TUKL, Evidence, Ericsson, Cantabria)

Several of the partners from the OS and Networks cluster work together in the two STREP projects FRESCOR and ACTORS. The main objective of FRESCOR (FP6) is to develop the enabling technology and infrastructure required to effectively use the most advanced techniques developed for real-time applications with flexible scheduling requirements, in embedded systems design methodologies and tools, providing the necessary elements to target reconfigurable processing modules and reconfigurable distributed architectures.

The approach to achieve this main objective is to integrate 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 is achieved by a contract model that specifies which are the application requirements with respect to the flexible use of the processing resources in the system, and also what are the resources that must be guaranteed if the 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.

ACTORS (FP7 project coordinated by Ericsson) addresses design of resource-constrained software-intensive embedded systems with high requirements on adaptivity and efficiency. Three techniques will be combined:

- virtualization,
- feedback control, and
- data-flow programming models.

Virtualization techniques such as reservation-based scheduling provide spatial and temporal separation of concerns and enforce dependability and predictability. Reservations can be composed, are easier to develop and test, and provide security support.

Using feedback-based resource management, the resource allocation is based on a comparison of the actual resource utilization of, e.g., a set of activities or tasks, with the desired resource utilization. The difference is used for deciding how the resources should be dynamically allocated. Feedback control makes it possible to deal with uncertainties and variations in a controlled way and provides adaptivity to on-line changes in objectives, external conditions and use cases. By combining feedback control with resource reservations it is possible to handle incorrect reservations, reclaim and redistribute unused resources, and adjust to dynamic changes in resource requirements.

Execution efficiency and development efficiency require abstractions on a higher level than what is provided with C and threads/priorities. Data-flow models such as actor models provide the proper foundation for implementation of efficient, component based, and adaptive algorithms for both multimedia applications in consumer electronics and industrial control systems and signal processing applications. In ACTORS a design methodology will be developed that combines virtualization, feedback and actors-based dataflow programming. Three demonstrators will be developed:

- multimedia processing on cellular phone terminals,
- embedded control, and

- high-speed video processing for computer vision applications.

FRESCOR: http://www.frescor.org/

ACTORS: http://www.actors-project.eu/

Real-Time and Control (SSSA, ULUND, UPC)

SSSA and Lund jointly investigate new methodologies for reducing jitter and delay in the execution of control tasks. Three different approaches have been compared: a) splitting a task in input-processing-output parts to execute input and outputs at period boundaries; b) reducing relative deadlines, and c) exploiting non-preemptive scheduling to reduce input-output delays. Such methods have been evaluated with respect to implementation complexity, jitter and delay reduction, control performance, schedulability analysis, and resource utilization. New methods for reducing task deadlines have also been proposed.

A general framework has also been proposed for evaluating how the assignment of timing attributes (e.g., execution times, periods and deadlines) can affect the performance of a controller. This method is based on determining the feasibility region of the task set as a function of the given set of design variables.

Another research line started with Pisa and UPC deals with event-driven scheduling. The objective of this research is to exploit the knowledge of the system to be controlled to relax the periodicity constraints of control activities to reduce resource utilization.

Adaptive Control of MPEG-2 decoding (TUKL, ULUND)

Decoding MPEG-2 streams in resource constrained system faces the challenges of matching varying resource demand (due to MPEG-2 encoding) to varying resource availability (due to varying network bandwidth or CPU availability). Adaptation has to meet the demand of high resource utilization and avoiding issues such as oscillation between over and under utilization of resources, which can bring the system to an unstable state with low resource utilization. TUKL has developed a first controller for stream adaptation in resource constrained systems.

Task Allocation (York)

University of York has undertaken work in the area of selecting task allocations for real-time systems architectures which are robust to requirements changes. Finding a suitable task allocation which meets all of the system's timing requirements is an NP-hard problem and hence a large amount of research has concentrated on applying a range of optimization methods to this problem. The work, which uses a search based optimisation method, takes a step further by trying to find solutions which are of a high quality with respect to attributes other than timing. In particular, we emphasize flexibility in the design which allows enhancements to be made with limited changes to the architecture so that knowledge acquired about the previous design is still relevant and changes made to components which depend upon the task allocation are also limited.

The approach taken is inspired by work on scenario based architecture analysis. Use of scenarios within a search algorithm is more efficient than full sensitivity analysis and works by trying to meet as many requirements specified in scenarios as well as the current requirements. This improves flexibility in the design even when actual changes differ from those estimated by the scenarios. York has also done work for situations where changes can

be precisely defined before they occur. An example of this is run-time mode changes for pre-defined modes. In this situation reducing task allocation and priority changes between modes facilitates design and implementation and improves mode change performance if few or no task migrations are necessary. Finally they have investigated how the task allocation problem can be combined with a utility model to support graceful degradation in the presence of failures.

Flexibility for Energy-Aware Computing (York)

Previous work has been performed to establish the range of timing requirements that leads to valid control systems, i.e. for which the mandatory control requirements are met, e.g. stability. Given this range some work was performed to show how this flexibility in the rates at which software is executed can be harnessed as part of the scheduling problem. Specifically the flexibility was used to enhance both schedulability and energy efficiency. As part of this work the presence of energy anomalies were identified, the effect of computational model and context switches were demonstrated, and an algorithm to find the optimum design choices produced.

Adaptation for Fault Tolerance (York)

Fault tolerance is a widely studied area of real-time systems, however a more difficult and novel problem is fault prediction. The benefit of fault prediction is that the system can adapt to the potential problems before they occur and hence avoid them. However the challenge here is how to do this in a resource efficient way. In this work the problem is addressed in a flexible and adaptable way. Instead of relying on the results of static analysis, which is recognized as being expensive, time consuming and lacking portability, in vivo analysis of the system is performed using bio-inspired algorithms, specifically from Artificial Immune Systems. The work shows that reliable and responsive fault prediction can be performed with no prior information being given to the system.

Run-time resource management (DTU)

Understanding the dynamic behavior of run-time reconfigurable systems is a very complicated task, due to the often very complicated interplay between the application, the application mapping, and the underlying hardware architecture. However, it is a key issue to determine the right reconfigurable architecture and a matching optimal on-line resource management policy. Although architecture selection, application mapping and run-time system have been studied intensively in the past, they have not been thoroughly studied and modelled in the context of run-time reconfigurable system. DTU has extended its simulation framework COSMOS to study the dynamic behavior of run-time reconfigurable systems. COSMOS is an extension of the ARTS multiprocessor simulation framework which were developed during ARTIST2.

Through a number of design space exploration experiments, they have pinpointed the critical design issues in the reconfigurable architecture study and analyze their impact on the architecture performance. Experiments with various run-time resource management polices have shown that it is possible to gain performance from such architectures and have suggested some general guidelines for obtaining efficient run-time resource management [WuHaMa08].

3.2 Individual Publications Resulting from these Achievements

The individual publications generated by ULUND are presented in the deliverables from the OS and Networks cluster.

SSSA

Yifan Wu, Enrico Bini, and Giorgio Buttazzo, "A Framework for Designing Embedded Real-Time Controllers", Proceedings of the 14th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2008), Kaohsiung, Taiwan, August 25-27, 2008.

TUKL

Rodrigo Ferreira Coelho, Gerhard Fohler, "A control theory based method for increased resource efficiency in real-time MPEG-2 video stream adaptation", Proceedings of Work-in-Progress Session, 29th IEEE Real-Time Systems Symposium 2008, December 2008.

University of York

Paul Emberson and Iain Bate, Extending A Task Allocation Algorithm For Graceful Degradation Of Real-Time Distributed Embedded Systems, To Appear in the Proceedings of the 29th IEEE Real-Time Systems Symposium (RTAS 2008), 2008.

Iain Bate, Utilising Application Flexibility in Energy Aware Computing, Proceedings of the 14th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, 2008

N. Lay, I. Bate, Improving the reliability of real-time embedded systems using innate immune techniques, Journal of Evolutionary Intelligence, 2008

Verimag

Jacques Combaz, Jean-Claude Fernandez, Joseph Sifakis and Loïc Strus. "Symbolic quality control for multimedia applications" Real-Time Journal, Volume 40, Number 1, October, 2008

ETHZ

Nikolay Stoimenov, Simon Perathoner, Lothar Thiele: Reliable Mode Changes in Real-Time Systems with Fixed Priority or EDF Scheduling. To be published DATE 2009.

University of Bologna

Michele Magno, Davide Brunelli, Piero Zappi and Luca Benini, “A Solar-powered Video Sensor Node for Energy Efficient Multimodal Surveillance”, in Proceedings of the 11th Euromicro Conference on Digital System Design (DSD 2008), Parma, Italy, 2008

University of Catania

S. Vittorio, E. Toscano, L. Lo Bello, “CWFC: A Contention Window Fuzzy Controller for QoS support on IEEE 802.11e EDCA”, In Proceedings of the 13th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA’08, Hamburg, Germany, Sep. 2008, pp. 1193 - 1196, ISBN 978-1-4244-1505-2.

KTH

M. Persson, T. Naseer Qureshi, M. Törngren. “Suitability of Dynamic Load Balancing in Resource-Constrained Embedded Systems: An Overview of Challenges and Limitations”, Workshop on Adaptive and Reconfigurable Embedded Systems (APRES'08), St. Louis, MO, USA, April 21, 2008

Feng, L., Chen DJ, and M. Törngren: “Self configuration of dependent tasks for dynamically reconfigurable automotive embedded systems”. In Proceedings of the 47th IEEE Conference on Decision and Control, Cancún, Mexico, 2008

Ingo Sander and Axel Jantsch, "Modelling Adaptive Systems in ForSyDe", Electronic Notes in Theoretical Computer Science, vol. 200, no. 2, pp. 39-54, February 2008.

Jun Zhu, Ingo Sander, and Axel Jantsch, "Performance Analysis of Reconfiguration in Adaptive Real-Time Streaming Applications", Proceedings of the 6th Workshop on Embedded Systems for Real-Time Multimedia, October 2008.

Jun Zhu, Ingo Sander, and Axel Jantsch, "Energy efficient streaming applications with guaranteed throughput on MPSoCs", Proceedings of the International Conference on Embedded Software, October 2008.

Technical University of Catalonia

Camilo Lozoya, Pau Martí, Manel Velasco and Josep M. Fuertes (2008), Control Performance Evaluation of Selected Methods of Feedback Scheduling of Real-time Control Tasks. In 17th IFAC World Congress, Seoul, Korea, July 2008.

Manel Velasco, Pau Martí and Camilo Lozoya (2008), On the Timing of Discrete Events in Event-Driven Control Systems. In 11th International Conference on Hybrid Systems: Computation and Control (HSCC08), St. Louis, MO, USA, April

TU Braunschweig

Steffen Stein and Rolf Ernst. "Distributed Performance Control in Organic Embedded Systems." In *Autonomic and Trusted Computing (LNCS)*, Volume 5060/2008, pp 331-342, June 2008.

Univ of Aveiro

F. Santos, L. Almeida, L. S. Lopes. Self-configuration of an Adaptive TDMA wireless communication protocol for teams of mobile robots. ETFA 2008, 13th IEEE Conference on Emerging Technologies and Factory Automation. Hamburg, Germany, 15-18 September 2008.

F. Santos, L. Almeida, L. S. Lopes. Adaptive wireless communication for teams of mobile robots: a position paper. 7th Int Workshop on Real-Time Networks. (satellite of ECRTS 2008), Prague, Czech Republic, 1st July 2008.

Hongbin Li, Luis Almeida, Fausto Carramate, Zhi Wang, Youxian Sun. Connectivity-Aware Motion Control among Autonomous Mobile Units. SIES 2008, 3rd IEEE Symposium on Industrial Embedded Systems. Montpellier, France, 11-13 June, 2008.

DTU

[WHM08] Kehuai Wu, Esben Rosenlund Hansen, Jan Madsen, Towards Understanding and Managing the Dynamic Behavior of Run-Time Reconfigurable Architectures, in the proceedings of the Conference on Engineering of Reconfigurable Systems and Algorithms (ERSA'08), July 2008.

ISEP-IPP

Luís Nogueira, Luís Miguel Pinho. "Dynamic QoS Adaptation of Inter-Dependent Task Sets in Cooperative Embedded Systems". In Proceedings of the 2nd ACM International Conference on Autonomic Computing and Communication Systems, ACM Press, 2008

Luís Nogueira, Luís Miguel Pinho. "Handling QoS Dependencies in Distributed Cooperative Real-Time Systems". In IFIP Distributed Embedded Systems: Design, Middleware and Resources, Springer, 2008

IMEC

The relevant publications are listed in the Software, Synthesis, Code Generation and Timing Analysis cluster, the Hardware platforms and MPSoC cluster deliverables of Year 1.

3.3 Joint Publications Resulting from these Achievements

Manel Velasco, Pau Martí and Enrico Bini, "Control-driven Tasks: Modeling and Analysis", Proceedings of the 29th IEEE Real-Time Systems Symposium (RTSS08), Barcelona, Spain, December, 2008.

Enrico Bini and Anton Cervin, "Delay-Aware Period Assignment in Control Systems", Proceedings of the 29th IEEE Real-Time Systems Symposium (RTSS08), Barcelona, Spain, December, 2008.

Clemens Moser, Lothar Thiele, Davide Brunelli and Luca Benini, "Approximate Control Design for Solar Driven Sensor Nodes", In The 11th International Conference on Hybrid Systems: Computation and Control (HSCC 08),St. Louis, USA, April 22-24, 2008.

Richard Anthony, Paul Ward, DeJiu Chen, James Hawthorne, Mariusz Pelc, Achim Rettberg, Martin Törngren (2008). A Middleware Approach to Dynamically Configurable Automotive Embedded Systems. The First Annual International Symposium on Vehicular Computing Systems. July 22-24, 2008 - Trinity College Dublin, Ireland.

D.J. Chen, R. Anthony, M. Persson, D. Scholle, V. Friesen, G. de Boer, A. Rettberg, C. Ekelin (Chen – ERTS). An Architectural Approach to Autonomics and Self-management of Automotive Embedded Electronic Systems. Embedded Real-Time Software in Toulouse, France, January 29-February 1, 2008.

Achim Rettberg, Richard Anthony, DeJiu Chen, Isabell Jahnich, Gerrit de Boer, Cecilia Ekelin, "A Dynamically Reconfigurable Automotive Control System Architecture" at IFAC World Congress, July 6-11, 2008, Seoul, Korea.

Ricardo Marau, Nuno Figueiredo, Rui Santos, Paulo Pedreiras, Luís Almeida, Thomas Nolte. Server-based real-time communications of Switched Ethernet. CRTS 2008 - 1st Workshop on Compositional Theory and Technology for Real-Time Embedded Systems (satellite of RTSS 2008), Barcelona, Spain, November 30, 2008.

Ricardo Marau, Luis Almeida, Paulo Pedreiras, Thomas Nolte. Towards Server-based Switched Ethernet for Real-Time Communications. Proceedings of Work-In-Progress Session of ECRTS 2008, 20th EUROMICRO Conference on Real-Time Systems, Prague, Czech Republic, 2-4 July 2008.

The relevant joint publications involving IMEC, UCM, TU/e & DUTH are listed in the Software, Synthesis, Code Generation and Timing Analysis cluster, the Hardware platforms and MPSoC cluster deliverables of Year 1.

3.4 Keynotes, Workshops, Tutorials

Keynote : Karl-Erik Årzén (ULUND): "Adaptivity in Embedded Systems – Why, What and How"
Workshop on Adaptive and Reconfigurable Embedded Systems (Part of the Cyber-Physical Week 2008), St Louis, April 21, 2008

Invited Talk L. Thiele (ETHZ): MPSOC Conference. Aachen, Germany, June 23-27, 2008.

Summer School: Course on Embedded Systems (ETHZ, L. Thiele), Florianopolis, Brazil, August 25-2, 2008.

Tutorial L. Thiele (ETHZ): Analysis of Distributed Embedded Systems. CASTENESS WORKSHOP ROMA, Jan. 15-18, 2008.

Invited Talk L. Thiele (ETHZ): Workshop Mapping Algorithms onto MPSOC. Germany, June 16-17. 2008.

Invited Talk L. Thiele (ETHZ): MPSOC Conference. Aachen, Germany, June 23-27, 2008.

Invited Talk Jan Madsen (DTU): "*Adaptive Embedded Systems Challenges of Run-Time Resource Management".* 8th International Forum on Application-Specific Multi-Processor SoC (MPSoC). *St. Gerlach, The Netherlands, June 23-27, 2008.*

Keynote: Jan Madsen - On Line, Real Time Darwinism - Challenges of the Future. DIAG Conference 2008, September 4-5, Skjoldenæsholm, Jystrup, Denmark. This presentation gave an overview of the evolution of adaptive embedded systems platforms, with a focus on resource management such as performance, low power, and reliability.

ArtistDesign meeting, location: Düsseldorf, Germany; date: 27th and 28th of November 2008: Within the frame of this ArtistDesign meeting which addresses the mapping of applications to MPSoCs, ETHZ presents an overview and a SW demonstration of the Distributed Operation Layer framework.

CASTNESS 2008 Workshop; location: Rome, Italy; date: 15th-18th of January 2008: The objectives of CASTNESS workshops and schools are, first, to provide training about the future of multi-processor/adaptable embedded systems (system SW, HW architectures, applications) and second, the cross-dissemination among European projects. ETHZ presented an overview and a SW demonstration of the Distributed Operation Layer framework, included in a complete MPSoC design flow, as well as detailed information about the design space exploration and mapping optimization steps within this framework.

First International Workshop on Adaptive and Reconfigurable Embedded Systems APRES 2008 (satellite of the 14th IEEE Conference on Real-Time and Embedded Technology and Applications - RTAS 2008, St. Louis, USA), 21 April 2008. Co-funded by Artist. Co-organized by Luis Almeida (Aveiro)

Workshop : Multicores: From Theory to Practice
Kaiserslautern, Germany – 2008 10 28
Objectives for the meeting: Schedulability analysis is far more complex on multicore systems than the uniprocessor case and depends on the way computational activities are allocated to the various processors. Second, interprocessor communication has a strong impact on task response times and resource access protocols, and hence must be carefully estimated. The workshop aimed at stimulating the discussion on the mentioned topics by a mix of presentations and discussions. The workshop was co-organized and co-funded with the OS and Networks cluster and the ACTORS STREP project

Organizer: Gerhard Fohler, TUKL, Enrico Bini, SSSA
Other participants: Around 20 participants internal and external to ArtistDesign
Conclusions : The meeting provided a good starting point for further joint activities by outline fundamental issues and feasible and realistic directions of research.
http://www.artist-embedded.org/artist/Topics,1498

Course on Real-Time Control Systems: Theory and Practice
Pisa, Italy – April 2-18, 2008

Objectives: The objective of the course was to introduce classical control notions applied to real-time computing systems. Topics included Discrete time systems, Exact Real-time simulation, period selection, delayed models, controllability, observability and performance of

discrete time controllers, real-time computing of control systems, timing and implementation, control of real-time systems, event-driven systems, scheduling of event driven systems.

Organizers:

- Giorgio Buttazzo - Scuola Superiore Sant'Anna, Italy
- Manel Velasco – University of Catalonia, Spain

Course on Real-Time Kernels for Microcontrollers: Theory and Practice
Pisa, Italy – June 23-25, 2008

Objectives for the course: The course was aimed at:

1. providing the fundamentals concepts of real-time computing systems, including scheduling, resource management and timing analysis;
2. introducing the OSEK/VDX standards, taking as a reference implementation the Erika Enterprise kernel;
3. showing how to apply such concepts in practice, with examples based on the Altera Nios II and the Microchip dsPIC DSC microcontrollers;
4. teaching participants how to develop simple control applications using Erika Enterprise with code generation from functional models.

Organizers:

- Giorgio Buttazzo - Scuola Superiore Sant'Anna, Italy
- Paolo Gai, Evidence Srl
- Tullio Facchinetti, University of Pavia, Italy
- Ettore Ricciardi – ISTI-CNR, Pisa

URL: http://www.artist-embedded.org/artist/Real-Time-Kernels-for.html

4. Overall Assessment and Vision

4.1 Assessment for Year 1

The integration among the partners is demonstrated by the number of joint publications, projects and events organized within the cluster. The main examples are workshops, graduate courses, and the various research consortia that have led to European projects, like FRESCOR, ACTORS, and PREDATOR.

4.2 Overall Assessment since the start of the ArtistDesign NoE

The overall assessment of the work that has been performed during the year is very positive. Several workshops and meetings have been organized by the partners. Of special importance was the kick-off meeting in Lund where the work within the activity was organized. These meetings act as the interface between the different clusters on issues related to embedded system adaptivity. The partners work on a number of challenging research issues, both individually and together, in the latter case often within the umbrella of STREP projects. The level of participation among the partners in embedded FP6 and FP7 projects is very high. It can be expected that the number of collaborations and joint publications between the partners will increase during the coming years.

The partners have also contributed to education about adaptive and feedback-based approaches. This has been performed within summer schools or special courses, this first year often co-organized with Artist2. There are also several contacts between industry and academia within the activity, e.g., collaborations involving NXP, Ericsson, Volvo, STMicroelectronics, and Evidence just to name a few.

A major challenge for this activity is to integrate the more hardware-oriented partners from, e.g., the MPSoC cluster with the more software-oriented partners from the OS and networks cluster. Currently the activity is dominated by partners from the latter cluster.

4.3 Indicators for Integration

There were no explicit indicators stated for this activity for the first year. However, the quantifiable indicators for the first year include:

- More than 8 joint publications
- More than 12 research collaborations involving more than one partner, including several European projects
- More than 9 meetings or workshops organized or co-organized by the partners.
- Three educational events (summer schools, courses etc) organized or co-organized by the partners. This includes the Graduate course on Embedded Control Systems given at KTH in May 2008 within Artist2
- The creation of a wiki (http://www2.control.lth.se/ArtistAdapt/) in order to communicate and disseminate the results of the activity.

The indicators for integration for Year 2 involve the following goals:

- At least 10 joint publications
- More than 15 research collaborations

- More than 10 meetings or workshops organized by the partners. This include the annual activity meeting that the coming year will be held at SSSA in Pisa in April 2009.
- Three educational events. This includes the Graduate course on Embedded Control System given four times in Artist2 which now will be continued within ArtistDesign. Compared to previous editions the course will include a larger part on feedback-based adaptivity than previously. The course will also involve more partners from the OS and Networking cluster than before. The course will tentatively be given in Pisa in May 2009.
- The content of the wiki will be substantially expanded.

4.4 Long-Term Vision

The use of adaptivity and feedback to provide performance and robustness in embedded systems becomes more natural, the more complex and hard to statically analyze the systems are. Since increased complexity and an ever increasing amount of software is one of the most prominent trends in embedded systems today we are convinced that adaptive techniques will be increasingly important for the future.

The long-term for this activity on the 4-year horizon is to generate a substantial advance in theory, methods and tools of relevance to adaptivity in embedded systems and to disseminate this into industry and to the scientific community at large.

5. Transversal Activity Participants

5.1 Core Partners

Transversal Activity Leader & Team Leader	
	Professor Karl-Erik Årzén Lund University URL: http://www.control.lth.se/user/karlerik/
Technical role(s) within ArtistDesign	Leader for the Transversal activity “Design for Adaptivity”. Team leader for Lund University. Participates in the OS and Networks cluster
Research interests	Embedded control, real-time systems, adaptive resource management, feedback applied to computer systems
Role in leading conferences/journals/etc in the area	Co Chair 4th Intl. Workshop on Feedback Control Implementation and Design in Computing Systems & Networks (FeBID 2009)
Notable past projects	HRTC, CHEM, RUNES, ARTIST2, ACTORS (ongoing)
Awards	The Dr Guido Carlo-Stella award in manufacturing automation from the World Batch Forum in 2006 for achievements in manufacturing automation and information structuring
Further Information	Leader for the cluster for Control for Embedded Systems in Artist2 (2005-2008)

Team Leader	
	Prof. Gerhard Fohler Technical University of Kaiserslautern (TUKL) URL: www.eit.uni-kl.de/fohler
Technical role(s) within ArtistDesign	The role of TUKL is to investigate resource management policies for controlling the quality of service in multimedia applications. The team is leading the activity on Adaptive Resource Management for Consumer Electronics and is involved in the development and analysis of algorithms for video streaming applications. A further focus is on flexible scheduling, with the aim of integrating offline and online approaches.
Research interests	Real-time scheduling, integration of offline and online scheduling, QoS management, video streaming and media processing.
Role in leading conferences/journals/etc in the area	Chairman, technical committee on real-time systems, Euromicro Member of executive board technical committees on, IEEE real-time systems, IE embedded systems Area editor real-time, Journal of System Architecture, Elsevier Program chair, IEEE Real-Time Systems Symposium, 2006 Program chair, sub track real-time systems, DATE 2005-2007 Program committee member of most real-time related conferences
Notable past projects	FRESCOR - Framework for Real-time Embedded Systems based on COntRacts, EU IST STREP WASP - Wirelessly Accessible Sensor Populations, EU IST IP BETSY - BEing on Time Saves energY continuous multimedia experience with low battery power, EU IST STREP FIRST - Flexible Integrated Real-Time System Technology, EU IST STREP“ FABRIC: Federated Applications Based on Real_time Interacting Components”, IST-2001-37167 (2002-2003) investigated QoS management methods for home networks.
Awards / Decorations	Best paper award, ECRTS 2008

Team Leader Activity Leader for "Real-Time Networks"	
	Prof. Luis Almeida University of Aveiro URL: http://www.ieeta.pt/lse
Technical role(s) within ArtistDesign	Leader of the team from the University of Aveiro.
Research interests	Real-time communication (traffic scheduling, protocols,…) Flexible architectures for distributed embedded systems
Role in leading conferences/journals/etc in the area	Usually participates in the Organizing and /or Program Committees of conferences in the fields of Real-Time Systems (e.g., RTSS, ECRTS, RTAS) and industrial communications (e.g., WFCS, ETFA, FET). Has chaired several workshops (e.g., RTN, WTR, WiP sessions). Reviewer for several related journals (e.g., IEEE TII, TIE, TC, ACM TECS, Kluwer JRTS)
Notable past projects	ARTIST (FP5 accompanying measure). CAMBADA – Cooperative Autonomous roBots with Advanced Distributed Architecture. Specification and development of a team of cooperating autonomous robots for the Robocup Middle-Size Soccer League. Particular focus has been devoted to the architecture of each robot and their communication for information sharing. http://www.ieeta.pt/atri/cambada/ DISCO, DIStributed embeddable systems for COntrol applications. The objectives of the project were to investigate techniques and to develop solutions to improve flexibility and adaptability in distributed embedded control systems in order to reduce operation and maintenance costs while maximizing the utilization of system resources. http://www.ieeta.pt/lse/DISCO_web.pdf CIDER, Communication Infrastructure for Dependable and Evolvable Real-time systems. The project pursued two objectives: to analyze the usability of Ethernet in dependable applications (static set-up) and to devise the necessary mechanisms to allow the set-up to change dynamically (dynamic set of services and hosts) while providing the required dependability. http://www.hurray.isep.ipp.pt/activities/cider/
Awards	Best Paper Award in WFCS 2004 Best Paper Award in SICICA 2000

Team Leader	
	Prof. Luca Benini, University of Bologna http://www-micrel.deis.unibo.it/%7Ebenini/
Technical role(s) within ArtistDesign	Member of the Strategic Management Board Co-leads Hardware Platforms and MPSoC Design Participates in Intercluster activity: Design for Adaptivity Participates in Intercluster activity: Design for Predictability and Performance Leader of the JPRA Activity: “Platform and MPSoC Design”
Research interests	(i) Development of power modeling and estimation framework for systems-on-chip. (ii) Development of optimal allocation and scheduling techniques for energy-efficient mapping of multi-task applications onto multi-processor systems-on-chips. (iii) Development of energy-scavenging techniques for ultra-low power sensor network platforms.
Role in leading conferences/journals/etc in the area	▪ Program chair and vice-chair of Design Automation and Test in Europe Conference. ▪ Member of the 2003 MEDEA+ EDA roadmap committee 2003. ▪ Member of the IST Embedded System Technology Platform Initiative (ARTEMIS): working group on Design Methodologies ▪ Member of the Strategic Management Board of the ARTIST2 Network of excellence on Embedded Systems ▪ Member of the Advisory group on Computing Systems of the IST Embedded Systems Unit. ▪ Member of the technical program committee and organizing committee of several technical conferences, including the Design Automation Conference, International Symposium on Low Power Design, the Symposium on Hardware-Software Codesign. He is Associate Editor of the IEEE Transactions on Computer-Aided Design of Circuits and Systems and of the ACM Journal on Emerging Technologies in Computing Systems. ▪ Fellow of the IEEE.
Notable past projects	ICT-Project **REALITY - *Reliable and variability tolerant system-on-a-chip design in more-moore technologies.*** Funded under 7th FWP (Seventh Framework Programme). ICT-2007.3.1 Next-Generation Nanoelectronics Components and Electronics Integration. Start date: 01/01/2008; Duration: 30 months; Contract Type: Collaborative project; Project Reference: 216537; Project Cost: 4.45 million euro; Project Funding: 2.9 million euro. ICT-Project **PREDATOR - *Design for predictability and efficiency.*** Funded under 7th FWP (Seventh Framework Programme). ICT-2007.3.3 Embedded Systems Design. Start date: 01/02/2008; Duration: 36 months; Contract Type: Collaborative

	project; Project Reference: 216008; Project Cost: 3.93 million euro; Project Funding: 2.8 million euro. ICT-Project **GALAXY - *interface for complex digital system integration.*** Funded under 7th FWP (Seventh Framework Programme). ICT-2007.3.3 Embedded Systems Design. Start date: 01/12/2007; Duration: 36 months; Contract Type: Collaborative project; Project Reference: 214364; Project Cost: 4.08 million euro; Project Funding: 2.9 million euro. ICT-Project **DINAMICS - *Diagnostic Nanotech and Microtech Sensors.*** Funded under 6th FWP (Sixth Framework Programme). FP6-NMP 'Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices'. Contract Type: Integrated project; Project Reference:IP 026804-2. Start date: 01/04/2007. Duration: 18 + 30 months. Project Cost:7276856 Euro. Project Funding: 4499542 Euro. http://www.dinamics-project.eu/ ICT-Project **SHARE - *Sharing open source software middleware to improve industry competitiveness in the embedded systems domain.*** Funded under 7th FWP (Seventh Framework Programme). ICT-2007.3.7 Network embedded and control systems. Start date: 01/05/2008; Duration: 24 months; Contract Type: Coordination and support actions; Project Reference: 224170; Project Cost: 1.1 million euro; Project Funding: 590000.00 euro.

Team Leader	
	Dr. Stylianos Mamagkakis IMEC vzw. http://www.imec.be
Technical role(s) within ArtistDesign	Representing IMEC Nomadic Embedded Systems (NES) division in: -Cluster: SW Synthesis, Code Generation and Timing Analysis -Cluster: Operating Systems and Networks -Cluster: Hardware Platforms and MPSoC Design -Intercluster activity: Design for Adaptivity -Intercluster activity: Design for Predictability and Performance -Intercluster activity: Integration Driven by Industrial Applications
Research interests	Stylianos Mamagkakis received his Master and Ph.D. degree in Electrical and Computer Engineering from the Democritus Uni. Thrace (Greece) in 2004 and 2007, respectively. Since 2006, he coordinates a team of PhD students within the NES division at IMEC, Leuven, Belgium. His research activities mainly belong to the field of system-level exploration, with emphasis on MPSoC run-time resource management and system integration.
Role in leading conferences/journals/etc in the area	Stylianos Mamagkakis has published more than 35 papers in International Journals and Conferences. He was investigator in 9 research projects in the embedded systems domain funded from the EC as well as national governments and industry.
Notable past projects	Project leader of MNEMEE IST project www.mnemee.org Project leader of OptiMMA IWT project www.imec.be/OptiMMA Participation in: 1 international IMEC project (M4), 3 European IST projects (AMDREL, EASY, ARTIST2), 2 Greek projects (PRENED, DIAS)
Awards	1st prize in 'Technogenesis' Competition for Business Innovation, Greece, June'06 3rd prize in 'Otenet Innovation 2006' Competition for Business Innovation, Greece, November'06
Further Information	http://www2.imec.be/imec_com/nomadic-embedded-systems.php

Team Leader	
	Prof. Eduardo Tovar Polytechnic Institute of Porto (ISEP-IPP), Porto (Portugal) URL: http://www.hurray.isep.ipp.pt/asp/show_people.asp?id=1
Technical role(s) within ArtistDesign	The role of ISEP-IPP team is to investigate distributed embedded systems, with a particular focus on communication protocols for WSN and MANETs. The team is leading the activity on Real-Time Networks and involved in flexible scheduling technologies, resource management policies and QoS-aware collaborative computing. The team has also a strong commitment in Real-Time Languages.
Research interests	Real-time systems, wireless sensor networks, multiprocessor platforms, communication networks, factory automation and system integration.
Role in leading conferences/journals/etc in the area	Executive Board Member of the Euromicro Technical Committee on Real-Time Systems. Program Chair ECRTS'05, RTN'02, WDES'06. General Chair of WFCS'00, ECRTS'03. Program committee member in several editions of ERCTS, RTSS, RTAS, RTCSA, ICDCS, SRDS, WFCS, ETFA, EMSOFT and other IEEE, ACM and Euromicro events on real-time systems, embedded systems and factory communication systems. Reviewer for Real-Time Systems, IEEE Transactions on Computers, ACM Transactions on Embedded Computing, IEEE Transactions on Industrial Informatics.
Notable past projects	"REMPLI: Real-time Energy Management via Power-lines and Internet", NNE5-2001-00825 (2003-2006) investigated advanced scheduling and protocols for power-line communication systems (PLC). "R-Fieldbus: High Performance Wireless Fieldbus in Industrial Multimedia-Related Environment", IST-1999-11316 (2001-2003), integrated advanced real-time mechanisms in hybrid wired/wireless fieldbus neworks. Mobility protocols and end-to-end deadlines.. "CABERNET: Network of Excellence in Distributed Computing Systems Architectures", IST-2000-25088 (2001-2003). "CIDER: Communication Infrastructure for Dependable Evolvable Real-time systems", POSI/1999/CHS/33139 (2001-2003), Portuguese Science Foundation project on real-time communication networks.
Further Information	Senior Member of IEEE

Team Leader	
	Prof. Björn Lisper (Mälardalen University) http://www.idt.mdh.se/personal/blr/
Technical role(s) within ArtistDesign	Activity leader for "Timing Analysis" Timing analysis, program analysis.
Research interests	Timing analysis, static program analysis, language design for embedded and real-time systems, program transformations, parallelism
Notable past projects	FP7 STREP ALL-TIMES, Integrating European Timing Analysis Technology (coordinator). http://www.all-times.org/ Several national projects, funded by Swedish Research Council, VINNOVA, KKS, SSF, Ericsson

Team Leader	
	Professor Alan Burns University of York, UK URL: www.cs.york.ac.uk/~burns
Technical role(s) within ArtistDesign	Undertakes research in real-time systems scheduling, particularly for flexible systems. Also concerned with the development of programming languages for this domain.
Research interests	Scheduling, languages, modeling and formal logics.
Role in leading conferences/journals/etc in the area	Previous Chair of the IEEE Technical Committee on Real-Time Systems. Edited special issue of ACM Transactions on Embedded Systems (on education).
Notable past projects	DIRC – Dependability Interdisciplinary Research Collaborations – A large, UK, 6-year, multisite project looking at dependability of computer-based systems. Burns was a PI and managed the work on temporal aspects of dependability. FIRST – EU funded project concerning flexible scheduling FRESCOR – EU follow on project to FIRST

Team Leader	
	Lothar Thiele (ETH Zurich)
Technical role(s) within ArtistDesign	Main areas of research: Embedded Systems and Software Artist2 activities and role: Communication Centric Systems: Formal Performance Analysis, Linking Simulation and Verification, Design Space Exploration of Embedded Systems
Research interests	Research interests include models, methods and software tools for the design of embedded systems, embedded software and bioinspired optimization techniques.
Awards / Decorations	In 1986 he received the "Dissertation Award" of the Technical University of Munich, in 1987, the "Outstanding Young Author Award" of the IEEE Circuits and Systems Society, in 1988, the Browder J. Thompson Memorial Award of the IEEE, and in 2000-2001, the "IBM Faculty Partnership Award". In 2004, he joined the German Academy of Natural Scientists Leopoldina. In 2005-2006, he was the recipient of the Honorary Blaise Pascal Chair of University Leiden, The Netherlands. Chair of ACM SIGBED.

Team Leader	
	Prof. Giorgio Buttazzo Scuola Superiore Sant'Anna (SSSA), Pisa (Italy) URL: http://feanor.sssup.it/~giorgio/
Technical role(s) within ArtistDesign	Coordinating the cluster on Operating Systems and Network and the activity entitled "Resource-Aware Operating Systems". Providing support on real-time scheduling, operating systems, resource management, overload handling, energy aware algorithms, and quality-of-service strategies.
Research interests	Real-time operating systems, dynamic scheduling algorithms, quality of service control, multimedia systems, advanced robotics

	applications, and neural networks.
Role in leading conferences/journals/etc in the area	Editor-in-Chief of the Journal of Real-Time Systems (Springer). Associate Editor of the Journal of Embedded Computing (Cambridge International Science Publishing). Executive Board Member of the Euromicro Conference on Real-Time Systems. Program Chair of RTSS'01, ECRTS'03, EMSOFT'04, HSCC'07. General Chair of RTSS'02, EMSOFT'04, ECRTS'07. Reviewer for Real-Time Systems, IEEE Transactions on Computers, ACM Transactions on Embedded Computing. Program committee member of most real-time related conferences.
Notable past projects	"FIRST: Flexible Integrated Real-time Systems Technology", IST-2001-32467 (2002-2005) investigated advanced scheduling for handling applications with various real-time requirements. "OCERA: Open Components for Embedded Real-time Applications", IST-2001-35102 (2002-2005) integrated advanced real-time mechanisms in open-source kernels. "FABRIC: Federated Applications Based on Real_time Interacting Components", IST-2001-37167 (2002-2003) investigated QoS management methods for home networks. "ARTIST: Advanced Real-Time Systems", IST-2001-34820 (2002-2005) investigated adaptive real-time systems for QoS management. "TRACS - Flexible Real-Time Architecture for Traffic Control Systems", ESPRIT III project No. 6373 (1992-1995) investigated real-time techniques for vessel control systems.
Awards	Best paper Award at the 10th Int. Conference on Real-Time and Embedded Computing Systems and Applications (RTCSA 2004), Gothenburg, Sweden, August 2004. Paper: "The Jitter Margin and Its Application in the Design of Real-Time Control Systems". Award for the best paper and presentation at the ANIPLA Workshop on Operating Systems for Industrial Control Applications, Milan, November 18, 1999. HUSPI Award given by Honeywell for the best journal publication on robotic systems, November 1987.
Further Information	Senior Member of IEEE

Team Leader in Activity: Design for Adaptivy	
	Professor Axel Jantsch KTH http://web.it.kth.se/~axel/
Technical role(s) within ArtistDesign	A. Jantsch contributes to KTH participation and to the work on formal models of computation and communication and the ForSyDe framework. Furthermore, he also contributes to Hardware Platforms and MPSOC Design with focus on run-time environments and analysis techniques.
Research interests	A. Jantsch's main research topics are models of computation, modelling and analysis of embedded systems and SoCs, networks on chip.
Role in leading conferences/journals/etc in the area <optional>	
Notable past projects	**ANDRES** (Analysis and Design of run-time Reconfigurable, heterogeneous Systems) Project) – EU FP6 (http://andres.offis.de/) **SPRINT** (Open SoC Design Platform for Reuse and Integration of IPs): EU FP6 (http://www.ecsi-association.org/sprint) **MOSART** (Mapping Optimization for Scalable multi-core ARchiTecture) – EU FP7 (http://www.mosart-project.org/)

Team Leader	
	Jan Madsen (Technical University of Denmark)
Technical role(s) within ArtistDesign	Main areas of research: Embedded Systems Design and Modeling Artist2 activities and role: System Modelling Infrastructure, Communication-Centric, Systems, Design for Low-Power
Research interests	Research interests include high-level synthesis, hardware/software codesign, System-on-Chip design methods, and system level modeling, integration and synthesis for embedded computer systems.

Role in leading conferences/journals/etc in the area	He is Program Chair for DATE07. He has been Tutorial Chair and Program Vice Chair for DATE06, Workshop Chair for CODES+ISSS'05, General Chair of CODES '01 and Program Chair of CODES '00. He is on the editorial board of the journal "IEE Proceedings – Computers and Digital Techniques"
Awards / Decorations	In 1995 he received the Jorck's Foundation Research Award for his research in hardware/software codesign

5.2 Affiliated Industrial Partners

Ericsson and NXP are affiliated industrial partners. They are, however, described in the corresponding thametic cluster deliverables.

5.3 Affiliated Academic Partners

Activity Leader for "Qos-aware components"	
	Prof. Alejandro Alonso Universidad Politécnica de Madrid. URL: http://www.dit.upm.es/aalonso
Technical role(s) within ArtistDesign	Activity Leader for "Qos-aware components" UPM leader on Adaptive resource management for CE"
Research interests	Design of real-time systems, programming languages, scheduling, distributed systems and quality of service
Role in leading conferences/journals/etc in the area	Participation in the Programme Committee of conferences such as Euromicro Real-Time Systems, International Conference on Reliable Software Technologies.
Notable past projects	MORE: Network-centric Middleware for GrOup communication and Resource Sharing across Heterogeneous Embedded Systems HIJA: High-Integrity Java Applications. The goal is to develop a new Java-based middleware platform for the creation of Architecture-Neutral, high-integrity, distributed Real-Time Systems (ANRTS) ROBOCOP and Space4U. Development of component framework for embedded devices. It includes support for QoS and resource management. TRECOM: Techniques for the development of advanced distributed real-time systems for safety and business critical systems.

Core Teamleader JPRA Activity "Design of Adaptivity"	
	Prof. Dr.-Ing. Rolf Ernst (TU Braunschweig) http://www.ida.ing.tu-bs.de/en/home/faculty_and_staff/ernst/
Technical role(s) within ArtistDesign	Core Teamleader in Platform and MpSoC Design, Platform and MpSoC Analysis, Design for Adaptivity, Integration Driven by Industrial Applications. Affiliated Teamleader in Design for Predictability and Performance
Research interests	Research interests include embedded architectures, hardware-/software co-design, design automation, real-time systems, and embedded systems engineering.
Role in leading conferences/journals/etc in the area	Rolf Ernst chaired major international events, such as the International Conference on Computer Aided Design of VLSI (ICCAD), or the Design Automation and Test in Europe (DATE) Conference and Exhibition, and was Chair of the European Design Automation Association (EDAA). He is a founding member of the ACM Special Interest Group on Embedded System Design (SIGBED), and was a member of the first board of directors. He is an elected member (Fachkollegiat) and Deputy Spokesperson of the "Computer Science" review board of the German DFG (corresponds to NSF). He is an advisor to the German Ministry of Economics and Technology for the high-tech entrepreneurship program EXIST (www.exist.org).

Team Leader	
	Prof. Lucia Lo Bello University of Catania (Italy) – Affiliated to SSSA, Pisa URL: http://www.diit.unict.it/users/llobello/
Technical role(s) within ArtistDesign	Support for the SHaRK kernel maintenance. Implementation of industrial multimedia system using SHARK. Execution time

	measurement. Stochastic analysis of soft real-time tasks in the context of priority-driven soft real-time systems. Calculation of stochastic response time profiles of tasks that are hierarchically scheduled using server based techniques. Support for real-time communication in distributed embedded systems, with particular reference to networked embedded systems used in factory communication and in automotive environments. Real-time communication over wireless networks: modeling, timing analysis, and transmission scheduling to support soft real-time traffic over 802.11, 802.15.4 and Bluetooth networks. Design issues and protocols for wireless sensor networks and networked embedded systems.
Research interests	Real-time scheduling, overload handling, real-time communication protocols, factory communication, real-time communication over wireless networks, wireless sensor networks, automotive communications.
Role in leading conferences/journals/etc in the area	Program Chair of ETFA 05, ETFA 07. WIP Chair of ETFA 06. General Chair of ECRTS 04. PC member of many editions of ECRTS, RTSS;,RTAS,ETFA, WFCS, RTN , FET, RTNS ,WTR. Reviewer for the Real-Time Systems Journal, IEEE Transactions on Industrial Informatics, IEEE Transactions on Industrial Electronics, IEEE Transactions on Computers, Computer Standard and Interfaces, Journal of System Architectures. On the Editorial Board of the International Journal of Embedded Systems.
Notable past projects	Italian National project PRIN 04 entitled “Study and development of a real-time land control and monitoring system for fire prevention”, funded by the Italian Ministry of University and Research (http://www.prin.polito.it/) European project ESPRIT 26951 "NOAH - Network Oriented Application Harmonization. Italian National COFIN 2001 inter-university project titled ‘’High-Performance Processing for Applications with High-Intensity Computational Requirements and Real-Time Constraints, funded by the Italian Ministry of University and Research (http://tsc.polito.it:7777/cofin2001/)
Further Information	Member of the International Electrotecnical Commission (IEC), Technical Committee SC65C, Working Group 11, Real-Time Industrial Ethernet (RTE), actively involved in standardization activities. Nominated expert member for the Italian Electrotechnical Committee (CEI-Comitato Elettrotecnico Italiano) in the Technical Committee SC65C “Digital Data Communications for Measurement and Control-

	Fieldbus for Use in Industrial Control Systems", Maintenance Team 9, "High availability automation networks". Member of the Technical Committee on Factory Automation of the Industrial Electronics Society (IES). Co-chair of the Subcommittee 10 "Intelligent Sensors and Sensor Networks in Industrial & Factory Automation".

Team Leader	
	Dr. Pau Martí Technical University of Catalonia, Barcelona, Spain URL: http://www.upcnet.es/~pmc16/
Technical role(s) within ArtistDesign	Real-time systems and control systems co-design
Research interests	Real-time and control systems, overload handling, jitter analysis and compensation, control theory.
Role in leading conferences/journals/etc in the area	Program committee member of major real-time and control conferences. Reviewer for the Real-Time Systems Journal.

5.4 Affiliated International Partners

Tarek Abdelzaher and Lui Sha are affiliated international partners to this activity. They are, however, listed in the corresponding thematic cluster deliverables.

6. Internal Reviewers for this Deliverable

Giorgio Buttazzo (SSSA)

Martin Törngren (KTH)