MRTC

MÄLARDALEN REAL-TIME RESEARCH CENTRE

www.mrtc.mdh.se

Annual Report 2004

Summary

Mälardalen Real-Time research Centre (MRTC) organises all research and postgraduate education at the department of Computer Science and Engineering (IDt), at Mälardalen University (MdH) in Västerås, Sweden. The research covers a wide spectrum – from pure computer science to applied electronics – but with an emphasis on computer engineering and software.

With a strong application focus on computers and computing in products and production systems (of various types), research is conducted in the disciplines of real-time and embedded systems, industrial software engineering, data communication, intelligent systems, and robotics.

This report presents the organisation, projects and achievements of MRTC in 2004, a year of consolidation of research previously established and preparations for the future, with the following high-lights:

- Three Ph.D. theses (Xavier Vera, Magnus Larsson, and Damir Isovic) were successfully defended.

- Nine Licentiate theses (Daniel Sundmark, Mikael Sollenborn, Magnus Bohlin, Markus Nilsson, Mohammed El Shobaki, Peter Nygren, Jan Carlsson, Rikard Lindell, and Goran Mustapic) were successfully defended.

- 8 new Ph.D.-students have been enrolled (2 of which are industrial PhD-students).

- 3 new senior researchers: Jakob Axelsson (adjoint professor from Volvo Car that joined our Software Engineering Lab), Sasikumar Punnekkat (Senior Lecturer, Software Engineering Lab), and Ning Xiong (Researcher, Computer Science Lab)

- 32 MSc-theses, 1 patent, and 106 publications, many presented at leading conferences world-wide.

- Mikael Nolin was appointed Docent (~Associate Professor)

- The start of the KK-foundation supported industrial graduate school SAVE-IT.

- Zealcore Embedded Solutions AB which is a spin-off company from MRTC was granted venture capital and is now developing at high pace.

- SSF granted 41 MSEK during 4 year to Factory-in-a-Box with Peter Funk as one co-applicant.

MÄLARDALENS HÖGSKOLA

MED STÖD AV STIFTELSEN FÖR KUNSKAPS- OCH KOMPETENSUTVECKLING

Preface

Mälardalen Real-Time research Centre (MRTC) was formally established January 1st 1999 as the result of a profile grant from the KK-foundation (KKS) and a focused effort on real-time related research since 1987 at the Department of Computer Science and Engineering (IDt).

2004 was the last year of the profile grant from KKS. This grant of totally 36 MSEK (and matching industrial involvement of close to 40 MSEK) has been a key factor in the rapid growth of MRTC. During its initial six years, MRTC has transformed from a few cooperating research groups to a full fledge research centre, as illustrated by the following key figures:
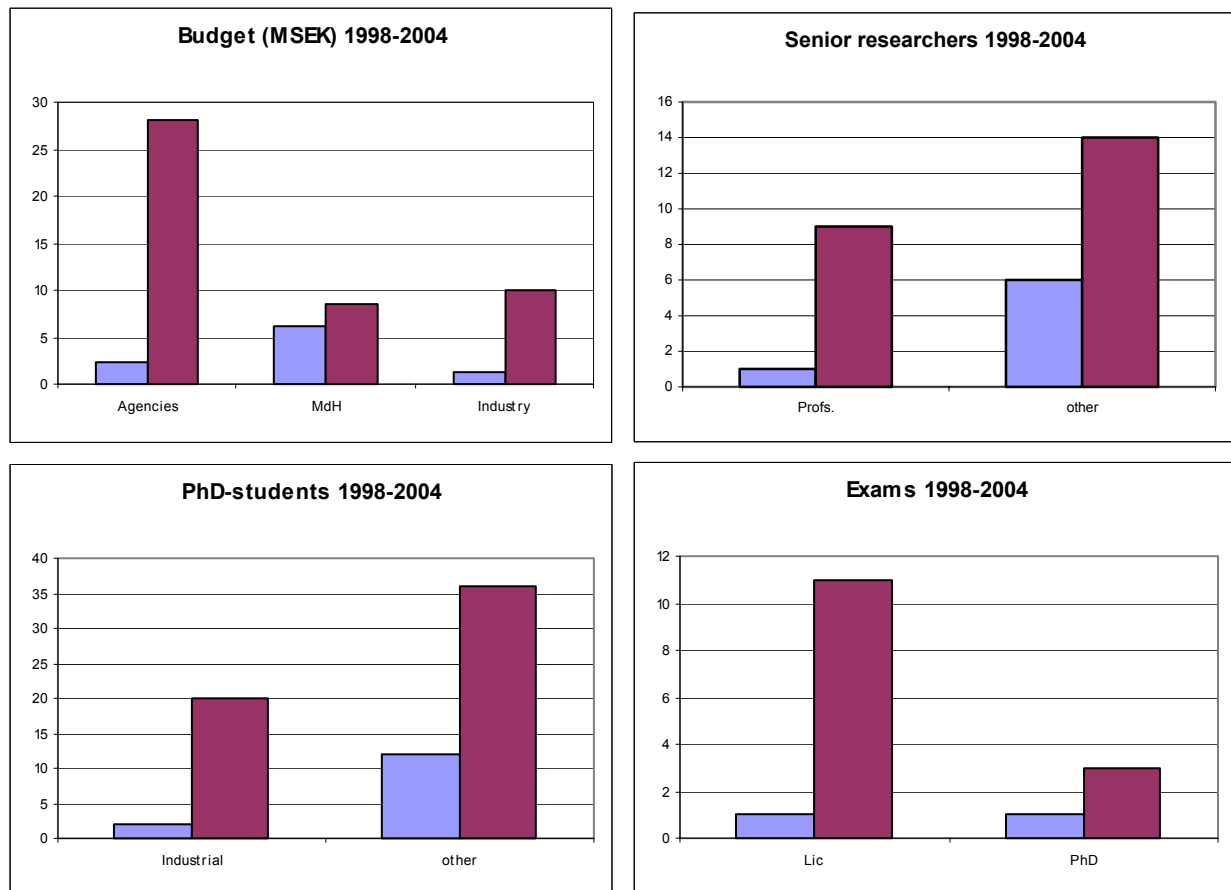
The single most important factor behind this development is our dedicated staff; including the initial core group which has maintained the cooperative atmosphere, recruited researchers that have brought new influences and competences, and the many graduate students that have made rapid progress and ensured steady production of research results.

However, 2004 was not only the end of the first phase of MRTC, it was also the beginning of the second phase of the centre, with a new organisation and focus on securing activities and funding for the coming years. In particular, 2004 was the year when:

- The dept. of Computer Science and Engineering (IDt) merged with the dept. of Electronics (IEl) and IDt/MRTC moved into the main university building in Västerås. As a result, existing research in biomedical technology and mechatronics at IEl is now a part of MRTC, and a new lab-structure was created. (We will keep the well known brand name MRTC for the extended centre, but will put less emphasis on its interpretation "Mälardalen Real-Time research Centre").
- The "Ketchup-effect" in graduate degrees from 2003 turned into a steady streem of graduate theses. In 2003, 13 graduate degrees (1 PhD + 12 Licentiates) were completed, followed by 12

degrees (3 PhD + 9 Lic) in 2004. Furthermore, the increase in PhDs and steady production will continue also in 2005.

- We submitted major applications both to the Strategic Foundation (SSF) and to Vinnova. The SSF-application proposes the establishement of Progress – a strategic research centre, while the Vinnova application proposes establishment of Vinn MRTC – a competence center for embedded software research. We have received positive feedback on the SSF-application and have qualified for the final round of evaluations. Feedback on the Vinnova application has not yet been given. Though being partly overlapping in technical scope, these initiatives are complementary in that Progress focus on long-term strategic research, while the thrust of Vinn MRTC is applied research in close industrial cooperation. The outcome of the evaluations of these proposals are extremely critical for the development of MRTC, since they have the potential of providing us with the funding for taking the next step from the platform established by the successful research during the initial six years of MRTC.

Apart from these future oriented and structural developments, an impressive number of achievements are presented in this report. With a continued strong support and interaction with our sponsors and partners we expect even more of 2005.

Hans Hansson
Director MRTC
Västerås, March 2005

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1   Mälardalen Real-Time research Centre (MRTC)

Mälardalen Real-Time research Centre (MRTC) was initiated by a grant from the Swedish KK-foundation (Stiftelsen för Kunskap och Kompetensutveckling) to further develop the real-time research at Mälardalen University (MdH) in close co-operation with Swedish industry. As a result, a group of leading industries has joined the MRTC-effort by supporting industrial postgraduate students and participating in research projects. Strong support from MdH, the Swedish Foundation for Strategic Research (SSF), and other funding agencies has enabled a fast build up of a focused research programme with a healthy balance between applied and fundamental research.

The research plan for MRTC is based on a three-pronged vision:

1. To provide state-of-the-art competence for industry.

2. To advance basic and applied research in relevant areas.

3. Education for engineers and researchers.

The advancements of these are mutually supportive, in that insights gained in one will guide the advancement in the others.

On a more technical level the guiding vision is to

*provide engineers with substantially better tools and methods for
the development of real-time computer systems and applications.*

Real-Time Systems

Real-time systems are computer systems that sense their environment and directly influence it through actions. Real-time systems must not only choose appropriate actions, but also choose them at appropriate times. Most real-time systems are embedded in products. For instance, an autonomous vehicle will have an embedded computer-based control system that has to respond in time to avoid collisions. Real-time computing is not about building "fast" systems; it is about building systems that are predictably "fast enough" to interact with their environments in well specified ways. Real-time systems are embedded in a multitude of applications and products, in areas such as multimedia, telecommunications, robotics, process control, flexible manufacturing, avionics, vehicular systems, air-traffic control, nuclear power plants, medical equipment and defence applications.

Developing real-time systems demands knowledge of and contacts with a number of research disciplines, including automatic control, computer science, computer and software engineering, and electrical engineering. The MRTC research is covering various aspects of all these areas, and – what is more important – attempts to bridge gaps between disciplines to provide solid engineering solutions to real problems.

MRTC is organised in the following interrelated and mutually supportive sub-programmes:

1. The MSc programmes in Computer Science and Real-Time Systems, which are research oriented MSc programmes integrated with the MRTC research.

2. The Graduate School, including a Ph.D.-programme and Licentiate-school .

3. Research projects, including application oriented industrial co-operation projects, as well as more traditional research projects.

4. Research infrastructure, including regular meetings and seminars, participation in national and international research networks, as well as a mobility programme (including the invitation of PostDocs, and support for international research visits).

1.1 Industrial co-operation

One of the cornerstones of MRTC is the many close industrial co-operations. Almost all our projects and activities include industrial partners.

In 2004 we had concrete co-operations with the following companies:

- ABB (Automation. Robotics, and Corporate Research)
- Arcticus Systems
- Bombardier Transportation
- CC-Systems
- Enea Embedded Technologies AB
- Ericsson (Microwave, Radio Systems, Research, and Utveckling)
- Funkai Intelligent Solutions
- Gatorhole AB
- Hectronic AB
- IAR Systems
- Level TwentyOne AB
- Mimer Information Technology AB
- Mitsubishi research labs, Boston, US
- Mecel AB
- Outocumpu, Avesta Steel Mill
- PBM StressMedicine AB
- Philips Research, The Netherlands
- Protang AB
- RealFast AB
- Rolls Royce aircraft engine design, UK
- Saab (Aerospace, Avionics)
- SenseBoard Technologies AB
- Siemens Business Systems, Germany
- SKF
- TeliaSonera
- Thomson Multimedia
- Tieto Enator
- TTTech, Austria
- Volcano Communication Technologies AB
- Volvo Car
- Volvo (Construction Equipment, Technology Development, and Truck)
- XILINX
- ZealCore Embedded Solutions AB

The co-operation with industry comes in many forms, including:

- Joint projects, with or without support from external funding agencies
- MRTC staff performing case-studies in industry
- MSc thesis projects
- Industrial graduate students
- Industrial engineers and researchers participating in MRTC projects
- Industry providing equipment and software
- Direct monetary support (donations)
- Guest lectures and field trips
- Spin-off companies

To further develop our interactions with industry we are establishing more long-term bilateral co-operations with some of our main industrial partners. It is our ambition to establish such co-operation with additional companies as well, and also to make MRTC a "hub" for co-operations between groups of companies in specific areas. An example of the latter is our plans to establish an industrial competence centre in Software Engineering, allowing companies in different sectors to exchange experiences and ideas with MRTC as catalyst.

Currently we have strategic long-term co-operations with four companies: ABB research, ABB Robotics, Volvo Construction Equipment, and Ericsson. Essential for the success of these types of co-operations, are long term goals and mutual benefits for both partners, as well as persons maintaining the portfolio. We believe that this way of working together is a model for the future. Some details about these co-operations:

ABB Research – The cooperation includes common projects, several industrial PhD students and, master students, participation in courses, common works on different applications, etc. In 2004 the following concrete results have been achieved:

- Two ABB CRC employees worked 50% as industrial PhD students. One (Magnus Larsson) obtained his PhD in March 2004.
- MRTC and ABB CRC organised or have been active in organisation of several international workshops and conferences
- ABB CRC employees have been guest lecturers at several courses at MdH
- Several international guest researchers have had talks for ABB employees
- Several master theses have been conducted jointly by ABB and MRTC
- About ten joint papers were published and presented international conferences
- MRTC, ABB CRC and Software Engineering Institute at Carnegie Mellon University have a successful cooperation

Common research policy and building a portfolio of common research activities are periodically discussed and updated. Dr. Fredrik Ekdahl from ABB CRC and Prof. Ivica Crnkovic from MRTC have the main responsibility for building and maintaining the strategic cooperation.

ABB Robotics – We have established a joint portfolio between ABB Robotics and MdH, including joint projects, industrial graduate students, courses, master thesis, trainee positions, and job rotations. In 2004, the portfolio consisted of:

- two research projects REMODEL and OpenController, supported by ABB Robotics, ABB Research, MdH, KKS and ASTEC. The projects are staffed by industrial graduate students, and permanent staff from both ABB and MdH. These projects are also closely connected to a collaboration project between ABB and Software Engineering Institute at Carnegie Mellon University. Several papers have been published.
- Joint participation in a EU Network of excellence (ARTIST-2).
- Organisation of several workshops
- Several master theses, conducted at ABB Robotics by MdH students.
- More than 20 trainee positions, provided for MdH students at ABB Robotics.
- Two persons from ABB that now temporarily are working for MdH.

The portfolio is evaluated four times per year. The portfolio is managed by Staffan Elfving, ABB Robotics and Christer Norström, MdH.

Volvo Construction Equipment – Mdh and Volvo CE have collaborated for more than ten years, including joint projects, industrial graduate students, master theses, courses, and industrial stays. The current portfolio consists of:

- Three research projects Drive , HEAVE and Grön bil. The projects are staffed by both industrial graduate students and staff from both MdH and Volvo.
- Volvo personnel are members in steering groups for several projects.
- Joint workshops
- Several master theses.
- Jobrotation where two PhD students at MdH have been working at Volvo to get an understanding in the challenges in development and maintenance of control system for heavy vehicles.

Ericsson – MdH and Ericsson have been collaborating for several years, in different areas. One example is Ericsson Microwave, where co-operations in the area of information systems, product data management and software configuration management are established. As of 2003 we have also initiated a co-operation around PLEX, as well as in Testing and Debugging.

For more details about industrial involvement in the different research projects, please consult the project presentations in the chapters presenting the laboratories.

1.2   Recent developments

This section highlights some of the new initiatives, decisions and projects during 2004 that we regard important, and that will have impact on our future development. For a more complete presentation of all our research activities, please read the lab presentations in subsequent chapters.

1.2.1   SAVE-IT

SAVE-IT is an industrial graduate school supported by the KK-foundation with 20.8 MSEK during a six-year period 2004-2009. Matching efforts will be provided by participating industries. MRTC has the main responsibility for SAVE-IT. Additional partners include Linköping University (IDA/RTSLAB), KTH (DAMEK), Uppsala University (IT/UppAal), and currently the following industries: ABB Research, ABB/Robotics, Bombardier Transportation, Ericsson, Saab, and Volvo CEC.

The scientific focus of SAVE-IT is closely related to that of the research programme SAVE (design of software for safety-critical vehicular systems). SAVE-IT will organise graduate education for 15 graduate students employed by participating companies, as well as promoting increased co-operation and exchange between all participating organisations.

In 2004 five students from MdH and one student from LiU were admitted to SAVE-IT.

Main items on the SAVE-IT agenda are:

- Network activities, including industrial visits, training in non-technical skills, such as leadership and project management, international visits, and team-building.
- Graduate courses, consisting of both methodology oriented courses and courses on specific scientific topics.
- Research projects performed by the graduate students. These will be conducted in close co-operation with participating industries, and in association with SAVE.

1.2.2   Evalunet II

During 2004, the KKS sponsored project EvaluNet II started. This is an enlargement and continuation of the ongoing EvaluNet project, and industry partners are Ericsson Research and Gatorhole AB. The research questions addressed are an extension to those of the EvaluNet project, the focus of EvaluNet II is on the development of network bandwidth measurement tools for use by network operators as well as end consumers. EvaluNet II will leverage on the results from the VINNOVA funded EvaluNet project, especially the algorithms for bandwidth measurement and prediction developed there.

1.2.3   PLEX

Since 1998, collaboration between Ericsson and MRTC, around methods and tools for analysis of PLEX programs, has taken place. This has been a low-intensity collaboration driven mainly through a number of M.Sc. projects. Now, the collaboration will rise to the level of a full-fledged research project, with the goal to develop methods and tools for correct parallelization of legacy PLEX software. Rewriting this software by hand is out of question due to the enormous cost this would incur. A working hypothesis is that it will be possible to adapt existing methods for parallelization of imperative programs: however, a key challenge will be to handle the unusual, pseudo-parallel execution model of the PLEX language and its underlying run-time system.

The decision to run the project was taken in late 2003. A Ph.D. student was recruited in early 2004 and the project is now running according to plan. During 2004 one result from the project was the seminar day on Soft Real-Time. The project is expected to run for at least two years. It will be co-funded by Ericsson and ASTEC.

1.2.4 Robotdalen (The Robot Valley Initiative)

Robotdalen is an initiative taken by Mälardalen University and Örebro University, together with regional companies and public actors, to create an innovation system with focus on robotics. The vision of Robotdalen is to establish Mälardalen as the world's leading region for research and industry in the following three application areas for robots: industrial robots, field robots and robots for health care.

The focus is on creating an effective system pushing innovations the whole way from ideas to successful products. Within the region of Mälardalen, the functional region of Robotdalen (Västerås-Örebro-Eskilstuna) already today hosts some of the world's largest and most successful companies focused on robots, automation, and contract vehicles.

The universities in the region have a unique educational and research competence within the central disciplines for robots, including real-time systems, embedded systems, control systems and sensors. The intention with Robotdalen is to increase the large amount of good ideas by creating new networks. For instance, the many good ideas emerging within larger companies, but which do not fit their business plan, should be taken care of by smaller companies that can develop them. Thanks to fast handling of "evaluation money" and useful contacts with other networks for financing and access to various expertises, Robotdalen will substantially facilitate the establishment of new companies.

Robotdalen is owned jointly by companies (currently 29 companies have joined the initiative), universities and enterprises (6) and public actors (9). These partners have committed to yearly finance 10 of 20 millions SEK which is the budgeted costs for the innovation system Robotdalen. The remaining funding is coming from Vinnova.

During 2004 a new process leader, Erik Lundquist, was recruited to Robotdalen.

One of the major projects within Robotdalen, is the RTT (in Swedish Robot Till Tusen), and the aim with the project is to find application areas for industrial robots in SME's. The main target for industrial robots has so far been the automotive industry, and this market is quite homogenous, but stands only for 12% of the possible market for industrial robots.

1.2.5 ARTIST2

During 2004 members from MRTC have joined the Network of Excellence - ARTIST2. The strategic objective of the ARTIST2 Network of Excellence is to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. We gather together the best European teams from the composing disciplines, and will work to forge a scientific community. Integration will be achieved around a Joint Programme of Activities, aiming to create critical mass from the selected European teams.

The ARTIST2 Network of Excellence on Embedded Systems Design will implement an international and interdisciplinary fusion of effort to create a unique European virtual centre of excellence on Embedded Systems Design. This interdisciplinary effort in research is mandatory to establish Embedded Systems Design as a discipline, combining competencies from electrical engineering, computer science, applied mathematics, and control theory. The ambition is to compete on the same level as equivalent centres in the USA (Berkeley, Stanford, MIT, Carnegie Mellon), for both the production and transfer of knowledge and competencies, and for the impact on industrial innovation.

1.2.6 Betsy

In September 2004 the Betsy-project was initiated. Betsy is a project within the EU 6th frame-work, IST programme, coordinated by Philips Research Lab, The Netherlands.

The aim of the BETSY project is to have multimedia streams on wireless hand-held devices seamlessly adapted to fluctuating network conditions and available terminal resources while reducing the energy consumption of the stream processing. This way the user can enjoy true multimedia experiences with freedom of movement in a networked home or at any hot-spot. To achieve this, we need to be able to make trade-offs between the use and consumption of network and terminal resources, such as bandwidth

use, CPU consumption, memory needed and power consumption by the terminal, while guaranteeing end-to-end timeliness - required for streaming data. The results of the BETSY project will make this possible.

1.2.7 teknIQ

teknIQ is a national program with 60 MSEK funding from the KK-foundation for a 6 year period from 1999. The program aims at increasing competence in embedded systems technologies in Swedish SMEs, with focus on developing and renewing products, increase profitability and long term survival rate. The program is jointly coordinated by MdH and the research institute ACREO.

Anders Martinsen at IDE is responsible for one of five regions (Mid-Sweden), as well as for the teknIQ training program. During 2004 researchers and students at MdH/MRTC have been increasingly involved in teknIQ, including:

- Several student projects, for example Distributed systems in trucks, Bluetooth for steering and measuring an electrical engine and Material test with the measuring environment program Lab View.
- Organisation of seminars where new innovative possibilities are presented and discussed. Examples of seminars in 2004 include Embedded Internet Systems and Computer Security, Bluetooth in industrial environment, Safety and security in products with embedded systems, Distributed systems and Fleet Management in Volvo and Scania trucks . The seminars were successfully completed with totally more than 250 participants.

Course offerings and development, including courses on

- Mechatronics
- Electronic design
- Communication with CAN and ProfiBus
- Embedded systems
- Electrical machines

The total number of SMEs was about 50 for these courses in 2004

A very successful activity in 2004 was the national Embedded award with two classes, one student class and one SME class. The winner in the SME class was Svenska Magnetfabriken from Hallstahammar, with a new product development in wireless steering of magnetic power. The design of the product was made by four of our students at the Product Development program in Eskilstuna and the company is a good example of a member at teknIQ education program. The prize was delivered at Tekniska Mässan in Stockholm, October 2004.

More information is available at www.tekniq.nu

1.2.8 minST

minST is a national program with 15 MSEK funding from the KK-foundation for a 2 year period from October 2004. The program mainly aims at increasing competence in micro system technologies (MEMS) in Swedish SMEs, with focus on developing and renewing products, increase profitability and long term survival rate. The program is jointly coordinated by MdH in collaboration with the research institutes ACREO and IMEGO. The activity and the way of working built on experience from the sister-program teknIQ.

Micro system technologies have a large potential in future products and Sweden has a good competence in this field. Components based on micro technology is being commercial on the market but many SMEs is not aware of this new technology.

Anders Martinsen at IDE is responsible for one of three regions (Mid-Sweden), as well as the minST training program.

More information is available at www.minst.nu

1.2.9 Intelligent integrated sensor systems for diagnosis, treatment and healthcare

In December the KK-foundation granted 3,9 MSEK to Ylva Bäcklund and Peter Funk for this new project that will be carried out in coperation with Hök instrument AB, Cardiology at the Central Hospital in Västerås, and PBM stressmedicine AB.

In this project relevant methods and technologies for diagnosis and therapy for patients with stress-related syndromes will be in focus.

1.2.10 Industrial PhD students in cooperation with SMEs

In December the KK-foundation decided to fund two new industrial students at two different SMEs, Ardendo and ElektroMekanik AB.

In the first project focus will be on Flexible Real-Time in multimedia with industrial PhD student Pengpeng Phoebe Ni. The second project has its focus on development and production of electronics with industrial PhD student Christer Gerdtman. Both students are to admitted in 2005.

1.2.11 Major applications to SSF and Vinnova

During 2004 much effort has been given to writing major applications for future research funding. One to the Swedish Foundation for Strategic Research, applying for a Strategic Research Centre – PRGOGRESS, and one to Vinnova, applying for a Competence Centre – VINN MRTC.

In the case of PROGRESS, the Foundation has decided to invite us to submit a full proposal. In the VINN MRTC case the decision is still pending.

Progress:

The motivation for the Progress-proposal is that the flexibility provided by the programmability of Embedded Computer Systems (ECS) permits dramatic product improvements, new functionality, and integration into larger systems that were not previously imaginable. Also, software aspects are central to enable product functionality, but also the source of a number of quality problems and are a major part of the development cost. This is further accentuated by the increasing complexity and integration of products.

The purpose of Progress is to strengthen Swedish competence in ECS software and systems. Focusing on predictability of software for ECS and predictability in development of ECS, Progress' research will aim to provide an adaptable standardised development process with easy-to-use development tools enabling efficient and predictable development of ECS. These are to include theories, methods, and tools for (i) predictable ECS built from software components, considering the life-cycle processes, as well as technology and methods, (ii) interfacing components with the underlying platform, interconnecting multiple platforms, and synthesising platforms from application requirements, and (iii) modelling and analysis through all stages of the component-based design chain. Since the increasing complexity of many industrial ECS may affect the relevance of research, progress will in interaction with industry ensure that considered research problems and results are valid in industrial settings.

Progress will provide large and small Swedish companies with leading edge expertise and methods for developing ECS in products and will enable Sweden to strengthen its front rank position in research related to ECS and other complex industrial systems.

Progress is coordinated by Hans Hansson, and may receive up to 12 MSEK/yr from SSF during a five year period.

Vinn-MRTC:

The challenge of the Vinn-MRTC competence centre is to provide processes and technology for development of next generation of industrial systems with 100 times more functionality and better quality and that will require 10 times less development time.

The centre will specifically focus on predictability in engineering of embedded computer systems with respect to development time and cost, and the overall system behaviour throughout the life-cycle of a system, including evolution of already existing industrial computer based systems. The main approach will be component-based development which focuses on building systems from existing components.

The research will include theories, methods, and tools for (i) building predictable embedded systems from software components, (ii) system modelling and analysis through all stages of the component-based design chain, and (iii) system life-cycle processes which comprise innovative aspects of systems evolution and their interactions with the environment.

Vinn-MRTC is coordinated by Ivica Crnkovic, and may receive up to 7 MSEK/yr from Vinnova during a ten year period.

1.2.12 MBA/T

During 2004 the development and start-up of a new a Executive Master in Technology Management programme was initiated. This process is carried through in close cooperation with both the KK-foundation and several industrial partners in telecom, automation, transportation and power technology segments. The goal is to have the first group of students entering the Executive programme in September 2006.

1.2.13 Factory-in-a-box

Successful application to the Swedish Foundation for Strategic Research, Proviking with "Factory in a Box" granted 41 MSEK during 4 year (application together with a Chalmers University of Technology, Linköping University and Jönköping University). Mats Jackson at Mälardalen University is main applicant and main project leader.

1.3   *Organisation*

MRTC has a scalable matrix-organisation with research laboratories as vertical entities, as shown below

| Steering Committee | Director
Prof. Hans Hansson
Assistant Director
Prof. Christer Norström
Research co-ordinator
Ylva Boivie | Advisory board |

Research laboratories

| **RTS Design Lab**
Prof H. Hansson | **Software Engineering Lab**
Prof I. Crnkovic | **Computer Science Lab**
Prof B. Lisper | **Computer Architecture Lab**
Prof. L Asplund
Moahmmed El Shobaki |

Research Projects

Postgraduate School

Director of postgraduate studies: Prof. Björn Lisper

Industrial Graduate School

Director: Prof. Ivica Crnkovic

MSc programmes in CS and RTS

Directors: Dr. Peter Funk/Dr. Jan Gustafsson and Prof. Gerhard Fohler

Undergraduate education

Directors: Åsa Lundkvist and Mohammed El Shobaki

The research labs represent competence areas in which basic research, as well as postgraduate and undergraduate education is conducted. The laboratories are responsible for performing research and providing resources in terms of teachers and supervisors for the following horizontal entities:

- **Research projects**, which are performed within the labs, between labs and/or with external partners. Each research project has a project leader responsible for the project budget and progress.
- **Postgraduate school**, including Ph.D. and Licentiate programmes. The postgraduate school is responsible for the postgraduate courses not included in the MSc program, as well as admittance and progress of postgraduate students. The actual project work and supervision is performed within the research labs and projects.
- **The industrial graduate school** of which SAVE-IT ios an important part is a separate programme within the postgraduate school, with annual admission of a group of industrial graduate students.
- **Master programmes** in computer science and real-time systems are specific MSc programmes performed in close cooperation with the research labs. The main tasks of this entity are, just as for the licentiate school, to plan and market the program, admittance, assignment of supervisors, and monitoring of progress.
- **Undergraduate education** is administrated by the directors of undergraduate studies, who assign courses to the different labs. The assignment of teaching staff to courses is decided within the labs. Course and curricula development is performed on initiative both from the research labs and the directors of undergraduate studies.

From 2005 the organization will be different, partly due to the merge with the Department of Electronics. MRTC will continue to represent all research activities at the Department of Computer Science and Electronics, but more focus will be given to the different research groups, as they are described below. From 2005 there will be 13 research groups, with typically two senior researchers and a group of approximately 6-10 PhD students. MRTC will have its steering committee and advisory board, as before, but also a management group consisting of Hans Hansson, Ylva Boivie, Christer Norström, Jan Gustafsson (director of graduate studies), Björn Lisper, Lars Asplund, Maria Lindén and Ivica Crnkovic.

1.4 Research groups and scientific achievements

Within the laboratories, the actual research is performed by research groups that have extensive internal and external co-operation. The following is a list and brief presentation of the current research groups at MRTC, including leadership, senior researchers, and sources of funding. Also, for each group some of the main scientific achievements in 2004 are listed. Details about projects, activities and achievements are provided in the following lab-specific chapters. Here the focus is on providing representative illustrations of the scientific progress in the different research groups.

Software-Enginering laboratory (SEL)

a) **Industrial Software Engineering group** – headed by Prof. Ivica Crnkovic; Senior Lecturer Sasikumar Punnekkatt, 8 graduate students; four of them industrial PhD students; focusing on Software Engineering for industrial systems (e.g. for automation systems); in 2004 one PhD completed. Funding from ABB, SSF, EU-IST, KKS, and MdH.

Scientific achievements 2004:

- A method for developing component technologies that provide mechanisms for predicting quality attributes of software systems. The method can be used to build prediction-enabled component technologies and validate the predictability theory. The method is demonstrated by experiments considering two different attributes: latency and consistency. The work is done in cooperation with SEI/CMU and ABB Corporate Research.
- Development of component model for embedded systems. The work is done within SAVE project together with other research groups.

- An analysis of different types of composability of quality attributes. The work explains what knowledge of the system environment is required for reasoning of quality attributes composition.
- Analysis and several case studies about merging existing software in new applications.
- An analysis of Product Data Management (PDM) and Software Configuration Management (SCM) tools, comparing and analyzing key functions of tools from both disciplines, as well as the processes in which they are used. Case studies from several large international companies are used to demonstrate the state-of-practice use of PDM and SCM.
- Analysis of integration processes and the improvements factors: Component-based software engineering and process standards such as CMMI.

b) **Embedded Systems Software Engineering group** – headed by Prof. Christer Norström; Prof. Jakob Axelsson, Senior Lecturer Dr. Kristian Sandström; Researcher Dr. Anders Wall; 6 graduate students; 2 licentiates 2004; focusing on Embedded Systems Software Engineering (e.g. for automotive and industrial robotics systems); funding from SSF, ABB, Volvo, KKS, and MdH.

Scientific achievements 2004:

- Case-studies about software architecture were completed, that show which factors have significant impact on software architecture design for complex embedded systems. The difference between "pure" software systems and software for embedded systems, such as their multidisciplinary nature, parallel development of hardware and software is emphasized.
- A book chapter for "Architecting Dependable Systems II" was completed. This contribution is based on a participative case study - a real world industrial project at ABB Robotics. It shows how system dependability is addressed when system openness increases.
- A set of tools have been developed in collaboration with ABB Robotics, related to modelling and analysis of the temporal behaviour of complex real-time systems. These tools include an implementation of the probabilistic property language (PPL) proposed in earlier work. ABB Robotics has recently started using these tools for monitoring, debugging and regression testing of performance properties.
- A model validation method for temporal behaviour models has been proposed. The developed tools supports this method by allowing the model to be compared with the real system with respect to properties formulated in a probabilistic property language (PPL).
- A concurrency control algorithm that can manage multiple parallel database transactions has been implemented and formally verified.
- The impact business requirements and business context has on architectural solution in the vehichle domain has been investigated. Applications that at first glance look very similar lead to very different architectural solutions.

Real-Time Systems Design laboratory

c) **Predictably Flexible Real-Time Systems group** – headed by Prof. Gerhard Fohler; 3 graduate students, 1 PhD in 2004, 2 PhDs planned for 2005; focusing on static and dynamic real-time scheduling, combining flexibility and predictability and application in media processing; funding from EU, SSF, and MdH.

Scientific achievements 2004:

- Scheduling methods to combine scheduling schemes which have been considered exclusive, i.e., earliest deadline first, fixed priority, and offline scheduling. The new algorithms are based on servers to enable coexististence of the diverse scheduling schemes.
- The application of combined scheduling schemes for media processing.
- Quality-of-Service architecture for system state information in home entertainment networks. The architecture provides for a decentralized interface between devices and resource management.
- Proposed real-time methods for resource reservation of MPEG-2 video stream processing and introduce flexible scheduling mechanisms for video decoding. First we identified realistic timing constraints demanded by high quality MPEG-2 software video decoding. Based on these, we

presented a MPEG-2 video frame selection algorithm with focus on high video quality perceived by the users, which fully utilize limited resources.

- A method to reduce the number of preemptions in fixed priority scheduled systems based on transformation techniques.

d) **Communication Performance Predictability and Analysis group** – headed by Prof. Mats Björkman; Researcher Dr. Bob Melander, Dr. Svante Ekelin; 5graduate students; 3 licentiates planned for 2005; focusing on communication for small embedded devices, and traffic measurement and analysis; funding from VR, Vinnova, KKS, CUGS, and MdH.

Scientific achievements 2004:

- Development of algorithms for the hierarchical scheduling of communication in layered sensor networks.
- Continued work on the characterization of network flow sizes and their impact on network performance. This is of importance for routing decisions in interior routing protocols.
- A light-weight measurement and analysis algorithm for active bandwidth measurements has been developed and implemented as an available tool.
- Initial measurements in wireless networks, where characteristics are fundamentally different from wired networks.

e) **Monitoring and Testing group** – headed by Dr. Henrik Thane; 5 graduate students; 1 licentiates in 2004; focusing on monitoring, testing, and debugging of real-time systems; funding from SSF, KKS, and MdH.

Scientific achievements 2004:

- Initiated a new line of work on automated construction of models based on inputs gathered online during the execution of a system. Called "model synthesis", the intention is to facilitate impact analysis, that is, to analyze the effect of planned modifications to an existing system. The area is related to other work in the area of reverse engineering. So far, this work has resulted in one published (CSMR05) and one submitted paper during 2005.
- During 2004 work have been done how to apply replay technology to regression testing of real-time systems. This includes a categorization of the problems in the domain of regression testing for multi-tasking real-time systems, and replay of systems with non complete recordings.
- Work on monitoring of software components, and use of monitored software components, as a general approach for engineering of embedded computer systems has been initialized. In our approach, a component's execution is continuously monitored and experience regarding component behaviour is accumulated. As more and more experience is collected the confidence in the component grows; with the goal to eventually allow certification of the component. Continuous monitoring is also the base for contract checking, and provides means for post-mortem crash analysis; an important prerequisite for many companies to start use 3rd party component in their dependable systems.
- The Deterministic Replay method for debugging real-time systems has been elaborated on and resulted in a Licenciate thesis.

f) **Real-Time Systems Design group** – headed by Prof. Hans Hansson; Researcher Dr. Mikael Nolin, 4 graduate students; focusing on design methods, architectures and communication for real-time systems; funding from SSF, Vinnova, KKS, EU, and MdH.

Scientific achievements 2004:

- Development of the SaveCCM component model and its associated component technology SAVEComp. This component model and technology allow control-flow (pipes and filters) type of models of (automotive) control software to be specified, analysed, and semi-automatically translated to executable code. First versions were developed, and preliminary experiments performed, in 2004.
- Our previous approaches to improve the schedulability tests of tasks with offset have been merged. Instead of a set of different incompatible techniques we have now presented a unified

solution where tight (near-optimal) response-times can be calculated several orders of a magnitude faster than with previous methods.

- The previous work on server-based scheduling for embedded communication has been extended with hierachical scheduling, combining native CAN, server-based CAN, and different queueing disciplines to allow a predictable mix of communications with different quality-of-service requirements.
- Needs and requirements were investigated for component based software engineering within the Swedish vehicular industry. One conclusion from this study is that no technology today meets all requirements. On the positive side, we found that each requirement was supported by one or more technologies. Hence, it should be possible to derive a technology suitable for vehicular software. Our investigation also showed that there are certain areas, such as analysis, testing and debugging, that are particularly important but that are not handled well by existing technologies. In response to these shortcomings we have proposed a concept of run-time monitoring to support, e.g., analysis, testing and debugging.

Computer Architecture laboratory

g) **Safety-Critical Systems group** - headed by Prof. Lars Asplund; 2 graduate students; focusing on hardware architectures for safety-critical systems and robotics sensory systems; funding from MdH.

Scientific achievements 2004:

- A tool for translating VHDL into Automata
- A tool for translating the Ada-95 Ravenscar profile into automata. The output generation is shared with the VHDL translation tool and UPPAAL automata are generated. Intermediate code which shows the control structure of the source code can also be generated.
- Development of a formally modeled and verified Multi-Pro Kernel. The Kernel that has been modeled and verified supports dynamic priorities, preemption, delays, interrupts, multiple hetereogeneous CPU's, and Protected Objects.
- SafetyChip in VHDL. The SafetyChip is a hardware unit with built in timers that monitor all clocks given in the formalism used to describe the application. The SafetyChip monitors that the transitions of the RTK conform to the schema derived from an automata model. At each transition timers are checked against defined timing limits. In the case of timer overflow or underflow an error flag is raised with a severity level that is defined by the user. Interrupts are generated when deviations from the schema are detected.

h) **Scalable Architecture for Real-time Application (SARA) group** – headed by Prof. Lennart Lindh; 7 graduate students; 2 licentiate in 2004; focusing on scalable multiprocessor systems, system-on-chip, and moving software functions into hardware; funding from KKS and MdH.

Scientific achievements 2004:

- New concept and implementation of a communication protocol between HW/SW tasks with client/server concept.
- New concept and implementation of a monitoring system for HW/SW tasks and multiprocessor system (patent).

Computer Science laboratory

i) **The Programming Languages group** – headed by Prof. Björn Lisper; Senior Lecturer Dr. Jan Gustafsson and Researcher Dr. Andreas Ermedahl; 9 graduate students (three external); 1 PhD and 2 licentiates in 2004; focussing on worst-case execution time analysis, as well as design and analysis of languages for real-time and embedded systems; funding from Vinnova, VR, KKS, CUGS, and MdH.

Scientific achievements 2004:

- A number of practical experiments and case studies where WCET analysis was applied to industrial real-time production code.

- Further development of methods for automatic flow analysis in WCET analysis tools
- A method to analyse programs w.r.t. data-independent execution, which can be used to optimize programs that have been designed to have constant WCET
- An improved event algebra for specifying composite events, which can be used to trigger actions in a high-level programming paradigm for event-driven systems.
- A new, more general algorithm for handling deformable objects in computer graphics.
- A new method to handle so-called cardinality constraints in constraint programming
- A formal semantics for sequential PLEX programs

j) **The Intelligent Systems group** – headed by Docent Peter Funk; two senior researchers, 5 (+3 associated) graduate students; 2 licentiate (+3 by associated students) in 2004; 9 MSc students, all focusing on applications of artificial intelligence methods and techniques in industrial and medical domains; funding from SSF and KKS.

Scientific achievements 2004:

- Methods, techniques and a research prototype that in interaction with clinician learns to automatically classify time series from sensor readings from patients. Tests by experts for decision support are ongoing.
- New case-based classification method using wavelets that is able to classify time series of data from sensors (sound, current etc.) and make reliable fault diagnosis based on experience. Ongoing implementation of research results into a product at ABB.
- An intelligent help desk that uses a range of AI methods and techniques to help engineers, or provide customer support. Research results are turned into a product in a spin off company.
- An AI based floating storage enabling Robots to maintain their own buffer storage on free floor space. This releases the robot from requiring input pallets and enables production of a variety of products without delay. Part of research result used in production at ABB Automation (a robot cell with a floating storage).

1.5 Management

The management, evaluation and monitoring of progress of MRTC is handled by

The MRTC Steering Committee, which consists of leading representatives from the labs and research groups. Main tasks include to

- propose distribution of funds to labs and projects.
- be responsible for the long-term strategic planning of MRTC.

The MRTC Director, who chairs the Steering Committee and is responsible for general grants to MRTC, such as the support from the KK-foundation and support from MdH. Main tasks include to co-ordinate applications, prepare and co-ordinate progress reports and evaluations. The research laboratories handle the management and planning of actual activities (projects, courses, etc.).

The MRTC Research Coordinator, who is responsible for building and maintaining an infra-structure in order to support both handling and management of projects and funding. Main tasks are to co-ordinate applications, agreements, and project progress reports, act as contact point for funding agencies, handling research information, as well as organizing research seminars and work-shops.

The Advisory board, which annually reviews the progress and plans of MRTC from both an industrial and scientific perspective. The board should also suggest corrective actions. Current members of the advisory board are:

- Prof. Alan Burns, Univ. of York, England
- Bernt Ericson, Former Vice President Research and Innovations Ericsson
- Vice President Christer Ramebäck, Process Automation Division, ABB Automation Products AB
- Prof. Hans Skoog, ABB Corporate Research
- Prof. Jack Stankovic, Univ. of Virginia, USA

- Prof. Neeraj Suri, TU Darmstadt
- Prof. Jan Torin, Chalmers

The Lab coordinators (the lab-leaders), are responsible for managing and developing the labs. This includes co-ordination and planning of activities, as well as administration of the labs (e.g., handling the budget and representing the lab externally).

The research group leaders are responsible for the research projects carried out in their groups.

1.6 Funding

MRTC was established as the result of a grant of 36 MSEK for the period 1999-2004 from the KK-foundation. This grant is intended for the establishment of a strong research group in real-time systems with active industrial co-operation. The latter is ensured by requiring direct 1-to-1 industrial matching of the KK-foundation grant, thus yielding a total research effort of 72 MSEK for the six-year period. This is a very favourable construction for MRTC, since the effect has been both that the already very close industrial links have been strengthened and formalized into projects, and that new co-operations have been established. Funding provided by industry is mainly in the form of industrial postgraduate students and industrial engineers participating in projects.

Though being one of the cornerstones of the MRTC funding, the KK-foundation grant is only one of several sources of funding for MRTC. The largest and most important source is the support from Mälardalen University (MdH), originating from the Swedish government. This funding allows us to conduct the basic research needed both for the more applied research funded by the KK-foundation and Industry, and for maintaining high quality in our undergraduate and postgraduate education.

In addition to the above, MRTC is also funded by more traditional competitive sources of funding, including grants from

- The Swedish Foundation for Strategic Research (SSF), via the national research programme in real-time systems ARTES and also via the programmes SAVE, FLEXCON, and BUTLER.
- The Swedish Agency for Innovation Systems (Vinnova), via its competence centre Advanced Software Technology (ASTEC), Robotdalen, EvaluNet, and via support for our involvement in the EUREKA EAST/EEA project,
- The Swedish Research Council (VR),
- The European Union, via Fifth and Sixth Framework projects and networks, and
- The KK-foundation in terms of several other specific projects, as well as the Industrial Graduate School SAVE-IT.

All research is performed in projects with specific goals with respect to achievements, publications, collaborations, and prototype tools. Each project includes both senior researchers and postgraduate students. A project typically has elements of both basic and applied research. The project leader is responsible for funding the project, either via the general MRTC grants or via direct external project grants.

As a quality measure, MRTC has an ambition that the majority of project funding should be external and competitive. In 2004, more than 80% of the funding was external, the majority from SSF, the KK-foundation (KKS), Industry (both via donations and direct involvement in projects), Vinnova, the Swedish Research Council (VR) and the European Union (EU). The diagram below summarises the MRTC funding in 2004 (for each source, name, amount and percentage are indicated). It should be noted that the majority of the included Industry funding is in terms of participation in research projects and does not represent direct monetary funding of MRTC.
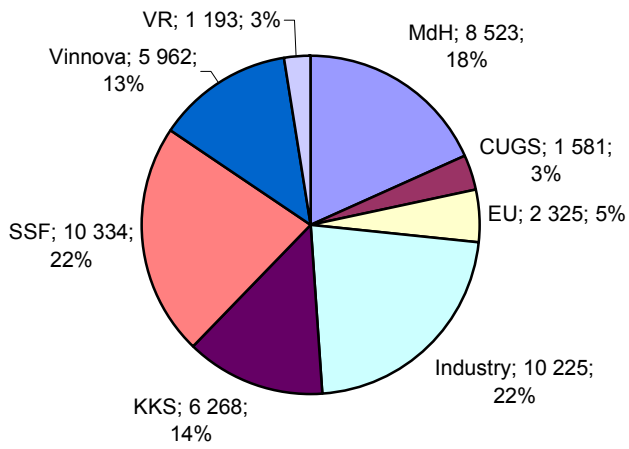
MRTC funding 2004 (total amount 38 MSEk

The following chart, showing the funding levels in MSEK for the years 1998-2004 gives an illustration of the rapid development of MRTC and of the fact that MRTC now has reached a point of steady-state.
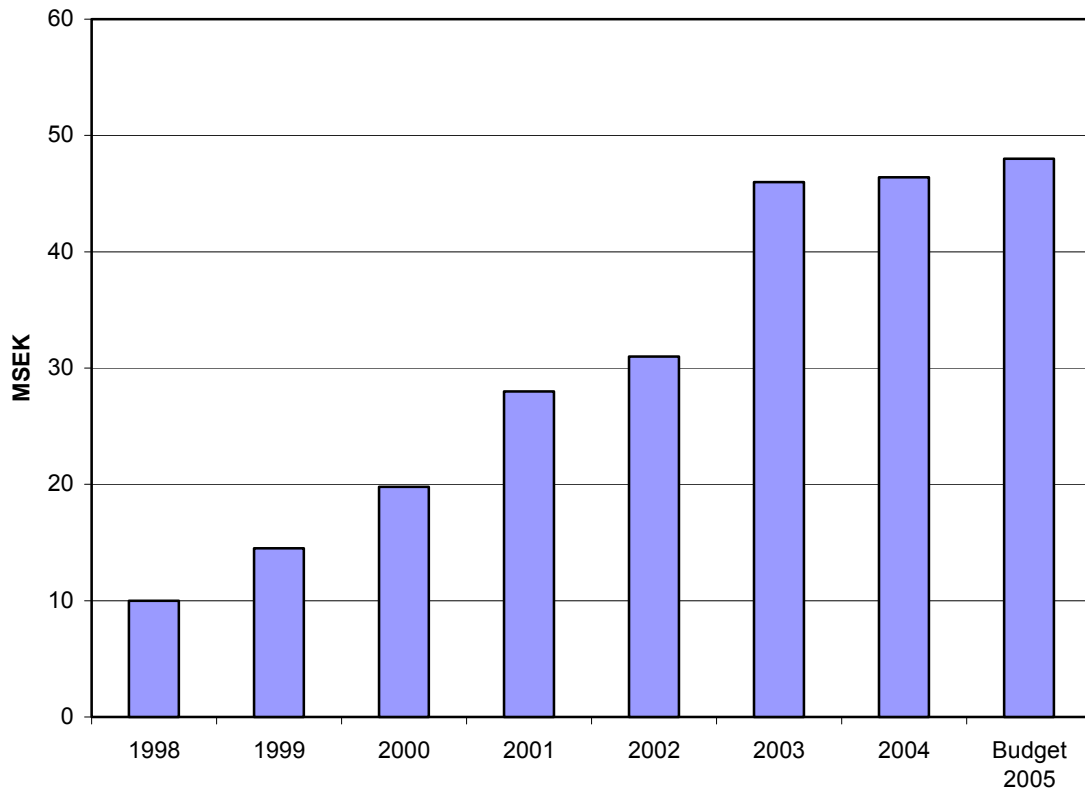
1.6 Postgraduate Education

An important and integrated part of the research at MRTC is the postgraduate education, and the perhaps most important "product" of MRTC is highly qualified Ph.D.'s and Licentiates who can strengthen the scientific competence in Swedish industry as well as in academia. We now have almost 55 postgraduate students: "regular" postgraduate students, teachers who are part-time postgraduate students and "industrial" postgraduate students who are employed by a company or research institute but can spend a fair amount of their time on postgraduate education.

After a period of rapid build-up, the postgraduate education is now in a consolidation phase. The main challenges ahead are to keep the research funding at such a level that the volume of the postgraduate education can be maintained, and to ensure the quality of the education and the graduated students. For the latter purpose, we have introduced a quality assurance system with annual student progress review meetings for advisors, public Licentiate and PhD proposals, and an active use of individual study plans. The harvest of this work has begun to materialize in the form of a sharp increase in the number of graduate exams: see further below.

During 2004, we participated in CUGS (The National Research School in Computer Science), with two modules consisting of two graduate students each plus supervision. We also had a number of graduate students enrolled in the ARTES network for graduate education in real-time systems. In December, finally, we were granted 20.8 MSEK from the KK foundation for the industrial graduate school SAVE-IT (Component Based Design of Safety Critical Vehicular Systems). This graduate school is closely connected with the SSF-supported SAVE research program. It will be a collaboration between MdH, LiU, KTH, UU, and a number of companies.

More information about the postgraduate education at MRTC is found at http://www.idt.mdh.se/phd/.

Courses

During 2004, MRTC has offered 8 postgraduate courses:

- Concurrency Theory and Time
- Component-Based Software Engineering fk
- Philosophy of Computer Science
- Research Methodology for Computer Science and Engineering
- Research Planning
- Methodologies for Case Studies
- Component Technologies
- Distributed Software Development

The postgraduate students can also select courses from other universities, courses given by national networks such as ARTES, courses from CUGS, common postgraduate courses at MdH, and local D-level courses that are qualified enough to also serve as postgraduate level courses. During 2004 the following Computer Science and Engineering D-level courses were given by MRTC-staff at MdH:

- Component-based Software Engineering, 5 p
- Computer Graphics, advanced course, 5p
- Component-based Design of Single-Chip Systems, 5p
- Safety-Critical Systems, 5p
- Logic Programming, 5p
- Engineering of Complex Embedded Systems, 5p
- Real-Time Systems, advanced course, 5p
- Semantics of programming languages, 5p
- Component Technologies, 5p
- Distributed Software Development, 5p

Some of the postgraduate courses have also been offered to undergraduate students as D-level courses. More information about our postgraduate courses can be found at http://www.idt.mdh.se/phd/courses.

Theses

In 2004, three PhD thesis and ten Licentiate theses were presented by MRTC staff:

Xavier Vera, Cache and Compiler Interaction, Ph. D. thesis, January.

Magnus Larsson, Predicting Quality Attributes in Component-based Software Systems, Ph. D. thesis, March

Damir Isovic, Flexible Scheduling for Media Processing in Resource Constrained Real-Time Systems, PhD thesis, December

Daniel Sundmark, Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components. Licentiate Thesis, March

Joakim Fröberg, Engineering of Vehicle Electronic Systems: Business requirements reflected in Architecture. Licentiate Thesis, April

Markus Bohlin, Design and Implementation of a Graph-Based Constraint Model for Local Search. Licentiate Thesis, April

Markus Nilsson, A case-based approach for classification of physiological time-series. Licentiate Thesis, May

Jan Carlson, An Intuitive and Resource-Efficient Event Detection Algebra. Licentiate Thesis, June

Mohammed El Shobaki, On-chip monitoring for non-intrusive hardware/software observability. Licentiate Theses presented at Uppsala University, September

Peter Nygren, Application Interface for Hardware and Software Threads. Licentiate Thesis, September

Mikael Sollenborn, Clustering and Case-Based Reasoning for User Stereotypes. Licentiate Thesis, October

Rikard Lindell, Towards new Interaction - a content centric data surface approach. Licentiate Thesis, October

Goran Mustapic, Architecting software for complex embedded systems. Licentiate Thesis, December

Presentations of these theses are provided in the chapters presenting the respective lab.

List of Postgraduate Students

The tables below list the MRTC postgraduate students and their advisory groups at the end of 2004. The column "Enrolled at" indicates the university where the student is formally enrolled as a Ph.D.-student.

Laboratory: CAL

Ph.D.-student	Formal main advisor	Advisor	Advisor	Employed at	Enrolled at
Mohammed El Shobaki	Lennart Lindh	**Hans Hansson**		MdH	UU
Johan Furunäs (lic)	**Lars Asplund**	Lennart Lindh	-	MdH	MdH
Raimo Haukilahti	Prof. Axel Jantsch	**Lennart Lindh**	-	MdH/KTH	KTH
Tommy Klevin	**Lennart Lindh**	-	-	RealFast	MdH
Gustaf Naeser (lic)	**Lars Asplund**		-	MdH	MdH
Susanna Nordström	Lars Asplund	**Denny Åberg**		RealFast	MdH
Stefan Sjöholm (lic)	**Lennart Lindh**	Prof. K. Kuchinski	Hans Hansson	ABB ASY/ RealFast	MdH

| Stefan Stjernen | **Lennart Lindh** | - | - | RealFast | MdH |
| Johan Stärner | Hans Hansson | **Lars Asplund** | Lennart Lindh | MdH | UU |

Laboratory: CSL

Ph.D.-student	Formal main advisor	Advisor	Advisor	Employed at	Enrolled at
Nerina Bermudo	**Björn Lisper**	Jan Gustafsson	-	TU Wien	MdH
Christina Björkman (lic)	Prof. **Lena Trojer** (BTH)	Björn Lisper	-	BTH/MdH	BTH
Markus Bohlin (lic)	Björn Lisper	**Per Kreuger** (SICS)	Martin Aronsson (SICS)	SICS	MdH
Jan Carlson (lic)	**Björn Lisper**	Christer Norström	Doc. Ulf Nilsson (LiU)	MdH	MdH
Baran Çürüklü (lic)	Björn Lisper	Prof. **A. Lansner** (KTH)	Peter Funk	MdH	MdH
Johan Eriksson	**Björn Lisper**			MdH	MdH
Roger Jonsson	Björn Lisper	Dr. **Jacek Malec** (Lund U.)	Peter Funk	MdH	MdH
Waldemar Kocjan	Björn Lisper	**Per Kreuger** (SICS)	Martin Aronsson (SICS)	-	MdH
Thomas Larsson (lic)	**Björn Lisper**	Dr. Tomas Akenine-Möller (Chalmers)	-	MdH	MdH
Rikard Lindell (lic)	Ivica Crnkovic	**Jussi Karlgren (SICS)**	Peter Funk	MdH/SICS	MdH
Markus Nilsson (lic)	**Peter Funk**	Ivica Crnkovic	Björn Lisper	Stress Medicine	MdH
Erik Olsson	**Peter Funk**			MdH	MdH
Christer Sandberg	**Björn Lisper**	Jan Gustafsson	-	MdH	MdH
Mikael Sandberg	**Björn Lisper**	Prof. Peter Fritzson (LiU)	-	MdH	MdH
Mikael Sollenborn (lic)	**Peter Funk**	Björn Lisper	-	MdH	MdH
Gordana Dodig-Crnkovic	Björn Lisper	**Lars-Göran Nilsson** (UU)		MdH	MdH

Laboratory: SEL

Ph.D.-student	Formal main advisor	Advisor	Advisor	Employed at	Enrolled at
Johan Andersson	**Christer Norström**	Björn Lisper		ABB	MdH
Daniel Flemström	**Ivica Crnkovic**			MdH	MdH
Johan Fredriksson	Ivica Crnkovic	**Kristian Sandström**		MdH	MdH

Joakim Fröberg (lic)	**Christer Norström**	Ivica Crnkovic	Kristian Sandström	Volvo CEC	MdH
Rikard Land (lic)	**Ivica Crnkovic**	Christer Norström	-	MdH	MdH
Stig Larsson	**Ivica Crnkovic**			ABB	MdH
Frank Lüders (lic)	**Ivica Crnkovic**	Björn Lisper	-	ABB APR	MdH
Dag Nyström (lic)	**Christer Norström**	Jörgen Hansson (LiTH)	Hans Hansson	MdH	MdH
Goran Mustapic (lic)	Ivica Crnkovic	**Christer Norström**	-	ABB	MdH
Jukka Mäki-Turja (lic)	**Mikael Nolin**	Christer Norström	Hans Hansson	MdH	**MdH**
Annita Persson-Dahlquist	**Ivica Crnkovic**			Ericsson	MdH
Christina Wallin (lic)	**Ivica Crnkovic**	Fredrik Ekdahl (ABB)	Stig Larsson (ABB)	ABB	MdH
Kurt Wallnau	**Ivica Crnkovic**	Hans Hansson	-	SEI/CMU	MdH
Mikael Åkerholm	Ivica Crnkovic	**Kristian Sandström**		MdH	MdH

Laboratory: SDL

Ph.D.-student	Formal main advisor	Advisor	Advisor	Employed at	Enrolled at
Henrik Abrahamsson	**Mats Björkman**	Dr. Bengt Ahlgren (SICS)	-	SICS	MdH
Radu Dobrin (lic)	**Gerhard Fohler**	-	-	MdH	MdH
Adam Dunkels	**Mats Björkman**	Dr. Thimeo Voigt (SICS)	-	MdH	MdH
Sigrid Eldh	Hans Hansson	**Henrik Thane**	Christer Norström	Ericsson	MdH
Mathias Ekman	Hans Hansson	**Henrik Thane**		Bombardier	MdH
Ewa Hansen	**Mats Björkman**	Bob Melander	Mikael Nolin	MdH	MdH
Joel Huselius (lic)	**Hans Hansson**	Henrik Thane	-	SICS	MdH
Kaj Hänninen	Hans Hansson	**Mikael Nolin**		MdH/Arcticus	MdH
Damir Isovic (PhD)	**Gerhard Fohler**	Ivica Crnkovic	-	MdH	MdH
Andreas Johnsson	**Mats Björkman**	Bob Melander		MdH	MdH
Tomas Lennvall (lic)	**Gerhard Fohler**	-	-	MdH	MdH
Anders Möller	Hans Hansson	**Mikael Nolin**		CC-systems	MdH
Jonas Neander	**Mats Björkman**	Mikael Nolin	-	MdH	MdH
Thomas Nolte (lic)	Hans Hansson	**Christer Norström**	**Sasikumar Punnekkat**	**MdH**	MdH

Anders Pettersson (lic)	Hans Hansson	**Henrik Thane**	-	MdH	MdH
Larisa Rizvanovic	**Gerhard Fohler**			MdH	MdH
Daniel Sundmark	Hans Hansson	**Henrik Thane**	Christer Norström	MdH	MdH

1.7 External Information

MRTC has a responsibility to keep the scientific community, industry, funding agencies and the general public informed about its activities and developments. An important carrier of information is the MRTC web-site www.mrtc.mdh.se, An associated database enables easy and convenient update and retrieval of information. Currently, the MRTC-web contains information about MRTC and the laboratories, projects, publications, seminars, and the staff.

The scientific community is informed via traditional dissemination channels, such as publications, participation in conferences, seminars, etc., and in direct co-operation with our partners. Participation in national and international research networks, such as ARTES, the European ARTIST network and the international Euromicro and IEEE committees on Real-Time Systems, are also very important.

Information exchange with industry comes in several forms, including

- Co-operation in joint projects
- Via the industrial postgraduate students
- Via the MRTC Industrial Day, which is an annual event with the purpose of presenting and discussing our achievements to industry in general and to our co-operation partners in particular. Since one day is not enough to present the multitude of projects and activities at MRTC, each industrial day has a special focus corresponding to a specific research direction. In 2004 the focus was on Complex Embedded Systems.
- Seminars, including both our own seminars and participation in industrial seminars organised by others.
- Involvement in technology transfer programmes. In 1999 MRTC was instrumental in winning the Expert Competence – Embedded Systems programme (TeknIQ) to MdH, and is now participating in the implementation of this programme. Anders Martinsen (CAL) is managing one of four regions in this programme. Se Section 1.2.7 ans 1.2.8 for details on the MRTC involvement in TeknIQ and MinsT
- Giving commercial courses on topics of our expertise. In 2004 the MRTC staff has given several instances of shorter industrial courses on real-time systems, reliability and circuit design
- Spin-off companies, where the main development in 2004 was a continued commercialisation of research results from CAL within the RealFast group. Another spin-off company - Zealcore Embedded Solutions AB – was subject to investment from KTH Seed Capital, and received a patent on the methods behind the BlackBox technology, the debugging technology developed in the Tatoo project

Funding agencies are informed via project proposals, evaluations and progress reports, but also via the web, and general material such as this report.

The general public, other departments at MdH, etc. are informed via the web, public lectures, articles in regional newspapers, regional TV and radio, articles in the trade-press, and the MdH periodical Delphi.

1.8 The MRTC Profile Grant

Mälardalen Real-Time research Centre (MRTC) was formally established January 1st 1999 as the result of a six year grant of 36 MSEK from the KK-foundation. Since the contract with the KK-foundation requires an equal matching by industry, the total effort is twice as large. This section specifically reports on the use of the Profile Grant, including associated industrial matching.

The following table summarizes the value of the industrial involvement and funding from the KK-foundation (actual and planned figures according to the updated contract) for the entire six-year profile programme (amounts in KSEK):

Year	From KK-foundation	Industrial involvement	Sum
1999	2 500	3 730	**6 230**
2000	2 824	6 716	**9 540**
2001	7 249	8 333	**15 582**
2002	10 119	7 668	**17 787**
2003	7 045	7 626	**14 671**
2004	6 263	3 045	**9 859**
Total	**36 000**	**37 178**	**73 118**

The following table shows how the industrial involvement has been and is planned to be distributed among participating industries (amounts in KSEK; discrepancy compared to above due to uncertainties in planned amounts and final amounts for 2003):

	1999-2003	2004	SUM
ABB	6 885	1 395	**8 280**
ABB Automation Products	11 677	0	**11 677**
ABB Robotics	1 040	0	**1 040**
ABB Corporate Research	3 329	850	**3 179**
CompFAB AB	1 880	0	**1 880**
Ericsson UAB	3 936	0	**3 936**
Ericsson AB		550	**550**
Eyescream AB	843	0	**843**
Mitsubishi Research	384	0	**384**
Protang AB	1 450	0	**1 450**
Volvo CEC	2 849	0	**2 849**
TietoEnator AB	300	0	**300**
RFE Real Fast Education AB	300	150	**450**
RFHC RealFast Hardware Consulting AB	200	100	**300**
Total	**34 073**	**3 045**	**37 118**

Finally, we report how the approximately 6,2 MSEK obtained from the KK-foundation as a part of the profile grant has been spent in 2004: Of these 6,2 MSEK approximately 4,4 MSEK were spent in 2004, the rest will be kept for 2005.

Project	Amount (KSEK)	Percentage
AI-group (CSL)	38	0,9%
APICS (SEL)	210	4,8%
Chipvision (CAL)	33	0,8%
Drive (SEL)	205	4,7%
Industrial IT (SEL)	301	6,8%
MultEx (SDL + SEL)	283	6,4%
OpenController (SEL)	275	6,3%
PSI (SEL)	144	3,3%
Remodel (SEL)	13	0,3%
SARA (CAL)	187	4,3%
SAVE (SEL+ SDL)	246	5,6%
SafetyChip (CAL)	228	5,2%
STINA (SEL)	333	7,6%
WCET (CSL)	76	1,7%
Coordination, information, VAT and MDH OH	1823	41,5%

Details about these and other projects are available in the following chapters.

2   The Computer Science Laboratory (CSL)

Lab leader: ***Prof. Björn Lisper***

The mission of the Computer Science Laboratory is to provide education in all relevant aspects of Computer Science, and research in Computer Science both in itself and applied to areas such as Software Engineering, Computer and Real-time systems, and Electronic System Design. The goal is to strengthen and secure the Computer Science part of the education, and to provide scientifically well founded methods and theories for the application areas.

During 2004, CSL had a staff of five senior researchers whereof one professor, three senior lecturers, and one researcher, 9 Ph.D. students, (3 of them industrial Ph.D. students), and eight lecturers, whereof four conducted part-time Ph.D.-studies. Education-wise, CSL is responsible for the Computer Science education ranging from basic courses in programming to advanced courses on programming language theory, algorithms, artificial intelligence, and computer graphics. The education is especially important since basic knowledge of computer science is required in virtually all engineering disciplines.

2.1   Focus

Due to the demand for a wide range of qualified Computer Science faculty the current research at CSL is quite diverse. The main focus is programming languages and artificial intelligence. Currently, research is carried out in the following areas:

Programming language analysis and design, in particular:

- Execution time analysis
- Language design for specification and programming of embedded systems
- Parallelization of PLEX
- Unit inference in modelling languages
- Constraint programming

Intelligent Systems/AI, in particular:

- Knowledge based methods and systems
- Learning systems, case-based reasoning, genetic algorithms and neural nets
- Intelligent human computer collaboration and decision support
- Philosophy of information and computing
- Human-machine interaction and computer graphics

There is a balanced mix between industrially oriented and academic research.

2.2   Education

CSL is responsible for the courses in Computer Science, which is a wide topic with many important sub-areas. The laboratory is responsible for the Bachelors/MSc programs in Computer Science and Computer Game Development, but also provides most computer science courses for the other programs at MdH. Thus, the teaching load on the laboratory is high. CSL also gives occasional postgraduate courses in Computer Science.

Together with SEL, CSL caters for the backbone of the Computer Science and Computer Engineering Programs: all the courses in introductory and advanced programming, algorithms and automata, programming language theory, artificial intelligence, autonomous systems, computer graphics, and scientific methodology. The courses form a continuous track from introductory to advanced level.

In 2004 the laboratory was responsible for close to 30 undergraduate courses. The courses are divided in: basic programming courses, and advanced computer science courses (such as object-oriented programming, functional and logic programming, computer graphics, etc.). The basic courses are intended

for students from different programs, while advanced courses are primarily taught to the students of computer science and engineering programs. The advanced courses are related to the topics of research.

The laboratory also gives postgraduate courses. The purpose of these courses is to focus on topics related to the research areas of the laboratory, for the benefit of the postgraduate students at the laboratory, but also to offer suitable postgraduate level computer science courses to Ph.D. students from other research areas.

2.2.1 Undergraduate courses

The undergraduate courses are classified in different levels ("A" to "D") that approximately correspond to the different years of study. Information about the courses can be found at http://www.idt.mdh.se/kurser/. The official course plans are found at http://www.mdh.se/utbildning/sok/.

Basic courses

The basic courses cover introductions to different programming languages and programming techniques. Some of the courses in this category are: Introduction to Computer Science, Programming in Java, Programming in C, Algorithms and Data Structures, and Introduction Course for the Computer Science Program.

Middle level and advanced courses

There are several groups of courses in specific areas of computer science: object-oriented programming, computer graphics, advanced programming languages, and language theory, as well as some "general purpose" courses. These courses cover the most common disciplines in Computer Science, and serve as a base for further postgraduate studies and research.

Courses in programming languages and -paradigms:

Object-Oriented Programming, 5p. The course gives an introduction to object-oriented analysis, design and programming of object-oriented systems.

Functional programming, 5p. The course treats important aspects of functional programming: freedom of side-effects, recursion, higher-order functions, advanced type systems, lazy vs. eager evaluation. The language Haskell is used for this part. An orientation is also given about more theoretical topics like lambda calculus, type inference, and proofs of program properties by induction.

Logic Programming, 5p. The course gives an in depth exploration of a powerful programming paradigm suitable for databases, search tasks in AI applications and knowledge based systems (declarative knowledge). Both theory, how logic programs are executed, their formal meaning and how to solve problems in the programming language Prolog are included.

Theoretical courses:

Formal Languages, Automata and Theory of Computation, 5p. This course presents the basic concepts of language and computation theory, including formal languages and their computational counterparts, equivalence between different computational models, computability and formal methods.

Compiler Theory, 5p. The course gives understanding of how data can be translated from one representation to another representation in a formal way.

Semantics of Programming Languages, 5p. Operational, denotational, and axiomatic semantics are introduced. The mathematical foundations for denotational semantics (lambda-calculus and domain theory) are covered, as well as applications, such as static program analysis (abstract interpretation).

Analysis of Algorithms, 5p. The course introduces basic methods for constructing and analysing algorithms, including: Asymptotic notation; recurrences; amortized analysis; upper and lower bounds; greedy algorithms; divide-and-conquer strategies; dynamic programming; graph algorithms.

Courses in intelligent systems/artificial intelligence

Artificial Intelligence, 5 p. The course provides an introduction to the basic concepts of artificial intelligence such as heuristic searching, representation of knowledge, learning methods, etc.

Case-based Reasoning, 5p - The course gives an in depth exploration of a powerful method and related methods called Case-Based Reasoning.

Artificial Intelligence in Depth, 5 p - The course gives an in depth exploration of artificial intelligence. The student chooses an area of special interest in agreement with the supervisor.

Other advanced courses in computer science

Introduction to Computer Graphics, 5p. The principles behind computer generated 2D- and 3D-pictures are covered, including scan conversion and clipping, geometrical transformations, projection, hidden surface elimination and different types of lighting models.

Computer Graphics Advanced Course, 5p. The course gives and understanding of different ways to represent surfaces and bodies and of different algorithms in use in advanced graphic programs to generate realistic 3D-graphics.

Methodology of Science and Technology, 5p. This course covers fundamental theory of science, an overview of the history of ideas in science, and topics in scientific writing.

Research Methodology for Computer Science and Engineering, 5p. The course introduces basic concepts and problems within science, specifically focusing on research methodology for the computer science and engineering fields.

Professional Ethics in Science and Engineering, 5p. The purpose of this course is to give knowledge of the philosophical foundations of ethics, develop a framework on which professional and ethical issues can be analyzed, and build up an awareness of various views of ethical issues as well as professionals ethical responsibilities.

2.2.2   International Master of Science Programmes

In 2004, a number of international Master of Science programmes (so-called "MIMA" programmes) were launched at MdH. These programmes target students who have a bachelor's degree, and wants to obtain a Swedish Master's degree in the same field. These programmes have 20 or 40 credits of courses, and a Master's thesis project of 20 credits. During 2004, CSL was responsible for the following programmes:

- Computer Science with Programming and Specification Languages Profile
- Computer Science with Intelligent Systems (AI) Profile

For more information, see http://www.mdh.se/ufo/int/mima/.

2.2.3   Postgraduate courses

In 2004, CSL has organised the following postgraduate courses:

Philosophy of Computer Science – A Swedish national course developed within the PI-network, which attracted a number of students from other universities. Supported by the KK-foundation

Research Methodology for Computer Science and Engineering – This course can also be taken as a graduate level course. For a description, see above.

Professional Ethics in Science and Engineering, 5p. This course can also be taken as a graduate level course. For a description, see above.

Advanced Functional Languages is a self study course, covering advanced functional programming techniques and some underlying theory. It can be seen as a more thorough version of the undergraduate course in functional programming.

Artificial Intelligence in Depth - This course can also be taken as a graduate level course. For a description, see above.

Case-Based Reasoning - This course can also be taken as a graduate level course. For a description, see above.

2.3 Research

During 2004, the research at CSL was organized in two research groups: the Programming Languages group, and the Intelligent Systems group. There are also some individual research projects, on topics outside these groups. These projects, and the achievements, are listed separately below. However, all personnel at CSL doing research are associated with one of the groups.

Cooperation with SICS has continued during 2004. One Ph.D. student at CSL has been financed by SICS during 2004, within a research project on advanced constraint programming. SICS has also provided advising for a Ph.D. student at CSL in the area of multimodal user interfaces. Two licentiate theses, resulting from this cooperation, were successfully defended during 2004.

The research at the laboratory is both internally and externally funded. In 2004 CSL had external funding from VR, the KK-foundation, Vinnova (through the ASTEC competence centre), EU, and SSF. The laboratory also received substantial software donations from AbsInt GmbH and Tidorum Oy.

2.3.1 Programming Languages Group

The programming languages group deals with research on different aspects of programming and specification languages. The focus of the group is the analysis and design of languages in real-time and embedded systems, but projects are also carried out in neighboring areas, like analysis of modelling languages. The group consists of one professor, one senior lecturer, one researcher, and nine Ph.D. students, whereof three are external. The group cooperates with SICS within the SICS-MdH collaboration, and one employee at the Västerås branch of SICS belongs to the group as external Ph.D. student. The group is also active in CUGS (the National Graduate School in Computer Science), with a member on the Steering committee and two Ph.D. students participating in the school. Finally, the group participates in the Vinnova-supported ASTEC competence centre in Uppsala, with two active research projects plus one member of the board.

Publications:

- Markus Bohlin. Design and Implementation of a Graph-Based Constraint Model for Local Search. Licentiate Thesis, April 2004.
- Jan Carlson. An Intuitive and Resource-Efficient Event Detection Algebra. Licentiate Thesis, June 2004.
- Jan Carlson, Björn Lisper. *An Event Detection Algebra for Reactive Systems.* Proc. Fourth ACM International Conference on Embedded Software (EMSOFT'04), pp. 147-154, Pisa, Italy, September 2004.
- Johan Erikson, Björn Lisper. *A Formal Semantics for PLEX.* Proc. 2nd APPSEM II Workshop (APPSEM'04), Tallinn, Estonia, April 2004.
- Waldemar Kocjan, Per Kreuger. *Filtering Methods for Symmetric Cardinality Constraint.* Jean-Charles Regin and Michel Rueher (eds) Proc. CPAIOR 2004, pp. 200-208, Nice, April 2004.
- Daniel Sandell, Andreas Ermedahl, Jan Gustafsson, and Björn Lisper. *Static Timing Analysis of Real-Time Operating System Code.* Proc. 1st International Symposium on Leveraging Applications of Formal Methods (IsoLA 2004), Paphos, Cyprus, October - November 2004.
- Christer Sandberg. *Inspection of Industrial Code for Syntactical Loop Analysis.* Proc. Fourth International WCET workshop (WCET 2004), Catania, Sicily, Italy, June 2004.
- Xavier Vera. Cache and Compiler Interaction (how to analyze, optimize and time cache behavior), Ph.D. Thesis, January 2004.
- Xavier Vera, Nerina Bermudo, Josep Llosa, Antonio Gonzalez. *A Fast and Accurate Framework to Analyze and Optimize Cache Memory Behavior.* ACM Transactions on Programming Languages and Systems (TOPLAS), March 2004.
- Jingling Xue, Xavier Vera. Efficient and Accurate Analytical Modeling of Whole-Program Data Cache Behavior. IEEE Transactions on Computers, January 2004.

The group has the following projects:

Worst-case execution time analysis (WCET)

Project leader:	Björn Lisper
Project members:	Andreas Ermedahl
	Jan Gustafsson
	Christer Sandberg
	Susanna Byhlin (M.Sc. student, spring 2004)
	Samuel Peterson (M.Sc. student, fall 2004)
	Daniel Sandell (M.Sc. student, spring 2004)
Partners:	Uppsala University (ASTEC), IAR Systems AB, Enea ET
	Volcano Communication Technologies,
	CC-Systems AB, Arcticus AB
	AbsInt GmbH
	Tidorum Oy.
Funding:	Swedish Research Council (VR),
	Vinnova (ASTEC)
	internal.

Project description:

Execution time analysis is critical in the design of hard real-time systems, since scheduling and correctness analysis requires accurate measures of the Worst Case Execution Times (WCET) of the involved software. Accurate WCET analysis is very important, since optimistic estimates invalidate the analysis, and pessimistic estimates give poor resource utilisation. This project is a part of a larger effort within the Vinnova-supported competence centre ASTEC at Uppsala University. Our part of the project is the automatic flow analysis in the tool.

Technical Vision

A WCET prototype tool, containing all parts (flow analysis, pipeline analysis, cache analysis, WCET calculation, ...) of the framework presented 1999 (ASTEC Report 99/02: Towards Industry Strength Worst-Case Execution Time Analysis, J. Engblom, A. Ermedahl, M. Sjödin, J. Gustafsson and H. Hansson).

The WCET prototype tool should be able to analyse "real" programs (not depending on special assumptions). It will handle troublesome features such as unstructured code, pointers, and recursion. The different parts of the tool are based on general approaches. The development of the theory and methods used are publishable in academia.

Results and achievements for 2004:

A number of case studies have been made, where WCET tool technology has been tested on real industrial code. Work on the prototype tool has progressed. A journal paper on program analysis to detect input-independent program flow (coauthored with P. Puschner and R. Kirner, TU Wien) has been accepted for publication.

- Jan Gustafsson, Andreas Ermedahl and Björn Lisper attended the international WCET workshop (WCET 2004) in Catania, Sicily, Italy. At the workshop, Christer Sandberg presented a paper (Inspection of Industrial Code for Syntactical Loop Analysis).
- Jan Gustafsson, Andreas Ermedahl and Björn Lisper have been working with the organization of a broader cooperation between European WCET groups, organized within ARTIST II as a NoE (Network of Excellence) network. They have attended two meetings, one in Dagstuhl in September, and one at Mallorca in November.

Dimensional Inference in Strongly Typed Specification Languages

Project leader: Björn Lisper
Members: Mikael Sandberg (Ph.D. student)
Funding: Internal

Project description:

Modelling languages such as Modelica and gPROMS specify dynamic systems for simulation. Current implementations lack the ability to detect if physical units and dimensions are correctly specified in the models. The goal of this project is to develop and evaluate efficient methods to verify that equations use dimensions in a consistent way. This is done through a form of type inference, which in the end boils down to the problem of solving a system of linear equations.

Results and achievements in 2004:

A small kernel language for equations, EKL, was defined, and a prototype tool for dimensional inference for EKL was partially implemented. EKL and its dimensional inference solver will be used in a prototype dimensional inference tool for Modelica.

Future plans:

The plans for the nearest future are to finish the dimensional inference tool for Modelica and to complete a Licentiate thesis (Mikael Sandberg).

High Level Languages for Hard and Embedded Real-Time Systems

Project leader: Björn Lisper
Members: Jan Carlson
Funding: Internal, CUGS

Project Description:

The research is motivated by the need for efficient and safe design of real-time systems. We believe that currently used languages, like C, do not provide adequate support for all aspects of the design process. The desirable properties for languages for this kind of system include simple and well-defined formal semantics, support for programming/specification on a high level of abstraction. They should not hide any inherent parallelism, and must provide means for resource-conscious programming when there is a need for it, but not confine the programmer to this kind of programming.

Current activities:

Event algebra: A reactive system must be able to detect occurrences of events to which the system should respond. Events can be simple, primitive events generated by the environment, or complex combinations of such primitive events. We are developing an algebra that allows the developer to specify complex events such as event sequences, non-occurrences, etc. A restriction policy is developed that allows an implementation of the algebra for which bounds on time and memory needs can be formulated. By proving a set of algebraic laws (such as associativity of the sequence operator), formal (and informal) reasoning is facilitated.

Results and achievements in 2004:

A licentiate thesis and a conference paper (EMSOFT'04).

Future plans:

We are curious to find out whether event algebra expressions are useful for specifying triggering conditions in component models for embedded systems, such as the one being developed within the SAVE project. A workshop paper developing this idea has been submitted.

Planned milestones:

- Ph.D. Proposal June -05
- Ph.D. Nov -06

Parallel Execution of PLEX Programs

Project leader:	Björn Lisper
Members:	Johan Erikson (Ph.D. student)
	Jan Gustafsson (assistant supervisor)
Funding:	Ericsson
	Vinnova (ASTEC)

Project Description:

PLEX is an in-house language at Ericsson for programming AXE telephone exchanges. It is sequential but pseudo-parallel: the application itself (handling telephone calls) is very parallel in nature. Ericsson would like to replace the current, sequential central processor in the AXE with a parallel processor. This requires parallel software. Rewriting the current software is no alternative (~20 Mlines of code): the existing PLEX code must thus somehow be parallellized. In this project, methods to parallelize PLEX programs will be developed. It is important that the methods yield correct parallelizations: AXE exchanges have to be very reliable.

This requires a formalization of PLEX semantics for both sequential and parallel execution models, in order to formulate criteria for when parallel execution must yield the same behaviour as sequential execution. From there, rules can be devised that can be applied when adapting PLEX programs manually for parallel execution. Later, in order to automate the task, program analyses can be formulated, implemented, and experimentally evaluated.

Current activities:

Right now, a formal semantics is developed for a parallel implementation of PLEX.

Results and achievements in 2004:

A formal semantics has been developed for sequential PLEX, and a workshop paper on this has been presented. A literature survey of relevant parallelization techniques has been written.

Future plans:

A licentiate thesis is planned for March 2006.

2.3.2   Intelligent Systems Group

The Intelligent Systems group consists of one associate professor, one assistant professor, five Ph.D. students and a number of master year students with AI research profile. The main interest of the group is research in artificial intelligence and its applications. The group is in particularly interested in methods and techniques such as Case-Based Reasoning, Artificial Neural Nets, Intelligent Agents, Genetic Algorithms, Intelligent Human Computer Interaction and Knowledge Representations, and Information Fusion. The intelligent system group has succeeded in attracting funding for a number of large research projects, from foundations like SSF and KKS, and industry such as ABB, Volvo, and SKF. The AI group has also initiated a number of successful multidisciplinary research projects with ISt, former IEL an IDP. Projects the AI group plays a major role in is ExAct (24 MSEK) and the following Factory-in-a-box project (41 MSEK, ExAct was a prerequisite for applying, Chalmers Tekniska Högskola, Högskolan i Jönköping, Linköpings Tekniska Högskola), Butler (SICS, Bombardier, Outocumpu, Avesta Steel Mill) shows that the intelligent systems group has an important role at MdH and the department and also is a key research group bridging and contributing to multidisciplinary research projects between departments at MdH and with other universities and university colleges. The group is also internationally recognised for its application-oriented AI and learning systems research.

Main results and achievements in 2004:

Start up year of the ExAct project funded by SSF Proviking. Participating companies ABB, Volvo, and SKF. A number of licentiate thesis and publications. This SSF ProViking project was also a prerequisite for the Factory in a Box project. The project budget during 4 years is 24.5 MSEK. Peter Funk is the main project leader.

Successful application to the Swedish Foundation for Strategic Research, Proviking with "Factory in a Box" granted 41 MSEK during 4 year (application together with a Chalmers University of Technology, Linköping University and Jönköping University). Mats Jackson at Mälardalen University is main applicant and main project leader.

Successful application to the Swedish Knowledge Foundation, KKS, "Intelligent sensor systems for medical applications" granted 3,9 MSEK cash funding during 3 year (application together with Ylva Bäcklund who is the main applicant).

One new Ph.D. student was admitted (Erik Olsson, IDt and ABB). He was associated with the ExAct project and the research group (main supervisor Peter Funk, IDt).

Mälardalen University and the AI group was given the trust to organize the yearly Swedish AI and Learning Systems event (3 days) and Peter Funk was elected organizer and chair for the event.

7 licentiate theses: two licentiate thesis in AI, Markus Nilsson, Mikael Sollenborn.

Employment of one new senior researcher in the AI group: Ning Xiong, PhD from University of Kaiserslautern, previously employed at KTH and the Swedish Defense Research Agency (FOI).

Spin-off company AI Labs, 5 former AI students commercialising research ideas based on research projects in the AI group.

Publications:

- Bengtsson M., Olsson E., *Technical Design of Condition Based Maintenance Systems - A Case Study using Sound Analysis and Case-Based Reasoning*. In MARCON (Maintenance and Reliability Conference),pages 12 Knoxville, TN, USA , May 2004.

- Çürüklü, B, *Early Stages of Vision Might Explain Data to Information Transformation*. In the proceedings of the Turkish Symposium on Artificial Intelligence and Neural Networks, Izmir, Turkey , June 2004.

- Çürüklü, B., Lansner A, *A Model of the Summation Pools within the Layer 4* (Area 17). In the proceedings of the Computational Neuroscience Meeting. Baltimore, USA , July 2004. Elsevier

- Funk P., *Artificial Intelligence Research for Medicin and Industrial Applications*. In AILS2004, pages 2 Lund , April 2004. Editor(s):Jacek Malek

- Funk P., Olsson E., *Diagnosis of Industrial Equipment using Case-Based Reasoning and Sound Comparison*. In AILS2004, pages 8 Lund, Sweden , April 2004. Editor(s):Jacek Malek

- Nilsson M, *A Case-Based Approach for Classification of Physiological Time-Series*. Licentiate Thesis. Mälardalen University Press, May 2004.

- Nilsson M, *Retrieving short and dynamic biomedical sequences*. In Proceedings of the 18th International FLAIRS Conference, Special Track on Case-Based Reasoning, Clearwater Beach, USA , May 2005. AAAI

- Nilsson M., Funk P, *A Case-Based Classification of Respiratory Sinus Arrhythmia*. In 7th European Conference on Case-Based Reasoning,pages 673-685 Madrid, August 2004. Springer. Editor(s):Funk P., Pedro A. Gonzalez Calero

- Nilsson M., Sollenborn M, *Advancements and Trends in Medical Case-Based Reasoning: An Overview of Systems and System Development*. In Proceedings of the 17th International FLAIRS Conference, Special Track on Case-Based Reasoning, pages 178-183 Miami, USA , May 2004. AAAI

- Nilsson M., Xiong N., Funk P, *Clinical decision support by time series classification using wavelets*. In Proceedings of the Seventh International Conference on Enterprise Information Systems (ICEIS'05) Miami, USA , May 2005. INSTICC Press. Editor(s):Chin-Sheng Chen, Joaquim Filipe, Isabel Seruca, José Cordeiro

- Olsson E., Funk P., Bengtsson M, *Fault Diagnosis of Industrial Robots using Acoustic Signals and Case-Based. Reasoning*. In 7th European Conference on Case-Based Reasoning,pages 686-701 Madrid, Editor(s):Funk P., Pedro Gonzales. August 2004. Springer

- Olsson E., Funk P., Xiong N, *Fault Diagnosis in Industry Using Case-Based Reasoning*. Journal of Intelligent & Fuzzy Systems, forthcoming, accepted, 10, November 2004. IOS Press

- Sollenborn M., Nilsson M*, Building a Case Base for Stress Diagnosis: An Analysis of Classified. Respiratory Sinus Arrhythmia Sequence*sIn Proceedings of the ECCBR 2004 Workshops, Editor(s):Pablo Gervas, Kalyan Moy Gupta. pages 55-63 Madrid, Spain , August. 2004. Springer-Verlag

- Xiong N., Funk P, *Construction of Fuzzy Knowledge Bases Incorporating Feature Selection*. Special issue of the Journal Soft Computing (accepted for publication), 2005. Springer-Verlag

Research projects:

AIM, Artificial Intelligence in Medical Applications

Project leader:	Peter Funk (IDt) & Bo von Schéele (SMAB)
Members:	Markus Nilsson (Ph.D. student)
	Mikael Sollenborn (Ph.D. student)
	Peter Funk (supervisor)
	Bo von Schéele (supervisor)
	Ning Xiong, Ph.D.
	Johnny Holmberg, Ph.D
	Johan Andrén (M.Sc. student, 2004)
	Daniel Andersson (M.Sc. student, 2004)
	Andreas Jonsson (M.Sc. student, 2004)
	Karin Karlsson (M.Sc. student, 2004)
	Jessica Malm (M.Sc. student, 2004)
	Farid Banihashemi (M.Sc. student, 2004)
Partners:	PBM StressMedicine AB
Funding:	KK-foundation
	PBM StressMedicine AB
	Mälardalen University
	teknIQ

Project description:

The AIM project addresses sensor readings in medical applications for diagnosis, prevention and rehabilitation. Sensor readings in medical context are becoming increasingly important. Classical sensor classification methods are not always sufficient for reliable diagnosis, prognosis and treatments (the case in stress diagnosis, our main target application). Techniques from artificial intelligence are used in a decision support context both for experts, clinicians and patients.

Results and achievements in 2004:

Two licentiate thesis (Markus Nilsson and Mikael Sollenborn), a number of Masters Thesis projects, numerous publications and participation at international events (conferences, workshops). Was selected as a successful example by KKS and presented with a talk and 5 minute film at the foundations 10th year anniversary. Also funding for project building upon the projects result has been secured 3.9 MSEK during 3 year (application together with Ylva Bäcklund, the main applicant).

ExAct, Intelligent Systems and Artificial Intelligence for industrial applications

Project leader:	Peter Funk. docent, IDt
Members:	Mats Jackson, professor IDP
	Ning Xiong, Ph.D
	Johnny Holmberg, Ph.D
	Markus Bengtsson, PhD student, MdH, IDP
	Milun Milic, PhD student, ABB Automation, IDP
	Erik Olsson, PhD student, ABB Automation, IDt
	Sofi Elfving, PhD student, Mälardalen University, IDP
	Anette Brannemo, PhD student, Volvo CEC, IDP
	Anna Andersson, PhD student, Volvo CEC, IDP
	Andreas Johansson (M.Sc. student, 2004)
	Mikael Hedelind (M.Sc. student, 2004)
	Adam Blomberg Hedelind (M.Sc. student, 2004)
	Henrik Bovin (M.Sc. student, 2004)
	Peter Sävström (M.Sc. student, 2004)
Partners:	PBM StressMedicine AB
Funding:	PBM StressMedicine AB

KK-foundation
Internal
teknIQ

Project Description

The ExAct project is coordinated by Peter Funk (CSL), with additional partners from MdH/IDP (Mats Jackson), Hercules Dalianis (KTH, Nada) and Paul Johannesson (DSV, Stockholm University). The goal of ExAct is three fold: firstly to create a flexible, intelligent, proactive, collaborative experience sharing framework for industry, secondly collecting and structuring experience (both human experience and automatically recorded experience by manufacturing equipment) and thirdly initiating competence cluster and experience sharing among users. ExAct includes a number of global companies (ABB Robotics, Volvo, SKF and SCEMM, universities (3) and one trade organisations with more than 70 companies. These partners have committed to finance 15.5 MSEK. SSF ProViking is funding 9 MSEK during 3 years.

Results and achievements in 2004:

Project has been ramped up, one senior researcher was employed (Ning Xiong), one new PhD student, Eric M. Olsson, a number of ongoing PhD students have been connected to the project and a number of Master thesis projects have been completed. The project has also produced a number of publication and participated in a number of international conferences and workshops. An application for ProViking phase 3 was handed in to SSF (prof. Mats Jackson main applicant) and 41 MSEK was granted (the single largest individual project run att Mälardalen University) and the project including 4 universities. The project is closely coordinated with the ExAct project making Mälardalen one of the most important centers of research with high relevance for production industry.

English Butler

The English Butler consortium is coordinated by Björn Levin (SICS), with additional partners from MdH/ISt (Erik Dahlqvist), and CSL (Peter Funk). The objective is to provide industrial plants with autonomous self-surveillance. The "English butler" is a system that monitors the process using the abundance of sensors and control devices built into modern process industries, detects deviations, and when possible takes corrective actions without operator intervention. The system will keep the operator informed and provide explanations.

Genetic Algorithm Theory

Project leader: Jacek Malec, Lund University
Members: Roger Jonsson (Ph.D. student)
                    Björn Lisper (local advisor)
                    Peter Funk (local advisor)
Funding: Internal

Project description:

Genetic algorithms are gaining an increasing amount of interest in many domains. Even though good results are often achieved, the theoretical framework is still young. Theoretical research today is using a Markov chain as a model for genetic algorithms. The main drawback with this model is that is only able to model very small problems.

Our research concerns the Markov chain model of the Simple Genetic Algorithm, where we aim at both simplifying the model so that it is useful for larger problems, and using it to find expressive features and correlate them to design choices. The design is today made by trial and error.

Plans and achievements:

A Licentiate thesis and a conference paper is planned for 2005.

Layout and Function of the Intracortical Connections within the Primary Visual Cortex

Project leader:	Anders Lansner (KTH)
Members:	Baran Çürüklü (Ph.D. Student)
	Björn Lisper (local supervisor)
	Peter Funk (second local supervisor)
Partners:	KTH, SANS, NADA
Funding:	CUGS (National Graduate School in Computer Science)

Project description:

The intention of this project is to reveal the mechanisms behind vision. A computer model of the cat's visual cortex is currently developed for this purpose. The model explains the interactions between neurons that populate the visual cortex, and hence demonstrates how cats and other species can see simple shapes, such as lines and contours.

Results achieved 2004:

Two conference papers, and a draft PhD thesis.

Future Plans:

Direction of our future research is to make the network model even more realistic. We are currently testing the cortical minicolumn network with Poisson neurons. Cortical neurons are known for their irregularity of the interspike interval. Preliminary results have shown that oscillation is possible to achieve with our network using Poisson neurons. Our intention is to expand the model with inhibitory neurons as well.

A Ph.D. thesis will be defended early 2005.

2.3.3 Other projects

The Siblings Project

Project leader:	Rikard Lindell
Members:	Rikard Lindell
	Jussi Karlgren (SICS)
	Ivica Crnkovic
	Peter Funk
Partners:	SICS
Funding:	Internal

Project description:

The aim of the Siblings project is to show that human computer interaction does not need to follow the guidelines of the desktop metaphor interface in order to yield good utility and user satisfaction. On the contrary the hypothesis is that these metrics would improve for different interaction paradigms. We know that today's interfaces merely explains how the computer works, thus if one were to create an interaction paradigm that better supports human behaviour, users should less frequently have to put up with computer idiosyncrasies.

From the technological end, the starting point of the project is to remove many of the underlying infrastructure components that the desktop metaphor explains to provoke new designs. The main components removed are: the file system including the concept of files, application programs, and windows. Instead the model for persistent storage of content is a database. Its entire contents is visualised on an infinitely large two-dimensional surface.

From the cognitive psychology end, the mental model for human information management to map on the interface is the theory of cognitive collages. The design relies on humans' spatial abilities for organising content. The visual presents of the information content works as reminders and feeds cognitive reference points. The use of only two dimensions omits mental rotations.

The Siblings project interaction paradigm effects: information visualisation, information navigation, user collaboration, multi modal interface usability, information access, program architecture, and scalability over different platforms.

Support for the Siblings project interaction paradigm approach is sought by implementing software prototypes, and by showing these prototypes to users. Current studies are focused on collaborative music improvisation.

Publications:

- Rikard Lindell, Towards new Interaction: A Content Centric Data Surface Approach, Licentiate Thesis, November 2004.

Future plans:

In the Siblings project we will continue by conduct deeper investigations of the fundamental data surface interaction paradigm and its applicability to multi modal interfaces and open ended creative tasks. We seek to continue with industrial partners for eye-gazing, music software, and animation software, as well as content providers. The goal will be to see if user can solve real-world task in the domain of music and animation with the prototype tools developed in the Siblings project.

Global Constraints in Constraint Programming and Local Search

Project leader: Björn Lisper
Members: Per Kreuger (SICS/Kista)
          Björn Lisper (MdH)
          Marcus Bohlin (SICS/Västerås)
          Waldemar Kocjan (MdH)
Partners: SICS
Funding: SICS, internal

Project Description:

The aim of this project is to increase the competence in constraint programming (CP) at MdH and in Västerås, in order to make this powerful optimization technique more easily available for the local industry. This will be achieved in three ways: by research education of the SICS staff in Västerås, by conducting research within CP, and by running industrial projects where CP is applied to real problems. The research conducted will focus on: local search methods and how they can be integrated within the CP framework, static and dynamic global constraints.

Publications:

- Waldemar Kocjan, Per Kreuger. *Filtering Methods for Symmetric Cardinality* Constraint. Jean-Charles Regin and Michel Rueher (eds) Proc. CPAIOR 2004, pp. 200-208, Nice, April 2004.

3D Graphics Simulation

Project leader: Björn Lisper
Members: Tomas Larsson
          Thomas Akenine-Möller, Chalmers
Partners: Chalmers University of Technology
Funding: Internal

Project description:

In this project, the focus is on developing new algorithms and optimization techniques for computer graphics and virtual reality. Currently, we are addressing the problem of doing fast and accurate collision detection between detailed geometric bodies that are commonly used in different kinds of graphics simulations. In particular, we address the problem of dealing with collision among deforming bodies that change their overall shape in every simulation time step.

Results and achievements in 2004:

Further development of efficient collision detection algorithms.

Future plans:

We plan to generalise our collision detection methods to a broader set of body types. We also plan to work on the collision detection problem arising in specific real-time simulation applications. In virtual surgery, for example, the instruments need to interact with soft tissues and organs in a realistic way.

PICO - Philosophy of Information and Computing

Project leader:	Gordana Dodig-Crnkovic
Members:	Gordana Dodig-Crnkovic
	Björn Lisper (main supervisor)
	Jan Gustafsson
	Lars-Göran Johansson (external supervisor, UU)
Funding:	Internal
	KK-foundation

Project description:

Philosophy of Information and Computing brings together scientific, philosophical and ethic perspective. That sort of analysis has not yet been done, and it is under development internationally within CAP (Computing And Philosophy) project. It is important for many reasons. For students, in contrast to the short-term knowledge of present day tools and technologies, PICO identifies long-term goals and context of the field. For the Computing community it establishes standards to assess the quality of research and its acceptability from the ethical and societal point of view. By bringing together contemporary ideas PICO provides an introduction to a fundamental area of research that is rapidly growing. This year we make a contribution to the field by organising E-CAP 2005 European Computing and Philosophy Conference.

Results:

A national course in Philosophy of Computer Science, with support from the KK-foundation, was given in 2004. See http://www.idt.mdh.se/personal/gdc/pi-network.htm. Three conference papers were presented. In addition to these, an M.Sc. thesis was written.

Publications:

- Gordana Dodig-Crnkovic. *On the Importance of Teaching Professional Ethics to Computer Science Students.* L Magnani (ed.) Proc. Computing and Philosophy Conference, E-CAP 2004, Pavia, Italy, November 2004.

- Gordana Dodig-Crnkovic. *Philosophy of Information, a New Renaissance and the Discreet Charm of the Computational Paradigm.* L Magnani (ed.) Proc. Computing and Philosophy Conference, E-CAP 2004, November 2004.

- Gordana Dodig-Crnkovic, Sandra Irobi Ijedma. *Model Validation, Evolutionary Systems and Semantics of Information.* L Magnani (ed.) Proc. Model-Based Reasoning In Science And Engineering: Abduction, Visualization, And Simulation, Pavia, Italy, December 2004..

Future:

In 2005, we will arrange the European Computing and Philosophy Conference (E-CAP). A Ph.D. degree is planned for 2006.

Computer Science Paradigms in Gender Research Perspective

Project leader:	Lena Trojer (Blekinge Institute of Technology)
Members:	Christina Björkman
	Lena Trojer
Partners:	Blekinge Institute of Technologies
Funding:	VR, BTH, MdH

Project description:

The aim of this project is to develop new possible, broader understandings and interpretations of Computer Science and its practices, starting in analysis of existing paradigms and knowledge processes within Computer Science and how these interact in forming the activities within the discipline. A starting point and special target of the project is the underrepresentation of women within Computer Science,

where possibly the way that Computer Science is defined, described and taught can be a factor of importance. Broadening the definition and understanding of the nature of Computer Science is of vital importance for a sustainable increase in women's participation in Computer Science.

Publications:

- Björkman, C. *Computer Science, Gender and Knowledge: Situated Readings.* In Mörtberg, C, Elovaara, P, Lundgren, A (Eds.), How do we make a difference?, pp.157-174. Luleå University of Technology.

Future:

The continuation of the research is planned to be in the directions given above.

2.4 Industrial co-operation

CSL cooperates with IAR Systems AB, Enea ET, Volcano Communication Technologies, CC-Systems AB, Arcticus AB, AbsInt GmbH, and Tidorum Oy on execution time analysis, through the ASTEC competence centre in Uppsala. The laboratory also collaborates with Ericsson around parallelization methods for PLEX programs, and with PBM StressMedicine, ABB Robotics, Volvo, SKF, and SCEMM in the intelligent systems area.

2.5 Theses

One Ph.D thesis and five Licentiate theses were presented by CSL staff in 2004:

Xavier Vera. Cache and Compiler Interaction (how to analyze, optimize and time cache behavior), Ph.D. Thesis.

Caches have become increasingly important with the widening gap between main memory and processor speeds. Small and fast cache memories are designed to bridge this discrepancy. However, they are only effective when programs exhibit sufficient data locality. In addition, caches are a source of unpredictability, resulting in programs sometimes behaving in a different way than expected.

Detailed information about the number of cache misses and their causes allows us to predict cache behavior and to detect bottlenecks. Small modifications in the source code may change memory patterns, thereby altering the cache behavior. Code transformations which take the cache behavior into account might result in a high cache performance improvement. However, cache memory behavior is very hard to predict, thus making the task of optimizing and timing cache behavior very difficult.

This dissertation proposes and evaluates a new compiler framework that analyzes and tunes cache behavior. The proposed framework is based on a new characterization of data reuse across multiple loop nests, which allows analyzing the cache behavior of whole programs with regular computations. The framework uses an accurate cost model that describes misses across different cache levels and considers the effects of other hardware components such as branch predictors, which drives the application of tiling and padding transformations. In order to select the best parameter values, we combine the cost model with a genetic algorithm to compute tile and pad factors that enhance the program performance.

Finally, our method explores the use of cache partitioning and dynamic cache locking to provide worst-case performance estimates in a safe and tight way for multitasking systems. We use cache partitioning, which divides the cache among tasks to eliminate inter-task cache interferences. We combine static cache analysis and cache locking mechanisms to ensure that all intra-task conflicts, and consequently, memory access times, are exactly predictable.

The results of our experiments demonstrate the capability of our framework to describe cache behavior at compile time. Extensive validation shows that our accurate cost model is appropriate to achieve significant speedups compared to state-of-the-art techniques. This dissertation also compares our timing approach with a system with a non-partitioned but statically locked data cache. Our method outperforms static cache locking for all analyzed task sets under various cache architectures, demonstrating that our fully predictable scheme does not compromise the performance of the transformed programs.

Markus Bohlin. Design and Implementation of a Graph-Based Constraint Model for Local Search. Licentiate Thesis.

Local search has during the last years evolved into a powerful technique for solving large combinatorial problems, often outperforming complete algorithms. The classical approach for generic constraint solving in local search is to provide a set of primitive constraints, which in turn can be used to form more complex combinatorial structures. Unfortunately, for several combinatorial structures there is no decomposition into binary constraints which is acceptable in terms of space and/or time complexity. Global constraints have been introduced in local search as time and space efficient modelling components, capturing the properties of common combinatorial substructures.

In this thesis we propose a compositional approach for global constraint design and implementation for local search. Traditionally, global constraints have been implemented as monolithic entities, often using a low-level language and requiring in-depth knowledge of the constraint system itself. In this work we propose to use graph structures, filters and cost components to create global constraints in a high-level C++ framework called Composer. The composed constraints can then be used for constraint solving in a generic, domain-independent local search solver. We show the theoretical model of the framework, and give algorithms for incrementally updating the costs and conflict levels of the constraints. We also show how to compose several well-known global constraints, and demonstrate by experimental results that a compositional approach at global constraint modelling is not only possible in practice, but also highly competitive with existing low-level implementations of constraint-based local search.

Jan Carlson. An Intuitive and Resource-Efficient Event Detection Algebra. Licentiate Thesis.

In reactive systems, execution is driven by external events to which the system should respond with appropriate actions. Such events can be simple, but systems are often supposed to react to sophisticated situations involving a number of simpel events occurring in accordance with some pattern. A systematic approach to handle this type of systems is to separate the mechanism for detecting composite events from the rest of the application logic. A detection mechanism listens for simple event occurrences and notifies the application when one of the complex event patterns of interest occur. The event detection mechanism can for example be based on an event algebra, i.e., expressions that correspond to the event patterns of interest are built from simple events and operators from the algebra.

This thesis presents a novel event algebra with two important characteristics: It complies with algebraic laws that intuitively ought to hold for the operators of the algebra, and for a large class of expressions the detection can be correctly performed with limited resources in terms of memory and time. In addition to the declarative algebra semantics, we present an imperative detection algorithm and show that it correctly implements the algebra. This algorithm is analysed with respect to memory requirements and execution time complexity. To increase the efficiency of the algebra, we also present a semantic-preserving transformation scheme by which many expressions can be transformed to meet criteria under which limited resource requirements are guaranteed. Finally, we present a prototype implementation that combines the algebra with the event system in Java.

Rikard Lindell. Towards new Interaction - A Content Centric Data Surface Approach. Licentiate Thesis.

Point-and-click, multiple views in windows stacked over each other, and menu selection were breakthroughs in the 70s and what was achievable with the computational power then available. The desktop metaphor explains to users the structure of file, directories, and programs. The computer industry has developed enormously since then. Computational power, the flow and deposits of information have now increased to a point where new approaches to interaction have to be considered.

This thesis presents a content-centric interface paradigm, which is called the data surface paradigm. The data surface paradigm contrasts with the desktop metaphor and elements of the desktop metaphor: windows, icons, menus, document files and application programs. The data surface paradigm is based on a reassessment of the fundamental design values of the desktop metaphor interface. It takes into account information navigation and retrieval, collaboration, and ongoing creative open-ended tasks and processes. As a design case the computer music creativity has been studied throughout the thesis. Interviews and observations of novices and expert users of music creativity tools identified their needs and inspired prototype designs. An iterative user-centred design process has been used to build and evaluate a series of three prototypes. Content is visualised on a flat infinitely large twodimensional surface. Users navigate

their content by zoom and pan, and incremental search. There are no windows. The unlimited area avoids the need to stack multiple views on top of each other. There are no icons. Content becomes its own icon when users zoom out, miniaturised in size but with preserved structure and metric relationships. There are no menus. Content affords typed commands and context help makes it easier for users to learn. Visual feedback and text completion of command substrings create a uniform model for command invocation and shortcuts. Users do not experience document files. The information content is visualised directly on the surface. Users have no need to deal with explicit file manipulation. The system manages the persistency of content. Users do not experience application programs. Small plug-in components provide services related to different information modality. Components are attached to the content, one component for each service and information modality. On the basis of cognitive science, observations, interviews, and usability evaluations of prototypes, strong indications sustaining the approach have been found. The final prototype was evaluated with 10 subject users. The prototype supported the services expected by the users, their creativity in action, and awareness in collaboration. Their responses to the final prototype were: "It feels free, it feels good for creativity, and it's easy and fun.

Markus Nilsson. A Case-Based Approach for Classification of Physiological Time-Series. Licentiate Thesis.

Complex measurement classification is often difficult, as in the medical domain, and it usually takes a long time to fully master all aspects involved. An automated measurement classification system would ease the diagnostic process for treatment personnel, especially for less experienced clinicians. This thesis contains results from research in the field of Artificial Intelligence (AI) applied to medical measurement classifications. Artificial Intelligence may be described as a variety of computational methods and techniques that exhibit intelligent behaviour. These methods and techniques enable problem solving comparable to humans.

The thesis presents a novel approach for multiple time-series analysis based on Case-Based Reasoning (CBR). CBR is an AI method based on a plausible cognitive model of human reasoning. The approach analyses parallel streams of measurements and uses CBR as well as other AI methods for classification and domain reduction. The approach is implemented as a system for classification of Respiratory Sinus Arrhythmia (RSA). The time-series are composed of physiological measurements as the system identifies dysfunctions within the RSA. RSA is identified by analysing the heart and the pulmonary systems of the human body. The developed system, named HR3modul, functions as a decision support tool for treatment personnel in the field of psychophysiological medicine. A classification proposal is presented to the user. The proposal is based on stored knowledge and current physiological time-series.

Mikael Sollenborn. Clustering and Case-Based Reasoning for User Stereotypes. Licentiate Thesis.

A user stereotype represents a certain kind of user who exhibits a set of specific characteristics - an abstraction of a group of similar users. Looking at statistical data gathered from a population of users, these groups can be identified either manually or using automated clustering techniques, and constructed by generalizing the most significant features of the identified groups. Case-Based Reasoning (CBR) is an Artificial Intelligence (AI) method based on the idea of reusing past experience in a domain-specific library of problem-solution descriptions, known as cases. By representing a solution to the problem of supplying a typical kind of user with appropriate information, it is natural to see user stereotype cases as part of a CBR process. This thesis describes the usage and creation of user stereotypes in novel domains, aided by the use of clustering techniques. The first application domain is personalization on the World Wide Web (WWW), where user stereotypes and a filtering technique called category-based filtering are combined to handle a frequently occurring problem on WWW sites attempting to automatically recommend items of interest to site visitors. In the second application domain, psychophysiological medicine, clustering is utilized to identify recurring patterns of previously classified time-series of Respiratory Sinus Arrhythmia (RSA). Using a combination of expert knowledge and repeated clustering, the aim is to incrementally build a case library of stereotypes which can be used in a CBR system for automated classification of RSA sequences.

2.6   Staff

Björn Lisper is professor in Computer Engineering at Mälardalen University since 1999, where he is responsible for the Computer Science research. He received his MSc (Engineering Physics) 1980, and Doctor of Technology (Computer Science) 1987, both from KTH, Sweden, where he also was appointed "docent" in Computer Systems (1991). He is a member of the board of the Vinnova-supported ASTEC competence centre in Uppsala, and of the steering group of the National Research School in Computer Science (CUGS). His current research interests are in programming language issues, targeting embedded, and real-time systems: program analysis and language design. He is also still interested in functional programming, and parallel computing.

Jan Gustafsson is Senior Lecturer in Computer Engineering at Mälardalen University since 1985. He has been the head of the department 1993 - 1997 and 1998 - 1999, and is one of the founders of the department, its educational programmes and its research.

He worked at ABB Västerås, Sweden 1975 - 1985 with development of real-time industrial control systems and was manager for the Base System Development (operating system, data communication and database system). He received a B.Sc. in Mathematics, Physics, Astronomy and Computer Science at Uppsala University, 1974, and a Licentiate degree in Machine Elements (Computer Controlled Mechanics) at KTH, Stockholm, Sweden, 1994. His current research concerns high-level analysis of real-time programs to calculate annotations to be used in WCET (Worst-Case Execution Time) analysis. His research is partly connected to ASTEC at Uppsala University. In May 2000 he graduated at Uppsala University.

Peter Funk is Senior Lecturer at Mälardalen University since January 1999 and leader the of the department's AI/Intelligent Systems group. He received his Ph.D. from the University of Edinburgh, Department of Artificial Intelligence (AI) for his research in knowledge based systems. Docent since 2002. He has been involved in industrial research at Ericsson for 9 year in the area of applied AI methods and techniques. He is the first who received the Wallenberg grant for scientific research three times. Winner of Mälardalen University's innovation competition, Idetävling >2002<. His research focuses on AI methods and techniques for industrial applications, and medical applications, intelligent human computer interaction and internet applications, to enable intelligent systems and functionality. His reseach and research projects have attracted more than 36 MSEK funding since he started his employement at Mälardalen University 6 years ago.

Gordana Dodig-Crnkovic is Senior Lecturer. She graduated 1979 in physics, received 1983 a M.Sc. and 1988 a Ph.D. in Theoretical Nuclear Physics, at the University of Zagreb. She is teaching Research Methodology for Computer Science and Engineering, Scientific Method in Computer Science, Professional Ethics in Science and Engineering, Formal languages, automata and theory of computation, and a National Course in Philosophy of Computer Science. Her research is in the area of Philosophy of Computation and Information, where she is also co-ordinating the national PI-network.

Andreas Ermedahl is a researcher at CSL. He holds a recent Ph.D on WCET analysis from Uppsala University. He now works in the WCET project at CSL.

Ning Xiong is a researcher at CSL. He holds a Ph.D. from University of of Kaiserslautern, previously employed at Royal Institute of Technology (KTH) and the Swedish Defense Research Agency (FOI). Main research interest are: Case-based reasoning, feature selection and machine learning; Computational intelligence techniques (e.g. fuzzy logic, neural networks and genetic algorithms) and their applications to process modeling and classification; Multi-sensor data fusion and time-series processing in relation with industrial CBR Systems.

Gunilla Eken is lecturer and director of undergraduate studies for the Computer Science programme at Mälardalen University. She is a member of the board for undergraduate studies at Mälardalen University. Gunilla received her MSc 1978 at KTH (Engineering Physics). She has been working at MdH since 1990, and before that in industry, mostly at ABB.

Boel Almér is lecturer at Mälardalen University since October 1999. She studied computer science (LTD) at Mälardalen University 1992-1995. She is lecturing courses in programming languages (Functional programming and Visual Basic) and she has developed a database course.

Christina Björkman is Lecturer and Ph.D. student. She received a MSc degree in Engineering Physics from the Royal Institute of Technology in 1983. She has been lecturer in Computer Systems at Uppsala university since 1985, where she in 2001 was involved in developing a new engineering programme. Her research interests are Gender issues in Computer Science Education. She is currently on leave of absence for research at Blekinge Institute of Technology.

Dan Levin is a Lecturer at CSL. He received a Bachelor of Technology in Linköping (1972). He has worked as a teacher at different levels for many years. He teaches mainly Programming and Algorithms & Data Structures. He is also involved in a Distance Learning Project at IDt.

Christer Sandberg is a Lecturer and PhD student at CSL. He received a Bachelor of Science at Mälardalen University 1994. He teaches mainly Programming, Algorithms and Data Structures and Compiler Theory. He is doing research within the WCET project.

Thomas Larsson is a Lecturer and Ph.D. student at the Department of Computer Engineering at Mälardalen University. His main interests are within the fields of real-time computer graphics, virtual reality and visualisation. He received a bachelor of computer engineering degree in 1996 a master of science degree, in computer engineering, in 1999, and a licentiate in computer science in 2003. Currently, he his working towards his PhD degree in the area of computer graphics.

Roger Jonsson is Lecturer and Ph.D. student at CSL. He received a Bachelor of Science in Applied Computer Engineering from Mälardalen University, Sweden (1995). His research interests is the theory of evolutionary algorithms

Rikard Lindell is a lecturer teaching computer graphics and Human-Computer Interaction. He is also a Ph.D. student with research interest in Human-machine interaction, and he received his licentiate degree in 2004.

Baran Çürüklü is a PhD student and lecturer. He received his Master of Science in Applied Computer Engineering from Mälardalen University, Sweden (1998), and his licentiate in 2003. His research interest is information processing in neocortex (computational neuroscience). His research is focused on population dynamics and different coding mechanisms used by the neurons in the primary visual cortex (V1) also known as the Broadmann's area 17.

Mikael Sandberg was a Ph.D. student and Lecturer at CSL until September 2004, and he is still enrolled as a Ph.D. student. He received a BSc in Computer Science from Mälardalen University (1999).

Jan Carlson is a Ph.D. student and lecturer at CSL. He received his M.Sc. degree in Computer Science from Linköping University, Sweden (2000), and his licentiate in 2004. His research interests include programming language design, functional and logic programming languages, and formal methods.

Xavier Vera was a Ph.D. student at CSL until January 2004, when he successfully defended his PhD thesis. He obtained his M.Sc. degree in Computer Science at Universitat Politecnica de Catalunya (UPC) in Spain (2000). His current research focuses on high level cache behaviour for embedded systems. Other topics: cache compiler optimizations and clustered architectures. He is now with Intel Labs in Barcelona.

Marcus Bohlin is a Ph.D. student employed by SICS. He received his licentiate degree in 2004. His area of research is local search methods in constraint programming.

Waldemar Kocjan is a Ph.D. student at CSL. Before 2004 he was employed by SICS, and January-June 2004 he was employed at CSL. He is still enrolled as a Ph.D. student. His area of research is efficient methods for solving dynamic constraint programming problems.

Markus Nilsson is an industrial Ph.D. student in artificial intelligence employed by PBM StressMedicine AB. His research interests are artificial intelligence methods and techniques for medical applications. He received his licentiate in 2004.

Mikael Sollenborn was an industrial Ph.D student until 20041231, employed by PBM StressMedicine AB and completed his Licenciate degree in 2004. His research focus was diagnosis in the medical domain using clustering, user stereotypes and case-based reasoning.

Johan Erikson is a PhD student at CSL. He received his M.Sc. degree in Computer Science from Mälardalen University in Västerås, Sweden (2002). His research is mainly focused at analysis of programming languages. Current activities deals with parallelization of software for Ericssons AXE-system.

2.7　　　　　　*National and International research co-operation*

CSL co-operates with the following national partners (academic only, industrial partners are listed in section 2.4):

- NADA, KTH on modelling of biological neural networks,
- IDA, LiU on the modelling language Modelica,
- Uppsala University, IT Dept., on WCET analysis,
- Lund University, Dept. of Computer Science, on Genetic Algorithms, and Computer Graphics,
- SICS on constraint programming, and human-machine interaction

The following international co-operation has taken place during 2004:

- The WCET group has participated in the Compilers and Timing Analysis cluster within the ARTIST2 EU Network of Excellence,
- Andreas Ermedahl collaborates with Friedhelm Stappert at C-lab in Paderborn on WCET analysis. A co-authored paper was submitted to IEEE Computer,
- Jan Gustafsson and Björn Lisper co-authored a paper (accepted for publication in Real-Time Systems) with Raimund Kirner and Peter Puschner of TU Wien, on program analysis for optimised single-path program execution,
- Peter Funk participates in an Intelligent Tutoring System project, at Trinity College (Owen Conlan), Dublin.

2.8　　　　　　*Services to the Scientific Community*

The following is a list of the most important services to the scientific community by members of CSL in 2004:

Björn Lisper:

- was on the program committees of the International Conference on Engineering of Reconfigurable Systems and Algorithms 2004,
- was discussion leader at Jonas Lundberg's Licentiate seminar at Växjö University,
- was on the grading committee of Sven Eklund (Halmstad University/Chalmers),
- served on the board for the ASTEC competence centre in Uppsala,
- was a member of the steering group of CUGS (National Graduate School in Computer Science) seated in Linköping.
- reviewed a number of papers for conferences and journals.

Peter Funk:

- was conference Chair and organizer of ECCBR 2004 (7th European Conference on Case-Based Reasoning) with Pedro A. Gonzalez Calero.
- was elected to the board of the Swedish Artificial Intelligence Society, SAIS, (deputy board member).
- was cited on back cover of one of the most influential AI lecture books (Luger 4th edition, Pearson Education 2004).
- was in Program Committee of AILS'04 , the 2nd joint workshop in Artificial Intelligence and Learning Systems
- was in Program Committee of KES'2004 Eighth International Conference on Knowledge-Based Intelligent Information & Engineering Systems
- was examiner for one licentiate thesis at Mälardalen University 2004 (Marcus Bohlin)
- was reviewer for Special Issue of the IJEB journal 2004.
- was Reviewer for conferences and workshops.

Jan Gustafsson:

- was PC Chair of ISORC 2004 (The IEEE International Symposium on Object-oriented Real-time distributed Computing) in Vienna, Austria. May 2004.
- was opponent at the licentiate presentation at the University in Lund May 18th 2004. Title of the thesis: Compiling Java for Real-Time Systems by Anders Nilsson.
- was session Chair at the 4th Intl. Workshop on Worst Case Execution Time Analysis, Catania, Italy, June 2004.
- was member of the PC of the IEEE Symposium on Reliable Distributed Systems (SRDS 2004), October 18-20, 2004, Florianopolis, Brazil
- was member of the PC of the International Journal of Computing and Information Technology (CIT) 2004.
- was member of the Steering Group for the intl. Workshops on Worst Case Execution Time Analysis.

Andreas Ermedahl:

- was on the program committee of the international WCET workshop in Catania, Sicily, Italy, June 29, 2004, in conjunction with the Euromicro conference on real-time systems.
- reviewed a number of papers for conferences and journals.

Gordana Dodig-Crnkovic:

- was coordinator of the PI-network: The Swedish national network on Philosophy of Informatics
- gGave an invited talk at the 2004 Annual Workshop of CUGS (The Swedish National Graduate School in Computer Science)
- reviewed papers for E-CAP 2004
- took part in the Scientific Committee of the MBR Conference
- i the director of E-CAP 2005 - Started preparations for the conference

Ning Xiong:

- was in the PC for ECCBR 2004 (7th European Conference on Case-Based Reasoning).
- was reviewer for for IEEE Transactions on Systems, Man, and Cybernetics journal.
- was in the program committee of SAIS-SSLS 2005.
- reviewed a number of papers for conferences and workshop.

2.9 Interactions with society

Björn Lisper is a member to the scientific advisory board of the journal Teknik & Vetenskap.

Andreas Ermedahl has coordinated and supervised a number of industrial case studies, where advanced timing analysis methods are being disseminated into industry.

The Programming Languages group arranged an industrial seminar on soft real-time systems together with Ericsson, where a number of Ericsson's leading experts gave talks on how their systems are organized to meet the demands on availability as well as real-time properties. (See http://www.mrtc.mdh.se/SoftRT/.)

Peter Funk was invited speaker to NORNA, the Nordic Natural Science Youth Summer Camp, July 2004. He was interviewed about his research and research projects at Mälardalen University a number of times, resulting in articles in national and regional press (Nyteknik, VLT, et.al.). He participated in a 5 minute film by the KK foundation about his research project. The film was used in their 10th anniversary as an example of an interesting research project (AI and medicine). He appeared on Radio Västmanland P4 broadcasting, together with Mats Jackson, about a new research project improving the competitiveness of Swedish production industry. Finally, he contributed with ideas on AI research based products to a spin-off company, AI Labs, with 5 former AI students (first product on the market).

3   The Software Engineering Laboratory (SEL)

Lab leader: Prof. Ivica Crnkovic

The mission of the Software Engineering Laboratory is to provide education in all relevant aspects of Software Engineering, and research in Systems and software engineering for industrial and embedded systems. To establish world class education and research in this utterly complex area extensive collaboration with industry is required.

SEL has a staff of 20 people: five senior researchers whereof two professors, one adjunct professor and two senior lecturers, 10 Ph.D. students (five of them industrial Ph.D. students), two research engineers, and three lecturers.

3.1   *Focus*

The main focus is directed towards industrial software and embedded systems engineering. Currently, research is carried out in the following areas:

Software engineering, in particular:

- Component-based software engineering
- Software configuration management
- Software development processes and software life cycles
- Software architecture of industrial systems

Embedded systems, in particular:

- Reintroduce analysability into existing systems.
- Architectures and reuse for automotive systems.
- Tailorable Embedded real-time databases.

Component models and architectures for Vehicular Systems in particular.

- Architecures, analysis and techniques for Open control system with extremely high reliability demands.

There is a balanced mix between industrially oriented and academic research.

3.2   *Education*

SEL is responsible for the courses in Software Engineering which are parts of both the Computer Science and the Computer engineering programs. The basic courses cover object-oriented programming and design while advanced courses are focused on different aspects of system and software engineering. The undergraduate courses are classified in different levels ("A" to "D") that approximately correspond to the different years of study. Information about the courses can be found at http://www.idt.mdh.se/kurser/.

SEL is repsonisible for the following courses:

Basic courses

- Introduction to Computer Science and Software Engineering
- Programming technique
- Algorithms and datastructures
- Programming with C++
- Object oriented programming

Middle level and advanced courses

- Object Oriented programming advanced course
- Software Engineering Course

- Component technologies
- Advanced Component-based software engineering
- Distributed Software Development
- Engineering for embedded systems
- Distributed Software Development

3.2.1 International Master Education in Software Engineering

International Master Education in Software Engineering lasts two semesters and includes advanced courses in software engineering and a master thesis. The students learn how to develop high quality complex software systems, which is invaluable for presumptive software architects, project leaders, and technical specialists. The laboratory's close cooperation with companies such as ABB, Volvo, and Bombardier is an additional strength and adds to the quality and relevance of the education.

Master year in Software Engineering is a part of University's International Master Academy.

3.2.2 Postgraduate courses

In 2004, SEL has organised the following postgraduate courses:

Component-Based Software Engineering – This is a joint course for MSc. and postgraduate students with different assignments. The course gives an introduction to component-based software engineering, in particular, the research trends.

Component Technologies – MSc. and postgraduate students attend the course from several universities in Sweden. The course gives an overview of different component-based technologies.

Research project planning course – The students have studied their research areas by writing short versions of state-of-the art reports and planning their research activities and methodologies

Methodologies in Case Studies – The course discusses different methods used in case studies in software engineering. In addition to the theoretical part in which studens discuss different papers, there is a practical part in which students perform a case study.

3.3 Research

During 2004, the research at SEL was organized in two research groups:

- The Industrial Software Engineering group
- The Embedded Systems Software Engineering group

The research at the laboratory relies on both internal and external funding. In 2004 SEL had external funding from EU, SSF, the KK-foundation, Vinnova (through the ASTEC competence centre), Ericsson, ABB, and Volvo.

3.3.1 Industrial Software Engineering group

The group focuses on research related to software engineering in industrial settings. Complex products, projects and organisations are the research target and the directions include technologies and processes. In particular different aspects of component-based technologies are considered. The group has intensive cooperation with industry, international research centra, and with universities in Sweden. The group closely cooperates with the Embedded Systems Software Engineering group as well as with groups from SDL.

The group consists of one professor and 8 PhD students, five of them industrial PhD students

The major results of this research in 2004 group were:

- Ph.D Thesis – Magnus Larsson, Predicting Quality Attributes in Component-based Software Systems

- Organisation of Euromicro Conference, Component-based Software Engineering Track, Rennes, France, September 2004.
- Organisation CBSE 2004 symposium at 25th International Conference of Software Engineering, Edinburgh, May 2004.
- Co-organisation of Swedish Fourth Conference on Software Engineering Research and Practise in Sweden, Linköping, Sweden
- Established cooperation with Technical University Eindhoven, The Netherlands
- Seminar presentation for EU commission – Component-based development for embedded systems

In 2004 the following projects have been active:

- APICS - Process for Efficient and Effective Integration of Component Based Software
- PSI – Prodact Dta Management and Software Data Magagement Interoperability
- FLEXCON - Flexible Embedded Control Systems
- Industrial IT
- ProPlat - Development and decisions processes
- STINA – Standard technologies in industral applications
- SAVE/Autocomp (a common project from both groups)
- DOTS – EU IST project in cooperation with MdH/IST

APICS - A Process for Efficient and Effective Integration of Component Based Software

Project Leader:	Ivica Crnkovic
Members:	Ivica Crnkovic
	Stig Larsson (Industrial Ph. Student)
	Fredrik Ekdahl (Industrial advisor)
Partners:	ABB
Funding:	ABB, SSF (SAVE-IT)

Project description

The project has started in Q2 2003. The research in Component Based Software Engineering has described requirements on individual components and the system aspects related to combination of components. However, the process for integrating components requires additional capabilities and characteristics to secure that the assembly of parts results in the expected product or system. These characteristics include both process oriented attributes such as review coverage and product oriented attributes such as performance. The goal of this project is to investigate and improve current practices in the integration of systems built on Component Based Software. The main research goal is to propose and evaluate integration processes for systems, with focus on real time systems.

Publications:

- *Selecting CMMI Appraisal Classes Based on Maturity and Openness,* PROFES 2004 - 5th International Conference on Product Focused Software Process Improvement, Kansai Science City, Japan. 2004 Author(s): Stig Larsson, F. Ekdahl
- *On the Expected Synergies between Component-Based Software Engineering and Best Practices in Product Integration,* In Euromicro Conference Rennes, France , August 2004. IEEE, Author(s): Stig Larsson, Ivica Crnkovic, Fredrik Ekdahl

PSI – Product Data Management and Software Configuration Management

Project Leader:	Ivica Crnkovic
Members:	Ivica Crnkovic
	Annita Persson Dahlqvist (Industrial Ph. Student)
Partners:	Ericsson
Funding:	Ericsson,
	KKS (SAVE-IT)

Project description

Product Data Management (PDM) is the discipline of controlling the evolution of a product design and all related product data during the full product life cycle, historically with the focus upon hardware product design. Software Configuration Management (SCM) is the discipline of controlling the evolution of a software product, with emphasis on the development phase. The PDM and SCM domains have evolved in parallel with none or little communication as the products were usually divided in software or hardware products. Today products are often complex systems consisting of hardware, software, and related documents, developed by several groups. This put high demands on support on several levels, both for the system level as well as for each group, especially during the development phase. One important requirement is the possibility to integrate product information systems where PDM and SCM is part of this integration. However the knowledge of software management and its relation to hardware management is very low. The possibilities to integrate PDM and SCM are one of the key factors in product information management of today. The companies have serious problems using PDM and SCM together, since the overall development process is usually complex and not properly defined, a common knowledge of both domains is low, and the integration possibilities provided by PDM or SCM vendors are limited. The first goal of this project is to investigate the similarities and differences between SCM and PDM, to analyse the requirements for their usage and to analyse the development processes using both PDM and SCM. The investigation is based on theoretical reasoning, literature study, and case studies from different industrial domains. The second goal is to propose an integrated model where both PDM and SCM are used in a common process and where information from these systems is exchanged. The feasibility of that model is validated in industrial case studies.

Publications:

- *Managing Complex Systems - Challanges for PDM and SCM*, Projects & Profits, IV-7(Rs 60):36-42, July 2004. ICFAI Press, Panjagutta, Indien, Author(s): Annita Persson-Dahlqvist, Ivica Crnkovic, Magnus Larsson

- *Quality Improvements by Integrating Development* Processes, In 11th Asia-Pacific Software Engineering Conference Busan, Korea , November 2004. IEEE, Author(s): Annita Persson-Dahlqvist, Ivica Crnkovic, Ulf Asklund

FLEXCON - flexibe controllers

Project Leader:	Karl-Erik Årzén Program director,
	Ivica Crnkovic, local project leader
Members:	Ivica Crnkovic
	Johan Fredriksson
Partners:	LTH Lund University
	KTH - Royal Institute of Technology
	HSV - Högskola Shövde
Funding:	SSF

Project description

The key challenge of FLEXCON is how to provide flexibility and reliability in embedded control systems implemented with COTS component-based computing and communications technology. Research is performed on design and implementation techniques that support dynamic run-time flexibility with respect to, e.g., changes in workload and resource utilization patterns. The use of control-theoretical approaches for modeling, analysis, and design of embedded systems is a promising approach to control uncertainty and to provide flexibility, which will be investigated within FLEXCON. Other focal points are quality-of-service issues in control systems, and testing-based verification and monitoring of flexible

embedded control systems. The main application area is adaptive industrial automation systems. An industrial robotics-based demonstrator will serve as the carrier of the project results.

Publications (from MRTC/SEL):

- *Quality Attribute Support in a Component Technology for Vehicular Software*, In Fourth Conference on Software Engineering Research and Practice in Sweden Linköping, Sweden, October 2004., Author(s): Mikael Åkerholm, Johan Fredriksson, Kristian Sandström, Ivica Crnkovic

- *Calculating Resource Trade-offs when Mapping Component Services to Real-Time Tasks,* In Fourth Conference on Software Engineering Research and Practice in Sweden Linköping, Sweden, October 2004., Author(s): Johan Fredriksson, Mikael Åkerholm, Kristian Sandström

- *Evaluation of Component Technologies with Respect to Industrial Requirements*, In Euromicro Conference, Component-Based Software Engineering Track Rennes, France , August 2004., Author(s): Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin

- *Introducing a Component Technology for Safety Critical Embedded Real-Time Systems*, In International Symposium on Component-based Software Engineering (CBSE7) Edinburgh, Scotland , May 2004. Springer Verlag, Author(s): Kristian Sandström, Johan Fredriksson, Mikael Åkerholm

Industrial IT

Project leader:	Ivica Crnkovic
Members:	Rikard Land (Ph.D. student)
	Kurt Wallnau (Industrial PhD student)
Partners:	ABB
	SEI/Carnegie Mellon University
	University of Zagreb
	Lund University
Funding:	The KK-foundation, ABB

Project description:

The architectural aspects (managing evolution of component-based systems), and semantic specification of components (contracts and component interfaces) are the main focus of the project. The project research work is also related to Software Configuration Management and Product Data Management. Several papers in this area have been published and the project members have been active in several international conferences and workshop.

Results:

Organisation of:

- Euromicro Conference, Component-based Software Engineering Track, Rennes, France, September 2004. IEEE
- Component-Based Software Engineering Symposium CBSE 2005, at 26th International Conference of Software Engineering, ICSE Edinburgh, Oregon , May 2004. IEEE
- SERPS´04 – Fourth Conference on Software Engineering Research and Practice in Sweden

Publications:

- *6th ICSE Workshop on Component-Based Software Engineering: automated reasoning and prediction*, ACM SIGSOFT Software Engineering Notes, 29(3):1-7, May 2004. ACM, Author(s): Ivica Crnkovic, Heinz Schmidt, Judith Stafford, Kurt Wallnau

- *Existing Approaches to Software Integration - and a Challenge for the Future*, In Fourth Conference on Software Engineering Research and Practice in Sweden Linköping, Sweden , October 2004., Author(s): Rikard Land, Ivica Crnkovic

- *Component-based approach for Embedded Systems*, In Ninth International Workshop on Component-Oriented Programming Oslo , June 2004., Author(s): Ivica Crnkovic

STINA - Standard Technologies in Industrial Applications

Project leader:	Ivica Crnkovic
Members:	Magnus Larsson (Industrial Ph.D. student)
	Frank Lüders (Industrial Ph.D. student),
Partners:	ABB
	CMU/SEI
Funding:	The KK-foundation,
	ABB

Project description:

The focus of the group is component-based software engineering (CBSE

), in particular use of the technologies for systems with stronger requirements. Component specification and predicable integration of the components is one of the group's research topics. Other topics are software configuration management and implementation of its principles to CBSE and component-based approach in designing systems with real-time requirements in industrial processes.

Results:

PhD thesis: Magnus Larsson, Predicting Quality Attributes in Component-based Software Systems

Publications:

- *Possible Implications of Design Decisions Based on Predictions*, In 26th International Conference on Information technology Dubrovnik, Croatia , April 2004. IEEE ,Author(s): Magnus Larsson, Ivica Crnkovic

- *Classification of quality attributes for predictability in component-based systems*, In DSN 2004 Workshop on Architecting Dependable Systems Florence, Italy , June 2004. IEEE, Author(s): Ivica Crnkovic, Magnus Larsson

3.3.2　　　Embedded Systems Software Engineering group

The core to a successful system is the basic architecture. We are studying the many aspects of architectures, especially related to embedded systems and reliability, which includes specification of architectures, architecture analysis, component models, and essential components, methods and tools in embedded systems. We are both considering models and analysis for developing new systems and techniques to reintroduce analyzability into existing systems. The basic approach is to formulate hypothesis and thereafter strengthen that hypothesis by extensive case studies, and finally prototype development. In 2004 we have performed several case studies, including starting the work to document existing knowledge about constructing complex software systems by interviews of architects of leading Swedish industries. This work aims at directly sharing experience between Swedish industries and to perform scientific analysis of available data and make results available to participating companies as well as the research community.

The group focuses on:

- Reintroducing analysability into existing systems.
- Architectures, reuse, and component integration for automotive systems.
- Tailorable Embedded real-time databases.
- Component models and architectures for embedded systems in general and Vehicular Systems in particular.
- Architecures, analysis and techniques for Open control system with extremely high demands on reliability.

The group consists of two professor, one senior lecturer, and 5 PhD students, 3 of them industrial PhD students.

The major results of this research group in 2004 were:

- Two licenciate theses (Joakim Fröberg and Goran Mustapic)
- Many papers at international conferences.

- A scientific methodology course on case studies for graduate students has been given..
- A paper in the Industrial Information Technology Handbook, Publisher IEEE CRC Press, December 2004.
- Establishment of a spin-off company (Zealcore)

In 2004 the following projects have been active:

- SAVE/ ComponentModel
- DRIVE
- COMET - COMponent-based Embedded real-Time database system
- OpenController
- REMODEL

Details of our projects in the design area are given below:

SAVE/ComponentModel

Project leader:	Kristian Sandström
Members:	Ivica Crnkovic
	Johan Fredriksson
	Mikael Åkerholm
Partners:	Save, Flexcon
Funding:	SSF

Project description:

Vehicles represents a class of embedded real-time systems where the requirements on safety, reliability, resource usage, and cost leaven all through development. The vehicular domain wants to practice Component based software development, which is a promising approach for efficient software development, enabling well defined software architectures as well as reuse. However, commercial component technologies are not used for those systems, they are simply to resource demanding, to complex and to unpredictable. The goal with the project is to define a component technology for resource constrained safety-critical embedded systems. The approach is to use a mature run-time platform such as a commercial real-time operating system, and enable component based design through powerful compile time techniques.

Results and achievements in 2004:

A component technology for Safety Critical Embedded RealTime Systems (AutoComp) where presented at the International Symposium on Component-based Software Engineering (CBSE7). This component model has also served as an important input for the the SAVE CCM component model. The concepts of the AutoComp component model have also been validated by the implementation and testing of the SAVE CCM model in an industrial system.

Publications:

- Mikael Åkerholm, Johan Fredriksson, Kristian Sandström, Ivica Crnkovic, Quality Attribute Support in a Component Technology for Vehicular Software. In Fourth Conference on Software Engineering Research and Practice in Sweden Linköping, Sweden , October 2004.
- Kristian Sandström, Johan Fredriksson, Mikael Åkerholm, Introducing a Component Technology for Safety Critical Embedded RealTime Systems. In International Symposium on Component-based Software Engineering (CBSE7) Edinburgh, Scotland , May 2004. Springer Verlag
- Mikael Åkerholm, Kristian Sandström, Johan Fredriksson, Interference Control for Integration of Vehicular Software Components. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-162/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May 2004

Future plans:

We will continue the research on predictable component models for embedded real-time systems (rts) and theories for efficient mapping of component models on to run-time systems for embedded rts. As a part of this research two licentiate theses will be presented in spring 2005.

DRIVE – Distributed Real-time systems In Vehicles

Project leader:	Christer Norström, MdH
Members:	Joakim Fröberg, Industrial Ph.D.-student at Volvo CE Components
	Kristian Sandström
Partners:	Volvo CEC
	Volvo Trucks
	Volvo Busses
Funding:	Volvo CEC
	the KK-foundation.

Project description:

On-board automotive electronic systems present a special problem formulation within in the domain of embedded systems in terms of reliability, cost, safety, and maintenance. At the same time, automotive industry faces challenges related to incleasingly complex systems. This project aims at providing guidance for analysing the business needs for a given organisation and providing guidance for design of architecture, selection of technology and methods for designing automotive on-board electronics. Especially, architectural and technical solutions for integration of electronic components will be addressed by a series of studies in automotive industry.

Results and achievements in 2004:

- Licentiate thesis defence April 04
- Article in IEEE Handbook on Information Technology in Industrial Automation.
- Conference paper presented in 5th IFAC International Conference on Fieldbus Systems and their Applications.
- VCE Electronic Architecture report.
- 2 Workshops on system architecture with industrial partners.
- A technical report on system engineering has been written.
- Four industrial case-studies on automotive architectures have been initiated and three of them have been completed.

Publications:

- *Engineering of Vehicle Electronic Systems: Requirements Reflected in Architecture*, Licentiate Thesis, Mälardalen University Press, April 2004, Author(s): Joakim Fröberg

- *A Comparative Case Study of Distributed Network Architectures for Different Automotive Applications*, In The Industrial Information Technology Handbook,pages 57-1 to 57-20, 2005. CRC Press ISBN: 0-8493-1985-4, Editor(s):Richard Zurawski, Author(s): Jakob Axelsson, Joakim Fröberg, Hans A Hansson, Christer Norström, Kristian Sandström, Björn Villing

- *A Comparative Case Study of Distributed Network Architectures for Different Automotive Applications*, In Handbook on Information Technology in Industrial Automation, 2004. IEEE Editor(s):Richard Zurawski, Author(s): Joakim Fröberg, Kristian Sandström, Christer Norström, Jakob Axelsson, Björn Villing

- *Real World Influences on Software Architecture - Interviews with Industrial Experts,* In IEEE Working Conferance on Software Architectures, Oslo, Norway Oslo , June 2004, Author(s): Goran Mustapic, Anders Wall, Christer Norström, Ivica Crnkovic, Kristian Sandström, Joakim Fröberg, Johan Andersson

- *Industrial Requirements on Component Technologies for Embedded Systems*, In International Symposium on Component-based Software Engineering (CBSE7) Edinburgh, Scotland , May 2004. Springer Verlag, Author(s): Anders Möller, Joakim Fröberg, Mikael Nolin

Future plans:

Focus on issues of electronic component integration in vehicle systems - PhD Thesis 06

COMET - COMponent-based Embedded real-Time database system

Project leaders:	Christer Norström, MdH
	Jörgen Hansson, LiU
Members:	Dag Nyström, Ph.D.-student, MdH
	Aleksandra Tesanovic, Ph.D.-student, LiU
	Mikael Nolin, MdH
Partners:	Volvo Construction Equipment Components AB,
	Mimer Information Technology AB
Funding:	SAVE

Project description:

This is a joint project between Mälardalen University and Linköping University. The goal of this research is to bridge the gap between embedded systems, real-time systems and database systems, with a particular focus on the software development tools. Significant amount of research has focused on how to incorporate database functionality into real-time systems without jeopardizing timeliness and how to incorporate real-time behaviour into embedded systems. However, research is sparse for embedded databases used in embedded real-time systems, which explicitly address (i) the development and design process, and (ii) the limited amount of resources in embedded systems. This type of research inherits the challenges from component-based software engineering, embedded systems, and real-time systems. Further, this research explicitly addresses system resource demand in the design of the embedded database in order to minimize system resource usage.

The goal is to build an experimental research platform for building embedded databases for embedded real-time systems. At a high-level, the platform consists of two parts. First, we intend to develop a component library, which holds a set of components that can be used when building an embedded database. Initially, we will develop a set of components that deal with concurrency control, scheduling, and main-memory techniques. At the next step, we develop tools that, based on the application requirements, will support the designer when building an embedded database using these components. More importantly, we want to develop application tools and techniques that support the designer in the composition and tailoring of an embedded database for a specific system using the developed components, and where the application requirements are given as an input. Further, we want to provide support to the designer when analysing the total system resource demand of the compositioned embedded database system; and help the designer by recommending components and methods if multiple components can be used, based on the application requirements.

Results and achievements in 2004:

Some of the results of the project include:

- Concepts for data management tools for embedded automotive systems. The tools together with the COMET RTDBMS, forms the COMET Development Suit.
- Extending the concurrency control algorithm 2V-DBP, to support hard real-time snapshot transactions. The new algorithm is denoted 2V-DBP-SNAP.
- A second implementation of COMET Real-Time Database Management System (RTDBMS), denoted MiniLine, suitable for static ECU configurations. COMET MiniLine is intended to interoperate with is larger counter part COMET BaseLine.

Publications:

- Dag Nyström, Mikael Nolin, Aleksandra Tesanovic, Christer Norström, Jörgen Hansson, "*Pessimistic Concurrency-Control and Versioning to Support Database Pointers in Real-Time Databases*", In The 16th Euromicro Conference on Real-Time Systems,pages 261-270 Catania, Sicily, Italy , June 2004. IEEE Computer Society

- Dag Nyström, Aleksandra Tesanovic, Mikael Nolin, Christer Norström, Jörgen Hansson, "*COMET: A Component-Based Real-Time Database for Automotive Systems*", In Workshop on Software Engineering for Automotive Systems.,pages 1-8 Edinburgh, Scotland, , May 2004. The IEE

- Dag Nyström, Mikael Nolin, Aleksandra Tesanovic, Christer Norström, Jörgen Hansson, "*Database Pointers: Efficient and Predictable Data Access in Real-Time Control-Systems*", in submission for Journal publication

Current activity: Integrating a real-time database mangement system (in our case COMET) as a part of the component framework (Save CCM), allowing components to be migrated among nodes in a distributed real-time system. Work on distributing COMET over a CAN network is planned. A doctoral thesis is planned in fall 2005.

OpenController

Project leaders:	Christer Norström
Members:	Goran Mustapic
	Anders Wall
	Peter Eriksson, ABB
	Ingemar Reyier, ABB
	Johan Andersson, ABB
Partners:	ABB Automation Technologies AB
	ABB Robotics
Funding:	ABB, ASTEC

Project description:

Industrial Robots are complex systems with hard real time, high reliability, availability and safety requirements. Robot Controllers are part of these systems and they are complex real time computers, which control a robot's mechanical arms. By their nature, Robot Controllers are generic and open computer systems, because to be useful, they must be programmable by end customers. This is typically done through software configuration parameters and a domain and vendor specific programming languages. For some purposes, this may not be sufficient. A way to add low- level software extensions to the system, basically extending the platform itself is needed, when for example a third party wants add a completely new sensor type that is not supported by the platform. The architecture evolution in this direction brings a whole new set of broad quality issues and other concerns.

Results and achievements in 2004:

Architectural analysis of an industrial robot control system from the quality perspective, to model and analyze effects of increasing openess, has been done.

Publications:

- Licentiate Thesis, Goran Mustapic, Architecting Software for complex embedded systems - Quality Attribute Based Approach to Openness, Mälardalen University Press, December 2004.

- *A Dependable Open Platform for Industrial Robotics - A Case Study*, Springer Verlag,, Author(s): Goran Mustapic, Johan Andersson, Christer Norström, Anders Wall

- *Real World Influences on Software Architecture - Interviews with Industrial Experts*, In IEEE Working Conferance on Software Architectures, Oslo, Norway Oslo , June 2004. IEEE, Author(s): Goran Mustapic, Anders Wall, Christer Norström, Ivica Crnkovic, Kristian Sandström, Joakim Fröberg, Johan Andersson

Remodel

Project leaders:	Christer Norström
Members:	Johan Andersson
	Anders Wall
	Björn Lisper
	Peter Eriksson, ABB
	Magnus Larsson, ABB
Partners:	ABB
Funding:	ASTEC, ABB

Project description:

When adding or changing code in a large software system, it can be hard to predict all effects of doing so. There is always a risk of introducing new bugs when fixing old ones. If the system has real-time

properities, it gets very interresting! Changing the features of a system also changes its timing, but to predict this impact is very hard, especially if the system is large. Today, many companies relies on extensive testing and hope they find all bugs before their customers do, but bugs related to timing can be very hard to find and reproduce, as they might only occur in very rare situations. Our approach is to create a model describing the timing of the system (i.e. when tasks execute and for how long, how they interact and so on) and use a set of tools to analyse it. For that we have developed the ART-ML modelling language, a simulator and have plans for a powerful data mining tool, the PPL query language. We have also developed a simulator. An ART-ML model describes the timing related attributes of the individual tasks in the system but also their behaviour from a temporal point of view. The behaviour is described in a imperative language with an explicit notation of time and probabilities. Time is explicitly consumed using a special statement and probability distributions are used to describe execution times. Further we plan to investigate how model can be automatically generated, either from the implementation (the code) or using observations, or a combination of both.

Publications:

- *A Dependable Open Platform for Industrial Robotics - A Case Study*, In , 2004. , Author(s): Goran Mustapic, Johan Andersson, Christer Norström, Anders Wall

- *Decreasing Maintenance Costs by Introducing Formal Analysis of Real-Time Behavior in Industrial Settings*, In Proceedings of the 1st International Symposium on Leveraging Applications of Formal Methods (ISoLA '04) Paphos, Cyprus , October 2004. , Author(s): Johan Andersson, Anders Wall, Christer Norström

- *Validating Temporal Behavior Models of Complex Real-Time Systems*, In Proceedings of the Fourth Conference on Software Engineering Research and Practice in Sweden (SERPS'04) Linköping, Sweden , September 2004. , Author(s): Johan Andersson, Anders Wall, Christer Norström

- *Real World Influences on Software Architecture - Interviews with Industrial Experts,* In IEEE Working Conferance on Software Architectures, Oslo, Norway Oslo , June 2004. IEEE, Author(s): Goran Mustapic, Anders Wall, Christer Norström, Ivica Crnkovic, Kristian Sandström, Joakim Fröberg, Johan Andersson

- *Correctness criteria for models' validation – A philosophical perspective*, In International Multiconferences in Computer Science & Computer Engineering, June 2004. , Author(s): Ijeoma Sandra Irobi, Johan Andersson, Anders Wall

3.4 Industrial co-operation

SEL has a wide co-operation with several industry companies, mostly related to industrial automation, industrial robotics, automotive and telecommunication. ABB and Volvo are very important partners that participate in several research projects and contribute to the research in form of industrial students and funding.

SEL has extensive cooperation with ABB Robotics and ABB Corporate Research. Several new projects have been started and common workshop, seminars and courses have been jointly organised. MdH/IDt has been identified as a strategic partner of ABB research in the area of software engineering. During 2004 there were 6 industrial graduate students sponsored by ABB.

The collaboration with Volvo Construction Equipment has continued and the industrial PhD student has completed his licentiate thesis in April 2004. A new project in the program Grön Bil has started which address safety issues. The collaboration has been extended with collaboration with Volvo Truck and Volvo Car. An Adjunct Professor from Volvo Car has joined SEL in March 2004.

Cooperation with Ericsson Microwave systems has continued and one industrial PhD student has joined SEL.

Cooperation with Bombardier has started. Several seminars have been given and one industrial PhD student has joined SEL.

3.5 Theses

In 2004 one PhD and 2 Licentiate theses were presented by SEL staff.

3.5.1 PhD Thesis

Magnus Larsson: Predicting Quality Attributes in Component-based Software Systems

Ph D Thesis 8, Mälardalen University Press, March 2004.

One of the major challenges to industry today is to provide products with high degrees of quality and functionality at low cost and short time to market. The cost and time to market requirements have quite successfully been addressed by the component-based approach. Unfortunately, satisfactory solutions for handling quality are not yet available. Hence, a still open challenge when building systems with software components is to accurately predict the quality attributes by the produced system. Component technologies widely used in office, desktop and internet domains provide support for integration of components into a system via well-defined functional interfaces. However, the quality attributes of the final software system, such as its performance, scalability or reliability, is not easy to determine for such systems, since current component technologies lack support for managing quality. For this reasons, the component-based approach, although attractive for many reasons, is difficult to utilize in domains in which quality attributes are of primary importance. This thesis demonstrates the possibility of developing component technologies that provide mechanisms for predicting quality attributes of software systems, given the quality attributes of their components. Moreover, a method that can be used to build prediction-enabled component technologies and validate the predictability theory is presented. The method is demonstrated by experiments and a discussion of two different attributes: latency and consistency. There are quality attributes that cannot be predicted equally accurately, if at all, as they lack a formal specification, measurement possibilities, and as they depend on many different factors, not only on properties of components. The thesis proposes a classification of different attributes from a prediction perspective: distinguishing quality attributes that can be predict directly from component properties, from those that need more information, such as usage profile or architecture. Having the means to reason about the qualities of a software design in the same way as one can reason about the qualities of a mechanical design is a dream of software engineers. By introducing predictability capabilities in component-based systems, this thesis is a small step towards fulfilling this dream.

3.5.2 Licentiate theses

Joakim Fröberg: Engineering of Vehicle Electronic Systems: Business Requirements Reflected in Architecture

Automotive vehicle electronic systems are developed facing a complex and large set of inter-related requirements from numerous stakeholders, many of which are internal to the Original Equipment Manufacturer, OEM. The electronic architecture, of the product, or its structure and design principles, form an equally complex construct; including technology and methods, which ultimately should be chosen to optimally support the organization's own business situation. Designing a complex computer system such as an in-vehicle electronic system is a process of choosing solutions that best meets the huge set of, often conflicting, requirements. In fact, the main part of the requirements does originate from the OEM business processes such as production, aftermarket support, variant handling, verification, and commonality.

The complexity of the large set of inter-related business requirements and the evolutionary design makes implications of design solutions difficult to understand. In this thesis, we have investigated four vehicle architectures and analyzed the relationship to their respective business requirements and business context. The study shows four functionally rather similar products with computer controlled power train, body functions, and instrument. The architectures might therefore be expected to be rather similar, but this study shows that the architectures deviate from strictly product centered design where product performance and features are the main goal of design.

In the light of this business situation, we explain the solutions and why design principles are pursued. The analysis shows that despite a common base of similar vehicle functionality the resulting electronic architectures used by the four organizations are quite different. The reason for this becomes apparent when looking at different business context and business requirements and their affect on the architecture. Differences in business situation drive the use of different methods for integration, different standards, different number of configurations, and different focus in the development effort. Some key parameters in business situation affecting architectural design decisions are shown to be product volume, size of market, and business requirements on openness and customer adaptation.

An important lesson from this is that one should be very careful to uncritically apply technical solutions from one industry in another, even when they are as closely related as the applications described in this work. Understanding the requirements from the business case is the key to choosing architectural solutions.

Goran Mustapic: Architecting Software for Complex Embedded Systems - Quality Attribute Based Approach to Openness

There has been such an increase in the complexity of systems embedded in modern industrial robots, construction equipment, cars, trains, systems in telecommunication networks etc. that the engineering of such systems requires the coordinated efforts of tens or hundreds of engineers. These engineering efforts are multidisciplinary, requiring software engineers, control engineers, hardware engineers etc. to work together in the design and implementation of the systems concerned. Many have a lifetime of 10-20 years which means that their maintenance must be carefully planned. Furthermore, most of the systems can be classified as safety-critical or dependable systems. The importance of software in complex embedded systems is increasing and software quality issues are becoming first level concerns. One of the keys to success in industry in the future will be the ability to develop high-quality embedded systems and their software on time in order to remain competitive. The complexity and size of these systems requires a systematic approach to software architecture analysis and design. To advance research in this area, we need to improve our understanding of software architecting for these systems. Among the disadvantages of current methods of software architecture design are that they target "pure" software systems and that they make simplifying assumptions that software architecture design of embedded systems begins from a well-defined, fixed list of requirements for a software subsystem. This thesis is divided into two parts and has two main objectives. In the first part, we describe the state of practice of software architecting of complex embedded systems. The objective here is to get a better understanding of the factors that influence the software architecture design of complex embedded systems. In the second part of the thesis, we study industrial robots, as open, complex embedded systems that can be extended and programmed by third party. The objective is to determine how software quality concerns and in particular dependability concerns can be systematically approached when system openness is increased. The main contributions of the thesis are the following. Several important common factors which influence the architectural design of complex embedded systems software are identified, the state of the practice is described and some areas that require further research are identified. In considering the design of open robotics system, the thesis shows which dependability means need to be applied in the architecture design phase, to support system openness. The dependability means are systematically applied within the context of software architecture approach based on quality attributes. The results presented in this thesis are based on industrial experience from the author's work as an engineer-researcher and from systematically performed interviews with several industry experts having positions as senior architects or similar in companies that develop complex and long-lived embedded systems.

3.6 Staff

Jakob Axelsson is adjunct professor in software and systems engineering. Systems. He studied Computer Science in Linköping, Sweden, and Lausanne, Switzerland. He received an M.Sc. from Linköping University in 1993, and a Ph.D. in 1997 for a thesis on hardware/software codesign of real-time systems. He has been working at ABB Corporate Research and ABB Power Generation (now Alstom) in Baden, Switzerland, Volvo Technological Development (now Volvo Technology) and Carlstedt Research & Technology in Göteborg, Sweden. He is currently with the Volvo Car Corporation in Göteborg, where he is program manager for research and advanced engineering for electrical and electronic systems. He is also chairman of the boards of the ARTES and SAVE-IT national graduate schools in real-time and embedded systems, and was until recently president of the Swedish chapter of the International Council on Systems Engineering (INCOSE).

Ivica Crnkovic is a professor of industrial software engineering at Mälardalen University where he is the administrative leader of the software engineering laboratory and the scientific leader of the industrial software engineering research. His research interests include component-based software engineering, software configuration management, software development environments and tools, as well as software engineering in general. Professor Crnkovic is the author of more than 40 refereed articles and papers on software engineering topics and a co-autor and co-editorof two books: Builiding releiable component-based Systems, and Implementing and integrating Product Data Management And Software Configuration Management. He has co-organized several workshops and conferences related to software engineering (in particularly component-based software engineering) and participated in Program Committees of software configuration management symposia and workshops. From 1985 to 1998, Professor Crnkovic worked at ABB, Sweden, where he was responsible for software development environments and tools. He was a project leader and manager of a group developing software configuration management systems and other software development environment tools and methods for distributed development and maintenance of real-time systems. From 1980 to 1984, he worked for the Rade Koncar company in Zagreb, Croatia. Professor Crnkovic received an M.Sc. in electrical engineering in 1979, an M.Sc. in theoretical physics in 1984, and a Ph.D. in computer science in 1991, all from the University of Zagreb, Croatia.

Christer Norström is professor in software and systems engineering. Previously, he was working as manager for future technology at ABB Automation Technology Products/ Robotics. He is also one of the founding members of the department. He has also worked as a consultant, in particular for the automotive industry. Christer has given numerous courses on real-time system for industry both in Sweden and in Europe. His research interests are design of real-time systems, reliability and safety methods, software engineering, and architectures for real-time systems. Christer is very interested in technology transfer from academia to industry which he has manifested that through several successful transfers to the automotive industry. Christer is member of the board of the Västerås Technology park and Robotdalen. He is also chaimen for the newly established spin-off company Zealcore Embedded Solution AB. Christer was previously department chairman at the Department of Computer Engineering, Mälardalen University. He received a Ph.D from Royal Institute of Technology (KTH), Stockholm in 1997, became Docent at KTH in 2001, and professor at Mälardalen University 2002. In year 2001 he was awarded best teacher at Mälardalen University.

Sasikumar Punnekkat has joined as a Senior Lecturer at Department of Computer Engineering in November 2004. He received Master Statistics (1982) and Master of Technology in Computer Science with honors (1984) from the Indian Statistical Institute. He joined the Indian Space research Organisation in 1984, and was involved in the design, development and testing of software for satellite launch vehicles. During 1993-97, he was recipient of the prestigious Commonwealth Scholarship and was awarded Doctor of Philosophy in Computer Science by the University of York, UK for his thesis on "schedulability analysis of fault tolerant real-time systems". Dr. Punnekkat was a post-doctoral research fellow (1999-2000) at Malardalen University and had worked on Real-Time aspects of Control Area Networks. He was a Senior Scientist at the Software Quality Assurance Division of Vikram Sarabhai Space Centre, India and was the Head of software test and Reliability Engineering during 2001-2004. Dr Sasikumar Punnekkat has more than 20 research publications in international conferences and journals. His research interests span various aspects of real-time systems, fault-tolerant computing, software engineering, software reliability and software testing.

Kristian Sandström is a Senior Lecturer in computer engineering. He received a Ph.D from the Royal Institute of Technology, Stockholm (2002). He has for many years given graduate, post-graduate, and industrial courses in several topics including; enginering of complex embedded systems, real-time systems, and distributed real-time systems. His research interest includes architecture, design, analysis, and implementation of embedded real-time systems with high demands on reliability. Furthermore, Kristian has worked as an embedded systems expert consultant for the industry during the last 8 years. He is one of the founders of the spin-off company ZealCore, where he works part time as a senior embedded systems expert responsible for company technology.

Anders Wall is a researcher at SEL He received his M.sc in computer science from Uppsala university in 1994, his Ph.Lic from Uppsala university in September 2000, and his Ph.D. from Mälardalen University in September 2003. Anders has three years of industrial experience from SW-development of industrial control systems at ABB. His research interest includes design of real-time systems, software architectures, component based software engineering for real-time systems and formal methods for real-time systems. He has given courses on software engineering, data communication, and project management at Mälardalen University.

Jukka Mäki-Turja is Lecturer and Ph.D. student. He received Bachelor of Science in Applied Computer Engineering from Mälardalen University, Sweden (1993) and Philosophiae Licentiate in Computer Science from Linköping University, Sweden (1997). His research interests are design of real-time systems, distributed real-time systems, scheduling theory, and analysis of real-time systems.

Joakim Fröberg Software Engineering Lab at the Department of Computer Science and MRTC Mälardalen University. Joakim Fröberg is an Industrial Ph.D. student employed Volvo Construction Equipment Components AB where he is working with electronic system architecture guidelines and integration issues at the department of product development/electronics. Joakim is also a Ph.D. student at the Software engineering laboratory where he is working in the DRIVE project to study requirements and design of vehicle electronic architectures. He received his M.Sc. in Industrial Control System at Salford University 1996 and his

licentiate degree at MdH 2004. His research interests include architectures of vehicle computer-based systems, but also systems and requirements engineering related to engineering of vehicle electronics.

Dag Nyström, former undergraduate student from the "Datateknikprogrammet". Enrolled as a Ph.D. Student at IDE (In that time known as IDt) in december 2000. Focussing on data management in vehicle control-systems. Working within the COMET project (sub-project under SAVE), developing the Real-Time Database Management System COMET, and methods to efficiently manage data in complex embedded systems. Teacher in the Operating Systems Course Teacher/developer of the Introductionary course in Computer Science. Head (Programansvarig) of the MIMA Software Engineering programs (2 programs). Guest Teacher in the Database Course

Johan Andersson Johan received a Masters degree in Computer Engineering at Mälardalen University in 2002, where he had studied since 1998. After the thesis project at ABB Robotics, he continued at the company as a consultant, working with embedded software development. In april 2003, he enrolled at MRTC as an industrial PhD student, financed by ABB and ASTEC. He currently spends about 50 % of his time in the Remodel project at MRTC and the rest in a related project at ABB.

Martin Skogevall is a Lecturer at SEL. He received a Masters of Computer Science at Mälardalen University in 2001. He teaches Object Orientation (introduction and advanced course). His interests are in software development and computer graphics.

Åsa Lundkvist is a lecturer and director of undergraduate studies at IDt. She received her Masters of Mathematics at Stockholm University in 1986 and has worked in various companies in Sweden, United States, France and United Kingdom before taking a position as lecturer at IDt. Åsa teaches programming languages.

Daniel Flemström is a lecturer at Mälardalen University since June 1999. He recieved his Master Of Science from Mälardalen University, Sweden 1995. He is teaching courses in programming languages, algorithms and data structures (C++/Java) and Component Based Technologies. Daniel is also giving a series of courses in advanced Industrial IT programming (VB and C++) at the ABB Academy.

Magnus Larsson was an industrial Ph.D. student employed by ABB Automation Products AB since 1993 and currently he is working as Program Manager for Software Architecture and Processes at ABB corporate research. He received a BSc at Mälardalen University and a MSc at Uppsala University 1995. He is interested in Component-based development, Software Configuration Management and real-time systems. He presented his licentiate thesis "Applying Configuration Management Techniques to Component-based Systems" in December 2000 and his Ph.D thesis on 'predicting Quality Attributes in Component-based Software Systems' in March 2004.

Frank Lüders is an industrial Ph.D. student, employed jointly by Mälardalen University and ABB Automation Products AB. His research interests include software engineering, software architecture, and distributed real-time systems. Frank received a BSc in Electronics Engineering from the Vestfold College, Norway in 1993, and a MSc in Electrical Engineering/Computer Systems from the Technical University of Denmark in 1997. He worked as a systems engineer at ABB Norway until November 1999.

Christina Wallin is an industrial Ph.D. student employed by ABB Corporate Research. Her main research interest is Software Engineering Processes. Hwer licentiate thesis "A process approach for senior management involvement in software product development" was presented in December 2004.

Rikard Land has been employed by Westinghouse since 1998 where he has worked as a software developer. The topic for his Master's thesis was a case study on software architecture at Westinghouse, and he received a M.Sc. at Mälardalen University 2001. Since then he has been employed at Mälardalen University as a Ph.D. student. His interests are software architecture and component-based software as a means of understanding and managing software evolution and integration. His licentiate thesis "An Architectural Approach to Software Evolution and Integration" was presented in September 2003.

Goran Mustapic is an industrial PhD student working at ABB Automation Technologies AB/ Robotics in Västerås. He received Electrical Engineering degree from University of Zagreb, Croatia in 1994. After spending several years in industry, working as a Software Engineer, he enrolled the PhD program at MdH in 2002. In December 2004, he received Technology Licentiate degree. The licentiate thesis title is "Architecting Software for Complex Embedded Systems - Quality Attribute Based Approach to Openness". Research interests include: Software Quality and Quality Modeling, Software and Systems Architecture, and their application in open complex real time systems.

Mikael Åkerholm is a PhD student at SEL. He received a master's degree in computer science and engineering from Mälardalen University in 2003, and continued with PhD studies at the same department directly. Mikaels research interests are component based software engineering, real-time, safety-critical, and embedded systems. He is participating in the SAVE project, which is a research project that tries to enable component based software engineering for safety critical vehicular systems.

Johan Fredriksson (MSc. 2002, BSc. 2001) is a Ph.D. student at SEL, a part of the Department of Computer Science and Engineering (IDt) at Mälardalen University (Mdh), and has been so since the beginning of 2003. Previous to commencing his graduate education, he was an undergraduate at the department between 1998-2002. Johans research interests are middlewares in component technologies, real-time for safety-critical, and embedded systems. He is participating in the SAVE project, which is a research project that tries to enable component based software engineering for safety critical vehicular systems.

Stig Larsson is an industrial Ph.D. student and is working as a scientist at ABB Corporate Research. His main reserach interest is software engineering. His experience includes management of company wide technology projects and management of development organizations with software and hardware development in several sites. He is responsible for product development processes in ABB. Stig Larsson recieved his MSc in Electrical Engineering from the Royal Institute of Technology, Stockholm, Sweden 1983.

Annita Persson Dahlqvist is a specialist in configuration management, software configuration management, and product data management at AB. She is the manager for the CM Managers group. She is also responsible for training, starting up new projects, process development, and supporting the organization regarding configuration management, and product data management issues. She earned her B.Sc in computer science from the University of Gothenburg, Sweden 1985. She has been working for Ericsson AB since 1985.

Kurt Wallnau has 20 years of experience in software research and development. Mr. Wallnau currently leads the Predictable Assembly from Certifiable Components (PACC) exploratory research project at the Software Engineering Institute (SEI) at Carnegie-Mellon University, Pitsburgh, US.. Prior to this work on PACC, Mr. Wallnau led work in the SEI COTS-Based Systems initiative. This work culminated in the Addison-Wesley book in the SEI Series, Building Systems from Commercial Components. At MdH he is working with his PhD thesis.

3.7 National and International research co-operation

SEL cooperates with the following national partners (academic only, industrial partners are listed in Section 1.1):

- Uppsala University, IT Dept., on real-time and component-based technology, in projects ARTIST, SAVE and within ASTEC
- KTH, on embedded systems and component-based approach in projects SAVE and FLEXCON
- Linköping University, on embedded systems, component-based approach in project SAVE
- Skövde Högskola, in the FLEXCON project
- Lund University, Dept. of Computer Science, on Software Engineering and embedded systems, projects Industrial IT and FLEXCON
- SICS on human-machine interaction
- Blekinge Institute of Technology, Department of Software Engineering and Computer Science, on Software Engineering.

The following international co-operation has taken place during 2004:

Ivica Crnkovic

- has been active (responsible for a workpackage) in EU IST project DOTS and EU CBSENet network group.
- has been active in ARTIST and ARTIST2 EU-IST Network of Excellence
- has started cooperation with L'aquila University, Italy, which resulted in students' exchanges

- has continued cooperation with University of Zagreb, Croatia in performance of a common course.
- has started cooperation with several universities and faculties in Croatia (Osijek, Split, Varazdin, Business and Management School n Zagreb)
- organiser of conference croatian researchrs of technical sciencies in Croarian and abroad.
- has continued cooperation with Technical University Eidhoven, The Nehterlands- mutual guest lectures have been organised

Christer Norström

- has been involved in the formation of the European network of Excellence - ARTIST2
- collaborates with the PACC project at Software Engineering Institute at Carnegie Mellon University in US and ABB.

3.7.1 Cooperation with International Software Engineering Groups

The Software Engineering Laboratory has started or continued already established cooperation with the following international research and education centers:

- Software Engineering Institute (SEI) at Carnegie Mellon University, Pittsburgh, US
- Monash University, Melbourne, Australia
- University of Zagreb, Croatia
- University of Split, Croatia
- Software Engineering Institute at CMU
- Technical University in Eindhoven, The Netherlands
- L'aqiula University, Italy
- Tufts University, Boston, US

Software engineering Insitute, Carnegie Mellon University

The Software Engineering Laboratory (SEL) has continued cooperation with SEI in the Component-based Software Engineering (CBSE) field, with focus on predictable assembly of certifiable components. The goal of this cooperation is to develop methods for efficient use of software components and from the known properties of components predict the behavior of the systems composed from these components. Predictability is of special interest for systems with specific requirements, in particular real-time, embedded and safety-critical systems.

In 2004 the activities related to this cooperation include:

- Kurt Wallnau, researcher at SEI has started to work on his PhD at IDt, with Ivica Crnkovic as advisor.
- SEI, University of Monash, Australia, Tufts University, US and MRTC organized a CBSE symposium at the ICSE conference in Toronto (CBSE 2005).
- SEI was actively involved in Euromicro CBSE conference track organized by SEL
- SEI, MdH and ABB Robotics worked on a research project related to component-based development.

Monash University, Australia

The Software Engineering group has continued cooperation with Monash University. In addition to activities listed above, Prof. Heinz Schmidt visited MRTC several time discussing SAVE and other related projects. Prof. Heinz Schmidt is a member of the advisory board for the SAVE project.

University of Zagreb, Croatia

Faculty of Electrical Engineering and Computing, University of Zagreb and SEL has cooperation in undergraduate and graduate education. The course was held in autumn 2004 as a common course (examinators prof. Mario Zagar, Zagreb , and Prof. Ivica Crnkovc, MdH).

Eindhoven University of Technology (TUe)

SEL has continues cooperation with Eindhoven University of Technology, The Netherlands. A plan for cooperation has been done, and possible some master and PhD students will be exchanged between the research centers, and a text book about CBSE will be developed.

L'aqualia University

Cooperation has been established between prof Paola Inverardi and Prof. Ivica Crnkovic. The cooperation includes exchange of master and PhD students and organisation of ESEC/FSE conference (European software engineering conference/Foundation on software engineering conference)

3.8   Services to the Scientific Community

The following is a list of the most important services to the scientific community by members of SEL in 2004:

Ivica Crnkovic

- Organiser of CBSE track on IEEE Euromicro Conference in Rennes, France, September 2004
- Program chair of CBSE symposium at IEEE international conference on software engineering in Edinburgh, May 2005, US
- The opponent on the PhD theses of A. Fiukov and E. Eskanazi at Technical University Eindhoven, the Netherlands, November 2004
- The opponent on the PhD thesis of Otto Preiss, Universify of Luisagne, Schwitzerland, April 2004
- Guest Lecturer at L'aqualia University, Italy, June 2004
- Invited speaker at CBSE Workshop at Manchetser University, May 2005
- Invited speaker at EU commission, CBSE for embedded systems
- Tutorial CBSE for embedded systems at Automated Software Engineering Conference, Linz, Sep. 2004
- Invited keynote at CIGRE Croatia congress
- Invited speaker on Microsoft Academy conference, Stockholm, Nov. 2004
- Invited speaker at Technical University, Eindhoven, The Netherlands, November 2004
- PC Chair of CBSE 2004 symposium at International Conference on Software Engineering
- PC Chair of Euromicro conference, CBSE track
- PC member for following conferences, symposia and workshops: CBSE 2004, WICSA 2004, ITI 2004, TELCOM 2004, SERPS'04, WADS 2004
- Expert evaluator for several applications to different European Foundations
- Co-editor of a special issue of Elsevier's Journal of Systems and Software- Component-based Software Engineering.

Christer Norström

- Guest editor for a special issue on factory communication in IEEE Transactions on Industrial Electronics
- Member of the International Advisory Board for "The Industrial Information Technology Handbook", IEEE CRC Press. The book comprises 112 individual chapters, around 1,400 pages, and published in December 2004.
- Member of the programme committee for IEEE Workshop on Factory Communication Systems WCFS2004 in Wien.
- Member of the PhD examination committee for Nicholas Wickströms, Chalmers Institute of Technology.
- Member of the PhD examination committee for Elisabeth Uhlemann, Chalmers Institute of Technology.

- Has in collaboration with Kristian Sandström been supervising Joakim Fröberg to completion of a licentiate degree. April 2004.
- Has been supervising Goran Mustapic to completion of a licentiate degree December 2004.

Jakob Axelsson

- Opponent to Mattias Weckstén's licenciate at Halmstad/Chalmers, April 2004
- Examinator for Goran Mustapic's licenciate at MdH, December, 2004
- Examiner and organizer of the graduate course Case-study Methodology
- Seminar presentation at IDA, Linköping University September, 2004
- Panelist at CODES-ISSS i Stockholm 040911
- Presentation at SecLink seminar, Eskilstuna, November 2004
- Chairing the board of ARTES
- Member of the board of INCOSE Sweden
- Charing the board of SAVE-IT
- PC member of CBSE 2004
- Reviewer for Microprocessor and Microsystems and Transactions on Embedded Computer Systems Journals

Kristian Sandström

- Has in collaboration with Christer Norström been supervising Joakim Fröberg to completion of a licentiate degree. April 2004.
- Reviewer for conference papers

3.9 Interactions with society

Ivica Crnkovic

- has organised Open-source Seminar for Västmanland, October 2004

Christer Norström

- has been giving several public lectures about the current development in embedded systems.
- has held a presentation for the EU-conference Industrial Change Network about growth and Robotdalen.
- has held a presentation for the Ministry of Industry, Employment and Communication about growth and Robotdalen.
- has been chairmen and driving force for an informal network about industrial IT and automation in Västerås. The objective of this network is to find new business opportunities.
- is member of the board of Västerås Technology Park.
- is member of the board of Robotdalen.

Kristian Sandström

- has given industry course in engineering of complex embedded systems.
- has initiated and been leading cooperation with a secondary school, providing student and teacher exchange.
- Is chairing the board of ZealCore Solutions AB

Jakob Axelsson

- Work on Technology Management MBA-T together with Christer Norström and Ylva Boivie.

4 The Systems Design Laboratory (SDL)

Lab leader: Prof. Hans Hansson

The mission of the Systems Design Laboratory (SDL) is to provide engineers with scientific methods and tools for designing safety-critical real-time systems. The goal is to advance state-of-art and practice for developing such systems into a mature engineering discipline, i.e., in analogue with the scientifically well founded methods and tools for mechanical construction. SDL develops methods for constructing safety-critical real-time systems, ultimately capable of guaranteeing their multitude of requirements to be fulfilled.

SDL has a staff including 9 senior researchers and 16 postgraduate students, the majority heavily involved in research. Equally important is the undergraduate education, where SDL is responsible for computer systems related courses, with a particular focus on computer based real-time systems.

4.1 Focus

In fulfilling its vision of a mature engineering discipline for safety-critical real-time systems SDL is currently focusing on:

- Design and specification methods for real-time systems. Especially models and high level analysis of embedded real-time systems with respect to both functional (like temporal, reliability and safety) and non-functional attributes (like maintainability and testability).
- Resource handling and scheduling, with an emphasis on assessing timing requirements.
- Predictable run-time systems, i.e., run-time systems amenable to analysis of functional and temporal correctness.
- Verification, including formal verification of system models as well as testing methodologies, both considering functional as well as timing aspects.
- Communication predictability, including performance analysis and methodologies for predictable communication services.

The majority of SDL activities are performed in close co-operation with industry and/or with an intention to actually produce results that in the short or medium term are beneficial for industry.

The focus is defined by the research, but is also clearly visible in the education.

4.2 Education

SDL is responsible for the majority of computer systems related courses at MdH, and is responsible for the MSc programme in real-time systems. Members of the lab frequently give specific postgraduate courses, courses for industry, guest lectures at other universities and tutorials at conferences.

SDL is responsible for the following undergraduate courses:

- Programming with C
- Operating Systems
- Data Communication
- Distributed Systems
- Real-Time Systems, basic course
- Real-Time Systems, advance course
- Safety-Critical systems

The basic course in real-time systems is the SDL core profile course. It is a course that with an engineering perspective introduces the elements and techniques for predictable real-time systems. This basic course is followed by more specialised courses (Advanced Real-Time Systems and Safety-Critical Systems) covering more advanced material.

During 2004, the MSc programme in Real-Time Systems was offered as one of the international programmes Master' within MIMA (Mälardalen International Masters Academy).

The pedagogical philosophy of the SDL courses is that they should contain both theory and a lot of practical exercises to train the students in both the art and craft of designing, implementing, verifying, and documenting complex software systems. Many courses also include aspects of project management, since the sheer size of some exercises necessitates collaboration of several students.

To motivate the lecturers to give their best performance and recognise excellent teaching achievements, a reward is annually given to the best lecturer of the group. This reward was for 2004 given to Henrik Thane.

In addition to the heavy involvement in undergraduate education, SDL researchers were involved in the following postgraduate courses in 2004:

- Research Methodology for Computer Science and Engineering (fall) [Hans Hansson, Gerhard Fohler]
- Concurrency Theory and Time (spring; given both at MdH and at Universitat Islas Balears) [Hans Hansson]
- Research Planning (fall; a course given within the ARTES graduate school) [Hans Hansson]

4.3 Research

The SDL research is focused on developing methods and tools for the design of safety-critical real-time systems, and is naturally structured into the following interrelated areas:

1. Design, in which we study design methods, architectures, architecture description languages, high level analysis on an architecture level, formal methods, and how to map architectures to a resource structure.

2. Predictably flexible real-time systems, in which algorithms and architectures to combine static and dynamic components are developed, thereby allowing the traditionally contradictory requirements of predictability and flexibility to be combined.

3. Monitoring, Testing and Debugging, in which methods and tools for real-time systems testing, debugging and monitoring are developed..

4. Platforms, in which novel real-time systems operating systems prototype and techniques are developed.

5. Real-time methods for multi-media processing, which applies and adapts real-time methods to meet requirements for high quality video and audio streaming, e.g., in home entertainment networks.

6. Small embedded devices.

7. Communication Performance, Predictability and Analysis, in which performance of communication subsystems is studied, as well as predictability and performance analysis of such systems.

Concretely, the research is conducted by the following co-operating research groups:

Predictably Flexible Real-Time Systems group, dealing with predictably flexible real-time systems and multi-media.

Communication Performance Predictability and Analysis group, dealing with Small embedded devices; traffic measurement and analysis

Monitoring and Testing group, dealing with monitoring, testing, and debugging of real-time systems

Real-Time Systems Design group, dealing with design methods, architectures and communication for real-time systems

In the following sections, the research in these groups is elaborated on, and projects and achievements in 2004 presented. More information about the project areas and specific projects can be found at www.mrtc.mdh/sdl.

4.3.1   Predictably flexible real-time systems research group

The staff and partners in this group are:

Group leader:	Gerhard Fohler
Members:	Damir Isovic
	Tomas Lennvall
	Radu Dobrin
	Larisa Rizvanovic
Partners:	Krithi Ramamritham, Indian Institute of Technology (IIT), Mumbay, India.
	Giorgio Buttazzo, Scuola Superiore S.Anna, Pisa, Italy
	Pau Marti, Josep Fuertes, Universitat Politecnica de Catalunya, Barcelona, Spain
	Liesbeth Steffens, Philips Research, The Netherlands
	Alan Burns, University of York, UK
	Michael Gonzalez-Harbour, University of Cantabria, Spain
	CSEM Switzerland
	Thomson Multimedia, France
	TU Eindhoven, The Netherlands
	IMEC, Belgium
	University of Cyprus, Cyprus
	C-LAB, Germany
	Industrial System Institute, Greece

Area description:

Predictability and flexibility have often been considered as contradicting requirements, in particular from the scheduling perspective. This strong exclusion, however, holds only for predictability on a very detailed level, which is not demanded in most scenarios. Our research identifies appropriate levels of predictability, extends algorithms and architectures to combine static and dynamic components, and enables designers to combine predictability and flexibility.

Real-time systems need to be reliable in order to be applicable in real-world environment. Our approach to reliability follows the lines of timeliness: Instead of providing for static solutions only, we provide for adaptive fault tolerance and self-evolving systems. Issues include scheduling, dynamic reconfigurations of hardware structures, and reliability measures.

In addition to these core areas, we have been investigating into extending the aforementioned principles in the areas of wireless networking and multimedia streaming under limited resources. We use the scheduling and resource reservation mechanism above to flexibly process MPEG-2 video streams

The following are the concrete projects in this area:

FIRST - Flexible Integrating Scheduling Technology – EU IST Project

The objective of the proposed research is to develop a real-time scheduling framework for applications demanding various types of tasks, constraints, and scheduling paradigms within the same system. The FIRST project will investigate the following issues:

- co- operation and coexistence of standard real-time scheduling schemes, time- triggered and event-triggered, dynamic and fixed priority based, as well as off-line based.
- integration of different task types such as hard and soft, or more flexible notions, e.g., from control or quality-of-service demands, and fault-tolerance mechanisms
- temporal encapsulation of subsystems in order to support the composability and reusability of available components including legacy subsystems
- FIRST will provide functionality for the schemes for POSIX compliant operating systems, including monitoring and maintenance of control systems over the Internet.

Project leaders:	Gerhard Fohler
Members:	Radu Dobrin

	Tomas Lennvall
	Robert Johansson, Research engineer
Partners	University of York , UK
	Universidad de Cantabria Spain
	Scuola Superiore S. Anna Pisa, Italy

FABRIC- Federated Applications Based on Real-time Interacting Components Architecture for a ubiquitous computing platform – EU IST Project

FABRIC - Federated Applications Based on Real-time Interacting Components Architecture for a ubiquitous computing platform – is an EU IST RTD project coordinated by Philips Research, The Netherlands. The project started 2002 with a duration of 18 months. It addresses issue in Inhome Entertainment Networks of Ambient Intelligence, in particular the issues of cross standard streaming.

Project leaders:	Gerhard Fohler
Members:	Larisa Rizvanovic
Partners	Thomson Multimedia, France
	INRIA, France
	Technische Universiteit Eindhoven, The Netherlands
	Scuola Superiore S. Anna, Pisa, Italy
	University College London, UK
	TNO, The Netherlands
	CSEM, Switzerland.

BETSY - BEing on Time Saves EnergY – EU IST Project

The aim of the BETSY project is to have multimedia streams on wireless hand-held devices seamlessly adapted to fluctuating network conditions and available terminal resources while reducing the energy consumption of the stream processing. This way the user can enjoy true multimedia experiences with freedom of movement in a networked home or at any hot-spot.

To achieve this, we need to be able to make trade-offs between the use and consumption of network and terminal resources, such as bandwidth use, CPU consumption, memory needed and power consumption by the terminal, while guaranteeing end-to-end timeliness - required for streaming data. The results of the BETSY project will make this possible.

Project leaders:	Gerhard Fohler
Members:	Damir Isovic
Partners	IMEC, Belgium
	University of Cyprus, Cyprus
	C-LAB, Germany
	Universität Stuttgart, Germany
	Industrial System Institute, Greece
	Philips Research, Netherlands
	Technische Universiteit Eindhoven, Netherlands
	CSEM, Suisse

Real-time Architecture for Networked Multimedia Streaming systems – Mälardalen University's personal grant for a graduate student

In a few years' time, most home entertainment devices, such as TV sets and VCRs, will be fully digital, demanding computing methods to match strict temporal demands of audio and visual perception. Consequently, the concept of ``one cable - one box'' will be replaced with pictures and videos available where and when demanded in-home as part of ambient intelligence in the living space. Similarly, video transmission and communication over mobile phone is already starting to become commonplace.

Key challenges to be addressed include specification of stream and resource characteristics, high demands on processing and timely delivery of multimedia streams, wireless communication between devices and transmission of streams, and architectures for the integration of numbers of devices from various

manufactures with diverse demands and capabilities. This project is planned to work on real-time architectures for networked multimedia streaming systems.

The project in this area faces challenges on a theoretical level, as new algorithms have to be developed which can match the varying multimedia streams with the varying network and CPU resources, with experimental aspects, as many parameters and trade-offs for the algorithms have to come from experiments and cannot be "calculated", all the way to implementation work, developing and implementing new architectures for system capable of handle such networked streaming issues.

FLEXCON - Flexible Embedded Control Systems – SSF

The key challenge of FLEXCON is how to provide flexibility and reliability in embedded control systems implemented with COTS component-based computing and communications technology. Research will be performed on design and implementation techniques that support dynamic run-time flexibility with respect to, e.g., changes in workload and resource utilization patterns. The use of control-theoretical approaches for modeling, analysis, and design of embedded systems is a promising approach to control uncertainty and to provide flexibility, which will be investigated within FLEXCON. Other focal points are quality-of-service (QoS) issues in control systems, and testing-based verification and monitoring of flexible embedded control systems. The main application area is adaptive industrial automation systems.

Project leaders:	Gerhard Fohler
Members:	Damir Isovic
Partners	Lund Institute of Technology - Department of Computer Science
	DAMEK - Royal Institute of Technology
	DRTS Group - University of Skövde
	ABB Robotics and ABB Automation Product

ARTIST – Advanced Real-time Systems, EU Network of Excellence, FP5

In actionline three: Adaptive Real-Time Systems for Quality of Service (QoS) Management.

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

| **Partners** | http://www.artist-embedded.org/Overview/ |

ARTIST – Advanced Real-time Systems, EU Network of Excellence, FP6

In Cluster Adaptive Real-time: this is a more recent approach to embedded systems design, where temporal constraints can be relaxed, which allows optimized use of resources. This includes applications – where managing the Quality of Service (QoS) is essential, such as telecommunication systems, multi-media, and wide-area networked applications. In this relatively new area, there is a recognized lack of design theory and tools.

| **Partners** | http://www.artist-embedded.org/FP6/Overview/ |

Publications:
Thesis

- Damir Isovic: Flexible Scheduling for Media Processing in Resource Constrained Real-Time Systems, Phd Thesis, Mälardalen University Press, November 2004.

Book contributions

- Pau Marti, Josep M. Fuertes, Gerhard Fohler: Networked Control Systems - An Overview, The Handbook on Information Technology in Industrial Automation(editor(s):Richard Zurawsky), CRC Press/IEEE Press, 2004.

Journal papers

- Damir Isovic, Gerhard Fohler, Liesbeth Steffens: *Real-time issues of MPEG-2 playout in resource constrained systems*, International Journal on Embedded Systems, 1, issue 2(ISSN 1740-4460), Cambridge International Science Publishing, June 2004.

Reviewed conference articles

- Weirong Wang, Al Mok, Gerhard Fohler: *Pre-Scheduling on The Domain of Integers*, IEEE Real-Time Systems Symposium, Lisbon, Portugal, December 2004.
- Damir Isovic, Gerhard Fohler: *Quality aware MPEG-2 stream adaptation in resource constrained systems*, 16th Euromicro Conference on Real-time Systems (ECRTS 04), Catania, Sicily, Italy, July, 2004
- Radu Dobrin, Gerhard Fohler: *Reducing the Number of Preemptions in Fixed Priority Scheduling*, In 16th Euromicro Conference on Real-time Systems (ECRTS 04), Catania, Sicily, Italy, July, 2004
- Weirong Wang, Al Mok, Gerhard Fohler: *Generalized Pre-Scheduler*, 16th Euromicro Conference on Real-time Systems (ECRTS 04), Catania, Sicily, Italy, July 2004.
- Manel Velasco, Pau Marti, Giorgio Buttazzo, Gerhard Fohler: *Managing Quality-of-Control Performance Under Overload Conditions*, 16th Euromicro Conference on Real-time Systems (ECRTS 04), Catania, Sicily, Italy, July 2004.
- Larisa Rizvanovic, Gerhard Fohler: *The MATRIX: A QoS Framework for Streaming in Heterogeneous Systems*, In RTMM - International Workshop on Real-Time for Multimedia, Catania, Sicily, Italy, June 29, 2004, June, 2004
- Peter van der Stok, Jan Jelle Bloomgaardt, Helmut Burklin, Gabriele Cecchetti, Jean-Dominique Decotignie, Hermann de Meer, Gerhard Fohler, Johan Lukkien, Gerardo Rubino: *The FABRIC project*, In First European Workshop on Software Architecture (EWSA 2004), with ICSE 2004, St Andrews, Scotland, May, 2004

4.3.2 Communication Performance, Predictability and Analysis group

Performance, predictability and analysis are important issues in the development of communicating real-time systems, soft real-time as well as hard real-time. For hard real-time systems, predictability and analyzability are properties of crucial importance. Communication designed for such systems must thus be predictable on all levels. Of special interest is how communication for small embedded systems can be designed and implemented with predictability and analyzability as primary requirements, while still maintaining performance. For systems with soft real-time requirements, a number of important issues have gained interest recently. Using the Internet as a data transport medium is one such issue. Although the Internet was originally designed to give best-effort service only, the performance of the Internet is indeed analyzable and predictable, although only statistically. In order to achieve such predictability, suitable models of Internet traffic must be developed. Traffic analysis and traffic modelling are therefore two important research issues on the path towards predictability of cross-Internet traffic performance. An issue of importance is the usage and performance of small nodes in massive systems, sometimes called sensor networks. Small nodes with limited resources, connected in massive networks, pose important research questions regarding connectivity, routing and resource utilization.

COMSED - Communication for Small Embedded Devices

Project leader: Mats Björkman
Members: Jonas Neander
Adam Dunkels
Partners: SICS
Funding: CUGS, SICS and internal

Project description:

Communication for small embedded devices pose several challenging problems, two of these are addressed in this project. One problem is how to minimize the resource consumption of the communication subsystem in such small embedded devices, while still maintaining performance and predictability.

This includes the study of how to minimize code sizes and memory usage, as well as how to design protocols for communication in a network of such systems so that the protocols themselves minimize resource utilization in the network, while still achieving good and predictable performance. The other problem that is studied is how to use proxies to offload small embedded devices. Research has so far concentrated on so-called front end proxies, where communication is routed through proxies and thus terminated short of the small embedded. In this project, we will study back-end proxies, where communication is terminated beyond the small embedded device.

The semantics of systems with such proxies and their performance is central to the project.

During 2004, Delay Tolerant Networks and their applicability in sensor networks have been studied, as well as the adaptation of real-time scheduling techniques to hierarchical sensor networks.

Future plans:

During 2005, the techniques for addressing and power management will be addressed. Also, asymmetrical protocols for lower radio power consumption will be investigated. Two licentiate theses are planned.

Traffic Measurement and Analysis

Project leader: Mats Björkman
Members: Henrik Abrahamsson
Partners: SICS
Funding: VINNOVA
         SICS
         Internal

Project description:

This project concerns traffic measurements and analysis in computer networks. The main focus is on methods and methodology for measurements and analysis, but tools for measurement are also a part of the project. Traffic measurement and analysis is important in today's and future networks. More powerful methods are however needed. Traffic characterization is an important first step towards development of more precise and powerful models for analysis or synthesis of traffic. Problems studied in this project include: models for generation of synthetic traffic, aggregated traffic and flow stability, and dynamic measurements for routing and load balancing.

Achievements:

Traffic characterization methods have been investigated and evaluated; bi-modal as well as multi-modal models have been studied and applied to real traffic traces. The issues of aggregated traffic and flow stability have been further studied, together with the applicability of traffic characterization in traffic analysis.

Future plans:

During 2005, the applicability of traffic characterization in traffic analysis will be in main focus.

EvaluNet – Network Performance Evaluation

Project leader: Mats Björkman
Members: Andreas Johnsson
         Bob Melander
         Svante Ekelin
Partners: SICS
         Ericsson Research
Funding: VINNOVA
         Ericsson Research
         SICS
         Internal

Project description:

EvaluNet is focused towards tools and methods for traffic characteristic estimation. A number of issues are addressed in the project. One issue concerns the combination of active and passive measurements in order to obtain faster and more accurate estimations. Another issue concerns the sharing of measurement results between clients having parts of a path in common. This could be done in order to reach more accurate estimations with less injected traffic. A third issue is how to perform network tomography from a set of peer-to-peer measurements, i.e. to obtain a multidimensional estimation of the network topology

and characteristics from a set of point-to-point measurements. A fourth issue is how to use advanced filtering in the estimation process.

Achievements:

Studies of the impact of cross traffic on estimation accuracy. Studies of the use of advanced filtering in the estimation process. Initial studies of performance in wireless networks.

Future plans:

During 2005, an architecture for shared measurements will be designed and evaluated. Studies on cross traffic effects on throughput and delay variance will be studied. Further studies of the use of advanced filtering in performance analyses will be performed. One licentiate thesis is planned.

EvaluNet II

Project leader:	Mats Björkman
Members:	Ewa Hansen
	Andreas Johnsson
	Bob Melander
Partners:	Gatorhole AB
	Ericsson Research
Funding:	KKS
	Ericsson Research
	Gatorhole AB
	Internal

Project description:

EvaluNet II is an enlargement and continuation of the ongoing EvaluNet project, and industry partners are Ericsson Research and Gatorhole AB. The research questions addressed are an extension to those of the EvaluNet project, the focus of EvaluNet II is on the development of network bandwidth measurement tools for use by network operators as well as end consumers.

EvaluNet II will leverage on the results from the VINNOVA funded EvaluNet project, especially the algorithms for bandwidth measurement and prediction developed there.

Achievements:

Studies of the impact of cross traffic on estimation accuracy. Studies of the use of advanced filtering in the estimation process. A prototype tool for bandwidth measurements has been developed.

Future plans:

During 2005, further studies of the use of advanced filtering in performance analyses will be performed. More advanced tools for network bandwidth measurements will be developed.

4.3.3 MTD Research Group (Monitoring, Testing and Debugging)

Group leader:	Henrik Thane
Members:	Anders Pettersson
	Daniel Sundmark
	Joel Huselius
	Mathias Ekman
	Sigrid Eldh
	Hans Hansson (associated)
Partners:	ABB Robotics
	ABB Corporate Research
	Bombardier Transportation
	ENEA Real-Time AB
	SAAB Avionics
	Volvo Construction Equipment Components AB

Zealcore Embedded Solutions AB
Level Twenty One AB
Ericsson
IAR Systems
Skövde University

Description

The goals of this research group are to develop methods for decreasing the ever accelerating cost for corrective software maintenance. In the industry today the largest part of the lifecycle cost for a typical computer based product is spent on corrective maintenance, i.e., testing and debugging. According to a recent study by NIST up to 80% of the life cycle cost for software is spent on testing and debugging. The increasing complexity of software, along with a decreasing average product development time, has increased the costs of errors.

The software used in industrial automation systems, vehicular control systems, medical devices, telecommunication, as well as in military and space applications have a high degree of software complexity. This complexity is typically caused by the usage of multiple embedded computers, millions of lines of program code, several concurrently interacting programs (multi-tasking) and dependence on an external context in real-time. A known fact is that bugs often are introduced early in the design but not detected until much later in the product lifecycle, typically during system integration and early customer acceptance tests (as illustrated in Figure1, graph C and D). For embedded real-time software this fact makes the situation really difficult since most failures that are detected during integration and early deployment tests are extremely difficult to reproduce, due to a large degree of interaction between software, hardware and the environment. This makes debugging of embedded concurrent systems costly, since repetitive reproductions of the failure is necessary in order to track down the bug. What makes matters worse is the fact that the actual act of observation may change the behaviour of the system, especially if the observation is performed using some software other than the application code (causing a probe-effect).
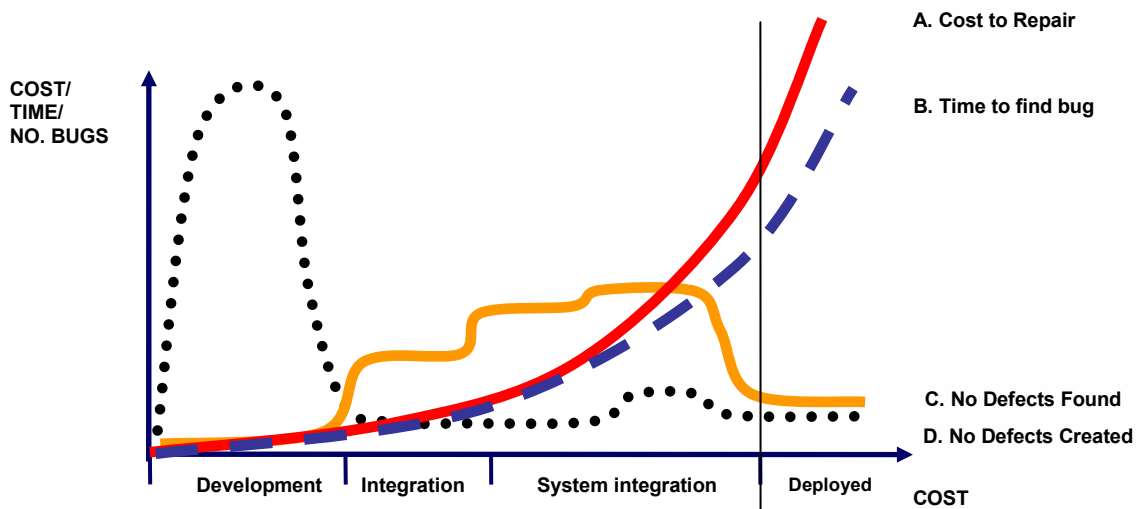

Figure 1. Graph *D*, shows the number of bugs introduced per lifecycle phase. Graph *C*, shows the number of bugs found per phase. That is, bugs are often introduced early but found late. Graph *B*, shows the relative time it takes to find one bug. More complex bugs are only found during later stages of software/hardware/environment interaction in combination with significant subsystem integration. Graph *A*, shows the cost per bug. The later a bug is found the more expensive it is, due to possible system redesign and the time spent to find it.

As Figure 1 (graph D) illustrates, the largest part of a software project is spent on corrective maintenance in the system integration, and the deployment phases; essentially 70% of the resources spent on testing and debugging is spent there. The industry is today dealing with corrective maintenance in the later phases using brute force, in terms of manpower. Consequently, the competitive edge becomes, in the long run, the cost for labour.

The availability of methods and tools dealing with testing and debugging in the later lifecycle phases are next to non existent in both academia and industry. Most existing methods deal with the development phase and the early integration phase, and usually assume that the product is designed from scratch. Most new products are however, evolved from code inherited from previous products. It is not uncommon that the legacy comprises the effort of 100s or 1000s of man-years. Consequently, current methods and tools are not appropriate, since the systems are not developed from scratch.

Results and achievements in 2004:

During 2004 a number of publications were published and presented, with Daniel Sundmark's Licenciate Thesis in March as a highlight.

Theses

- Daniel Sundmark. *Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components,* Licentiate Thesis, ISBN 24, Mälardalen University Press, March, 2004

Reviewed conference articles

- *Monitored Software Components - A Novel Software Engineering Approach -*, Daniel Sundmark, Anders Möller, Mikael Nolin, In The 11th Asia-Pacific Software Engineering Conference, Workshop on Software Architectures and Component Technologies, p 8, IEEE, Pusan, Korea, November, 2004.

- *Constant Execution Time Recording for Replay of Sporadic Real-Time Systems.* Joel G Huselius, Henrik Thane. In Proceedings of the 2:nd Workshop on Compilers and Tools for Constrained Embedded Systems (CTCES) Washington D.C., USA , September 2004.

Technical Reports

- *Replay Debugging of Embedded Real-Time Systems: A State of the Art Report*, Daniel Sundmark, MRTC report ISSN 1404-3041 ISRN MDH-MRTC-156/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, February, 2004

- *Predictable Assemblies using Monitored Software Components*, Daniel Sundmark, Anders Möller, Mikael Nolin, MRTC report ISSN 1404-3041 ISRN MDH-MRTC-160/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May, 2004

- *Results from the Validation of ECETES.* Joel G Huselius. Technical Report , Department of Computer Science and Engineering at Mälardalen University, January 2004.

LESS BUGS

Project leader:	Henrik Thane
Members:	Daniel Sundmark,
	Anders Pettersson
	Mathias Ekman
Partners:	Bombardier Transportation
	Level Twenty One AB
	Zealcore Embedded Solutions AB
Funding:	KKS
	Bombardier Transportation
	Internal

Project description:

In this project we propose research on improvement of the debugging and testing processes for deployed complex industrial systems as well as for systems with large legacies of program code. In previous projects we have successfully developed techniques for improving the debugging and testing process for complex embedded systems. Some of the results have even resulted in a spin-off company. We will elaborate and expand on that work and add real industrial constraints. Constraints such as:

- System dependencies on external environments in real-time
- Large amount of legacy software
- Highly standardized development environments with standard compilers, debuggers, and operating systems

- Low tolerance to performance degradation for diagnostic purposes. That is, diagnostic systems can only add 2-5% to the system load and should consume a minimum amount of memory.

Essentially, we want to find answers to the following questions:

- How to improve the diagnostic means in complex systems based on standard components, standard development environments, and standard operating systems, where a large legacy needs to be taken into account? That is, how to introduce diagnostic systems for testing and debugging in existing or new target systems with minimal performance degradation and without having to redesign the system.
- How can we decrease the time and money spent on debugging of complex software systems using tools and methods rather than brute force (people and money) as applied in the industry today? This work would entail an extension of our previously successful work on using black-box recorders and deterministic replay methods for reproducing complex failures during debugging of real-time software. Specifically, we would evolve the results from small embedded real-time systems to larger more complex industrial software systems running on standard operating systems like Microsoft Windows NT/2000/XP/Pocket PC or Linux.
- How to make use of the deterministic replay method in order to accelerate testing in complex industrial systems in later life cycle phases? This would essentially involve the usage of deterministic replay technology for regression testing and forced testing coverage, which otherwise is extremely hard to achieve using existing technologies. This would significantly expand on our previous work on testing.

4.3.4 Real-Time Systems Design Group (RTSD)

Group leaders: Hans Hansson/Mikael Nolin
Members: Kaj Häninen
Anders Möller
Thomas Nolte
Jukka Mäki-Turja (associated)
Partners: CC-Systems (Jörgen Hansson)
Arcticus Systems (Kurt-Lennart Lundbäck)
Volvo Technology (Henrik Lönn)
Volvo Construction Equipment (Nils-Erik Bånkestad)
LiU/RTSLAB (Jörgen Hansson/Simin Nadj-Tehrani)
KTH/DAMRK (Martin Törngren/Ola Redell)
UU/UppAal (Paul Pettersson/Wang Yi)

We are currently focusing on:

- Scheduling for real-time control systems.
- Architectures and reuse for automotive systems.
- Component based software development for vehicular systems
- Tradeoffs between reliability and timing requirements
- Real-Time Communication

Details of our projects are given below:

SAVE

Project leader:	Hans Hansson
Members:	Mikel Nolin
	Thomas Nolte
	Henrik Thane
	Joel Huselius
Partners:	LiU/RTSLAB (Jörgen Hansson/Simin Nadj-Tehrani)
	KTH/DAMRK (Ola Redell/Martin Törngren)
	UU/UppAal (Paul Pettersson/Wang Yi)
Funding:	SSF

Project description:

SAVE (Component Based Design of Safety Critical Vehicular Systems) is a national project supported by the Swedish Foundation for Strategic research (SSF) with 17MSEK during 2003-2005. SAVE is co-ordinated by Hans Hansson at SDL, and additional partners in SAVE are MRTC/SEL, LiU/RTSLAB, KTH/DAMEK, and UU/UppAal.

The goal of SAVE is to establish an engineering discipline for systematic development of component-based software for safety critical embedded systems. This will be vital to the Swedish industry, and paves the way for establishing an industry for safety-critical and other components.

The main innovation of SAVE is the interdisciplinary combination of architectural and component based design with analysis and verification, in the specific context of safety and real-time. The focus on a single application area (vehicular systems) will reduce the overall project complexity to a manageable level.

The main challenges in component-based development of safety critical applications are to handle the multitude of conflicting requirements, including safety vs. cost and time-to-market. Reuse of earlier work and integration of external components and sub-systems are essential in reducing cost and time-to-market, and the use of proper design methods and architectures is instrumental to accomplish this. Structuring is equally important, together with verification, to ensure safety.

SAVE is addressing the above by developing a general framework for component-based development of safety-critical vehicular systems, including

- Methodology and process for development of systems with components
- Component specification and composition, providing a component model which includes the basic characteristics of safety-critical components and infrastructure supporting component collaboration.
- Techniques for analysis and verification of functional correctness, real-time behaviour, safety, and reliability.
- Run-time and configuration support, including support for assembling components into systems, run-time monitoring, and evaluation of alternative configurations.

The following is a report of the activities and achievements in SAVE by SDL during 2004 (see also the corresponding report for SEL)

Main Activities

During 2004 our main activities within SAVE has been

- Research on component models for embedded systems. Design and development of SaveCCM (SaveComp component model) [Hans Hansson/Mikael Nolin].
- During the year, Joel Huselius initiated work on Dynamic Model synthesis (one publication accepted for CSMR05, a second publication submitted for publication). The essence of the work is to, by using recordings of the execution of a running system; create a model that can deliver the same behavior as that observed. The modeling language used is ART-ML, a probabalistic language developed at MdH by Anders Wall, Johan Andersson, and Jonas Neander. The intended use for the models is in impact analysis and in model verification.

- Thomas Nolte has been doing research on server-based scheduling of vehicular communications. Thomas has also been working with vehicular communications technologies, looking at, for example, CAN and FlexRay. This has resulted in 6 publications (1 conference/symposium, 2 workshops, 2 book-chapters and 1 journal publication, the book-chapters and the journal publication are accepted and finalized for publication, will be published during 2005).
- Management: Project management (Hans Hansson), and preparation of the SAVE-IT industrial graduate school (Hans Hansson, Mikael Nolin, Ylva Boivie)

Academic co-operation

Participation in the EU Network ARTIST – Action line on Component Based Design

Hans Hansson visited Universitat de les Illes Balears March-May, where he collaborated with Guillermo Rodriguez-Navas and Julian Proenza Arenas, regarding safety, fault-tolerance and modelling/verification.

Thomas Nolte has been visiting prof. Lucia Lo Bello at the University of Catania in Italy for 5 weeks in August-October. They have been working on, with SAVE relevance, vehicular communications, resulting in, for example, a workshop paper. More work are being finalised for publications. The visit will provide future cooperation between Thomas and Lucia during 2005.

Industrial co-operations

There are close links with the project HEAVE at MdH. HEAVE is a co-operation between SDL, Volvo Construction Equipment (Eskilstuna) and CC-Systems (Uppsala/Västerås) with the goal to enable the use of modern Component Based Software Engineering (CBSE) techniques within the industrial segment of heavy vehicles. Mikael Nolin is project leader for HEAVE (working 50% in the project). Industrial graduate student Anders Möller (CC-Systems, 75%) has additionally interacted with SAVE. (Main relevance for WP1, WP2, WP4 and WP5).

The debugging work of Joel Huselius and Henrik Thane is performed in co-operation with ABB Robotics and Zealcore.

Publications

- *Real-Time Server-Based Communication with CAN*, Thomas Nolte, Mikael Nolin, Hans Hansson, accepted for publication in IEEE Transaction on Industrial Electronics, 2005, date not set yet.
- *Managing Redundancy in CAN-based Networks Supporting N-Version Programming*, Juli´an Proenza and Jos´e Miro-Julia, Hans Hansson accepted for publication in IEEE Transaction on Industrial Electronics, 2005, date not set yet.
- *Real-Time in Embedded Systems*, Hans Hansson, Mikael Nolin, Thomas Nolte, submitted/accepted/finalised for publication in Embedded Systems Handbook, CRC Press, 2005, date not set yet.
- *Real-Time Systems*, Hans Hansson, Mikael Nolin, Thomas Nolte,Industrial Information Technology Handbook - Chapter 81, CRC Press, 2005, date not set yet.
- Hans Hansson, Mikael Åkerholm, Ivica Crnkovic, Martin Törngren, SaveCCM – a component model for safety-critical real-time systems
- In Euromicro Conference, *Special Session Component Models for Dependable Systems* Rennes, France , September 2004. IEEE
- Joel Huselius and Henrik Thane, *Constant Execution Time Recording for Replay of Sporadic Real-Time Systems*, in proceedings of the 2:nd Workshop on Compilers and Tools for Constrained Embedded Systems (CTCES), Washington D.C., USA, September 2004.
- Joel Huselius and Johan Andersson, *Model Synthesis for Real-Time Systems*. In Proceedings of the 9th European Conference on Software Maintenance and Reengineering, Manchester, UK, March 2005.
- Thomas Nolte, Hans Hansson, Lucia Lo Bello,*Implementing Next Generation Automotive Communications*, In Embedded Real-Time Systems Implementation Workshop(ERTSI 2004) in conjunction with the 25th IEEE International Real-Time Systems Symposium (RTSS 2004), Lisbon, Portugal, December, 2004
- Thomas Nolte, Mikael Nolin, Hans Hansson, *Hierarchical Scheduling of CAN using Server-Based Techniques*, In 3rd International Workshop on Real-Time Networks (RTN'04) in conjunction with the 16th Euromicro International Conference on Real-Time Systems (ECRTS 2004), Catania, Italy, June, 2004
- Thomas Nolte, Mikael Nolin, Hans Hansson, *Server-Based Real-Time Communication on CAN,* In Proceedings of 11th IFAC Symposium on Information Control Problems in Manufacturing, Salvador, Brasil, April, 2004

MultEx

Project leader:	Mikael Nolin, MdH
Members:	Jukka Mäki-Turja, MdH
	Kaj Hänninen, MdH
Partners:	Arcticus Systems, Volvo Technology Corporation
Funding:	MRTC

Project description:

In this project we will study how the software development process for embedded control systems can be made more efficient. More efficient, both with respect to development time, achieved software quality and hardware utilisation. Specifically, we will use novel theories that allow predictable integration of multiple execution paradigms within a computer system. We will study the impact this new ability has on how software-component models are designed and how the development process can be modified to allow efficient implementation of execution paradigm independent components. We will also investigate how such a modified development process can be supported by software engineering tools.

Results and achievements in 2004:

Kaj Hänninen was recruited as a PhD-student for MultEx in 2004. He completed the implementation if SSX tasks in the Rubus operating system and performed an evaluation. The evaluation shows that there can be substantial savings of RAM by using SSX tasks instead of traditional event-triggered operating systems tasks. The SSX tasks are particularly suited for realisation of component based software and will allow easy transition from time-triggered systems to event-triggered systems. Such a transition have the potential to free up CPU resources and allow savings by using cheaper hardware platforms.

Publications:

- *Tighter Response-Times for Tasks with Offsets.* In Real-time and Embedded Computing Systems and Applications Conference (RTCSA) Göteborg, Sweden, August 2004. Jukka Mäki-Turja, Mikael Nolin.
- *Efficient Response-Time Analysis for Tasks with Offsets.* In 10th IEEE Real-Time Technology and Applications Symposium (RTAS04) Toronto, Canada, May 2004. Jukka Mäki-Turja, Mikael Nolin.
- *Analysing Response-Times for Tasks with Offsets, Tight Resluts at Fast Speed.* MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-161/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May 2004. Jukka Mäki-Turja, Mikael Nolin.
- *Speeding Up the Response-Time Analysis of Tasks with Offse*ts. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-154/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, February 2004. Jukka Mäki-Turja, Mikael Nolin.

EAST/EEA

Project leader:	Mikael Nolin, MdH
Members:	Hans Hansson, MdH,
	Martin Törngran, KTH,
	Jad El-Khoury, KTH,
	De Jiu Chen, KTH,
	Ola Redell, KTH
Partners:	Volvo Technology Corporation, The SAVE project
Funding:	Volvo Technology Corporation via Vinnova

Project description:

EAST/EEA was an ITEA-project which goal is to improve the way software is ordered, constructed, integrated and reused in the European automotive industry. MRTC's project leader, Mikael Nolin, was responsible for coordinating other SAVE members' contribution to EAST/EEA.

EAST/EEA represents a major initiative within the European automotive industry. The partners include all major car manufacturers, their suppliers and automotive-software tool-vendors. The goal of EAST/EEA was to derive a framework for the next generation of electronic automotive features. The framework should support a common view on how electronic features are specified, developed and integrated. One of the explicit purposes of EAST/EEA was to come up with methodologies that will

allow a car manufacturer to integrate multiple features, developed by different suppliers on a single computing node within the vehicle. These methodologies will significantly reduce the amount of hardware (computing nodes and network wires) that is needed within a vehicle; as a conjecture both the production cost and weight of the vehicle will decrease. EAST/EEA was completed in June 2004 and delivered, e.g., the EAST ADL; a language for describing vehicular software on a variety of abstraction levels. The work of EAST/EEA is curretly continued in the industrial concortsium AutoSar.

Results and achievements in 2004:

During 2004 we have participated in numerous working meeting with the other EAST/EEA partners. We have also worked actively with EAST/EEA partners to produce the project deliverables, including the EAST ADL.

Publications:

- *FAR EAST: Modeling an Automotive Software Architecture Using the EAST ADL,* In ICSE 2004 workshop on Software Engineering for Automotive Systems (SEAS) Edinburgh , May 2004. H. Lönn, Tripti Saxena, Mikael Nolin, Martin Törngren

HEAVE

Project leader:	Mikael Nolin, MdH
Members:	Anders Möller, MdH, CC-Systems,
	Joakim Fröberg, MdH, Volvo Construction Equipment
Partners:	CC-Systems
	Volvo Construction Equipment
	SAVE project
	EAST/EEA project.
Funding:	KK-Foundation (KKS)
	CC-Systems
	Volvo Construction Equipment

Project description:

The project Component Technology for Heavy Vehicles (HEAVE) is a three year project where MdH will cooperate with Volvo Construction Equipment (Eskilstuna) and CC-Systems (Uppsala/Västerås) in order to enable the use of modern Component Based Software Engineering (CBSE) techniques within the industrial segment of heavy vehicles. The project leader, Mikael Nolin, will together with industrial PhD-students from Volvo and CC-Systems investigate the current practises and needs with respect to CBSE within the industrial segment. The next step will be to identify a suitable existing CBSE technique and if necessary propose modifications or additions to that technique. A demonstrator project using the (possibly modified) CBSE technique will be used to asses the usefulness of the technique. In HEAVE we will not only consider technical merits of any proposed CBSE technique. We will also consider how well the technique can be integrated into the development process and the possibility to gradually migrate into the proposed technique.

Results and achievements in 2004:

We have investigated the needs and requirements for component based software engineering within the Swedish vehicular industry. Those needs and requirements have been used to evaluate existing component technologies. This investigation resulted in the negative conclusion there exist no technology today that meets all the requirements. On the positive side, we found that each requirement was supported by one or more technologies; leading to the conclusion that it should be possible to derive a technology suitable for vehicular software. Our investigation also showed that there are certain areas, such as analysis, testing and debugging, that are particularly important but that are consequently not handled well by existing technologies. In response to these shortcomings we have proposed a concept of run-time monitoring to support, e.g., analysis, testing and debugging.

Publications:

- *SAVEComp - a Dependable Component Technology for Embedded Systems Software.* MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-165/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, December 2004. Mikael Åkerholm, Anders Möller, Hans Hansson, Mikael Nolin.

- *Monitored Software Components - A Novel Software Engineering Approach.* In The 11th Asia-Pacific Software Engineering Conference, Workshop on Software Architectures and Component Technologies, Pusan, Korea, November 2004. Daniel Sundmark, Anders Möller, Mikael Nolin.

- *Evaluation of Component Technologies with Respect to Industrial Requirements.* In Euromicro Conference, Component-Based Software Engineering Track Rennes, France, August 2004. Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin.

- *Industrial Requirements on Component Technologies for Embedded Systems.* In International Symposium on Component-based Software Engineering (CBSE7) Edinburgh, Scotland, May 2004. Anders Möller, Joakim Fröberg, Mikael Nolin.

- *Predictable Assemblies using Monitored Software Components.* MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-160/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May 2004. Daniel Sundmark, Anders Möller, Mikael Nolin.

- *An Industrial Evaluation of Component Technologies for Embedded-Systems.* MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-155/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, February 2004. Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin.

- *Requirements on Component Technologies for Heavy Vehicles.* MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-150/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, January 2004. Anders Möller, Joakim Fröberg, Mikael Nolin.

Future plans:

During spring 2005 a research stay at Monach University, Melbourne, Australia, will be perfored. For 6 months. Anders Möller will cooperate with the research group of Prof. Heinz Schmit, continuing the work on monitoring of component based systems. Duing fall 2005, the monitoning concept will be evaluated in an industrial setting

4.4 Theses

In 2004 SDL staff presented the following theses:

- Damir Isovic: PhD thesis: Scheduling for Media Processing in Resource Constrained Real-Time Systems
- Daniel Sundmark, Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components

Below, these theses are presented in more detail.

Ph Thesis

Damir Isovic: Flexible Scheduling for Media Processing in Resource Constrained Real-Time Systems

Date: November 9.

Opponent: Prof. Sanjoy Baruah, University of North Carolina.

Committee members: Prof Alan Burns (University of York), Prof Michael Gonzalez Harbour (University of Cantabria), Doc Jan Jonsson (Chalmers University)

Supervisor: Gerhard Fohler

Abstract:

The MPEG-2 standard for video coding is predominant in consumer electronics for DVD players, digital satellite receivers, and TVs today. MPEG-2 processing puts high demands on audio/video quality, which is achieved by continuous and synchronized playout without interrupts. At the same time, there are restrictions on the storage media, e.g.., limited size of a DVD disc, communication media, e.g., limited bandwidth of the Internet, display devices, e.g., the processing power, memory and battery life of pocket

PCs or video mobile phones, and finally the users, i.e., human's ability of perceiving motion. If the available resources are not sufficient to process a full-size MPEG-2 video, then video stream adaptation must take place. However, this should be done carefully, since in high quality devices, drops in perceived video quality are not tolerated by consumers.

We propose real-time methods for resource reservation of MPEG-2 video stream processing and introduce flexible scheduling mechanisms for video decoding. Our method is a mixed offline and online approach for scheduling of periodic, aperiodic and sporadic tasks, based on slot shifting. We use the offline part of slot shifting to eliminate all types of complex task constraints before the runtime of the system. Then, we propose an online guarantee algorithm for dealing with dynamically arriving tasks. Aperiodic and sporadic tasks are incorporated into the offline schedule by making use of the unused resources and leeways in the schedule. Sporadic tasks are guaranteed offline for the worst-case arrival patterns and scheduled online, where an online algorithm keeps track of arrivals of instances of sporadic tasks to reduce pessimism about future sporadic arrivals and improve response times and acceptance of firm aperiodic tasks. At runtime, our mechanism ensures feasible execution of tasks with complex constraints in the presence of additional tasks or overloads.

We use the scheduling and resource reservation mechanism above to flexibly process MPEG-2 video streams. First, we present results from a study of realistic MPEG-2 video streams to analyze the validity of common assumptions for software decoding and identify a number of misconceptions. Then, we identify constraints imposed by frame buffer handling and discuss their implications on the decoding architecture and timing. Furthermore, we propose realistic timing constraints demanded by high quality MPEG-2 software video decoding. Based on these, we present a MPEG-2 video frame selection algorithm with focus on high video quality perceived by the users, which fully utilize limited resources. Given that not all frames in a stream can be processed, it selects those which will provide the best picture quality while matching the available resources, starting only such decoding, which is guaranteed to be completed. As a final result, we provide a real-time method for flexible scheduling of media processing in resource constrained system. Results from study based on realistic MPEG-2 video underline the effectiveness of our approach.

Licentiate Thesis

Daniel Sundmark, Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components

Date: March 16

Opponent: Dr. Klas Nilsson, Lund

Examiner: Prof. Lars Asplund, MRTC

Supervisors: Prof. Hans Hansson, MRTC & Dr. Henrik Thane, MRTC

Abstract:

Men and women make mistakes. They always have and they always will. Naturally, software engineers are no exception to this rule. When software engineers make their mistakes, these manifest in the form of buggy software. Luckily, men and women often strive to correct the mistakes they make. In software engineering, this process is called debugging. In simple sequential software, debugging is fairly easy. However, in the realm of embedded real-time software, debugging is made significantly harder by factors such as dependency of an external context, pseudoparallelism or true parallelism, and other real-time properties. These factors lead to problems with execution behavior reproducibility. When a failure is discovered, we need to be able to reproduce this failure in order to examine what went wrong. If the erroneous behavior cannot be reproduced, we will not be able to examine the process leading to the failure. Previous work has proposed the use of execution replay debugging in order to solve this problem. Execution replay is a general term for a set of methods to record system behavior during execution and to use these recordings in order to reproduce this behavior during debugging sessions. This way, we may achieve a reproducable execution behavior for non-deterministic systems. Historically, many replay methods have been highly platform-dependent, craving specialized hardware, operating system or compilers. In this thesis, we describe a replay method, called Deterministic Replay, able to run on top of standard components. We also describe the Time Machine, which is the implementation of the

Deterministic Replay method. Further, we give an in-depth description of the method for pinpointing interrupts used by the Time Machine. In addition, we present results from two case studies where the Deterministic Replay method was incorporated into two full-scale industrial real-time systems. These results show that our method of debbugging multi-tasking real-time systems not only is applicable in industrial applications, but also that it can be introduced with little effort and small costs regarding application performance.

4.5 Industrial co-operation

Many of the research projects have strong industrial underpinning and are performed in close co-operation with our industrial partners as described in the project descriptions above. Our industrial partners include

- ABB Automation AB
- ABB Robotics
- ABB Corporate Research
- Bombardier Transportation
- CC-Systems
- Enea Real-Time AB
- IAR Systems
- Level TwentyOne AB
- Mimer Information Technology AB
- Mitsubishi research labs, Boston, US
- Mecel AB
- Philips Research, The Netherlands
- Rolls Royce aircraft engine design, UK
- SAAB Avionics
- Tieto Enator
- TTTech, Austria
- Volvo CEC AB
- ZealCore Embedded Solutions AB

4.6 Staff

Mats Björkman is Professor in Computer Communication at Mälardalen University, appointed in 2001. He received his Ph.D. in Computer Systems (Datorteknik) from Uppsala University in 1993, the thesis title was Architectures for High Performance Communication. Mats then held a post-doctoral research position at University of Arizona, working in the X-kernel research group. In 1995 he returned to Uppsala University as a senior lecturer in computer communication. His research interest includes communication performance analysis and predictability, small embedded systems, wireless communication and system-wide performance and predictability issues.

Gerhard Fohler is Professor and leader of the predictably flexible real-time systems group at SDL. He received his Ph.D. from Vienna University of Technology in 1994 for research towards flexibility for offline scheduling in the MARS system. He then worked at the University of Massachusetts at Amherst as postdoctoral researcher within the SPRING project. During 1996-97, he was a researcher at Humboldt University Berlin, investigating issues of adaptive reliability and real-time. Gerhard Fohler is currently chairman of the Technical Committee on Real-Time Systems of EUROMICRO.

Hans Hansson is professor in Computer Engineering, specialising in real-time systems, at Mälardalen University since 1997. He heads the MRTC, co-ordinates the national research initiative SAVE and the indiustrial graduate school SAVE-IT . He received an MSc (Engineering Physics), a Licentiate degree (Computer Science), a BA (Business Administration), and a Doctor of Technology degree (Computer Science) from Uppsala University, Sweden, in 1981, 1984, 1984 and 1992, respectively. He was appointed "docent" in Computer Systems at Uppsala University 1998. Hans was programme director for the national real-time systems research initiative ARTES 1998-2004, and was visiting professor at Uppsala University 1999-2004. Before joining MdH, Hans was department chairman at the Department of Computer Systems, Uppsala University, and researcher and scientific advisor at the Swedish Institute of Computer Science in Stockholm, Sweden. His current research interests include real-time system design, scheduling theory, distributed real-time systems, and real-time communications networks. He is co-founder of ZealCore Embedded Solutions AB.

Henrik Thane is a Senior Lecturer at SDL. Henrik has both an industrial and academic background. He received a Ph.D. from the Royal Institute of Technology in Stockholm (2000) and has worked as a programmer and consultant in the real-time systems area for several years. In addition to research he has during the last eight years worked as an expert consultant for the industry and given numerous industrial courses on design and verification of software in safety-critical computer based systems. Henrik's research interests are design and verification of safety-critical systems, monitoring, debugging and testing of (distributed) real-time systems, as well as real-time operating systems, and scheduling.

Henrik is also the CEO and President of ZealCore Embedded Solutions AB, a company focused on bringing state-of-the-art research debugging to the industry. Among the products provided are the unique BlackBox ReplicatorTM and the BlackBox RecorderTM for embedded systems.

Svante Ekelin was born in Stockholm in 1958. In 1982 he earned the degree of civilingenjör in Engineering Physics at KTH in Stockholm. Svante earned his PhD in Theoretical Physics at KTH, and spent one year as CNRS postdoctoral fellow with the Laboratoire de Physique Théorique in Bordeaux in 1987. After 11 years as associate professor of Mathematics at KTH, he joined Ericsson in 1999, where he is presently a senior researcher at the department of IP Networks within Ericsson Research.

Bob Melander is a part-time research scientist at SDL where he works in the computer communications research group. He received an MSc (Engineering Physics) and a PhD (Computer Science) from Uppsala University in 1997 and 2003, respectively. Bob is also affiliated with the Swedish Defense Research Agency (FOI) where he is member of the department of Systems Modelling. His research interests include network performance measurements and analysis, network/traffic modeling and simulation, mobile/wireless computing, and economics of computer networking.

Mikael Nolin is an associate professor at SDL. He is responsible for the projects EAST/EEA, HEAVE and MultEx. Mikael joined Mälardalen University in February 2002 after having worked at Melody Interactive Solutions with development of software for embedded information servers. Mikael received his PhD and MSc from Uppsala University in 2000 and 1995 respectively. His research is mainly in the areas of software architecture, component based software engineering, and tools for software synthesis and configuration. He is focusing mainly on software for the vehicular domain.

Ralf Elvsén is moving from theoretical physics to computer science. At present he takes courses and also gives elementary courses. He received his Ph.D from the University of Umeå in 1993. At this time he was working on non-linear wave phenomena in kinetic plasmas. He will subsequently join the research in real-time systems.

Damir Isovic is lecturer and postgraduate student at SDL. He received his MSc in Computer Engineering and a Diploma of Higher Education in Natural Science Mathematics and Astronomy from MdH in 1998 and 1999, respectively. His research interests include real-time systems and scheduling theory, with a specific emphasis on combining flexibility and reliability in construction of schedules. Damir is also evolved in the development and the maintenance of the internal web pages of Department of Computer Science at MdH.

Henrik Abrahamsson is a researcher at the Swedish Institute of Computer Science (SICS) and a PhD student at SDL. He has a MSc from Uppsala University and has been working at SICS since 1999. His research interests include Internet traffic engineering, traffic analysis and routing.

Radu Dobrin is a postgraduate student at SDL. He finished his master thesis in computer engineering at Mälardalen University in Västerås in august 2000. He worked as a research engineer at SDL during the second half of 2000. His research interests are flexible and predictable real-time systems, fixed priority scheduling and optimisation methods.

Adam Dunkels is a researcher at the Swedish Institute of Computer Science (SICS) since 2000 and a PhD student at SDL since 2002. He published his MSc thesis in 2000 after three years of undergraduate studies at Luleå University of Technology. His current research interests include lightweight communication support and Internet connectivity for tiny embedded devices and sensor networks, overlay and network architechtures, and security for small networked devices.

Mathias Ekman is an industrial Ph.D student at SDL, and is employed by Bombardier Transportation AB. He received his MSc in Computer Science at MDH during 2003. Mathias is working at Bombardier with development of safety critical real-time systems with focus on operating systems.

His research interests are monitoring, testing and debugging of distributed safety-critical real time systems.

Sigrid Eldh is an industrial Ph.D. student at SDL, and working as a Verification Expert within Ericsson AB. Her interest is efficient verification and testing of software, but also process improvement and testing techniques.

She is one of the founders of SAST (Swedish Association of Software Testing), founder of ASTA (Australian Software Testing Association), chair of the Swedish Board for Software Testing, handling testing standards and certification of testers, a member of the BCS ISEB examination panel and board, and also a founding member of ISTQB, International Software Testing Qualification board.

Joel Huselius (MSc 2001, Tekn. Lic. 2003) has been a Ph.D. student at Mälardalen University since the summer of 2001, part of this time has been spent in collaboration with the Swedish Institute of Computer Science. His work has so far resulted in a collection of conference papers and a Licentiate Thesis named "Preparing for Replay" – which he successfully defended in November 2003, acting opponent was Prof. Peter Fritzson of LiU, Sweden. Current research interests include debugging of real-time systems and mechanical model generation of real-time systems.

Ewa Hansen is a Ph.D. student at SDL. Prior to this position, she has been an undergraduate student at the department of computer engineering since 2001. Her current research interests are communication support for small embedded devices. Energysaving protocols for sensornetworks are her priority interest. She is a student member of ACM.

Kaj Hänninen received a MSc in Computer Engineering from Mälardalen University, 2003. His research focus on software engineering of embedded real-time control systems using multiple execution paradigms. Kaj is a member of the MultEx project.

Andreas Johnsson is Ph.D. student at SDL. His current research interests are measurement and analysis of available bandwidth, as well as other end-to-end characteristics, in best effort networks. He received a M.Sc. in Computer Science from Uppsala University in 2002.

Tomas Lennvall is a Ph.D student at SDL. He received a MSc Computer Engineering and a Licentiate Thesis from Mälardalen University in 2000 and 2003, respectively. His curent research interests are real-time systems, quality of service, multimedia, and wireless networks.

Anders Möller is an Industrial Ph.D. student employed by CC Systems AB and by MdH. He is working in the HEAVE project at SDL, a project to identify, define and evaluate a component technology for software components within the business segment of heavy vehicles. He received a M.Sc. in Engineering Physics at Uppsala University 2003., and presented his licentiate thesis in January 2005.

Jonas Neander is a CUGS Ph.D. student at SDL. His current research interests are communication support for small embedded devices. He is currently working within the sensor networks field where one important issue is to decrease the energy consumption in the network.

Prior to this position, he has been an undergraduate student at the department of computer engineering since 1998. He is a Student Member of IEEE and ACM.

Thomas Nolte is a Ph.D. student at SDL, working in the SAVE project. His research interests include distributed embedded real-time systems, especially communication issues, scheduling of real-time systems, automotive and vehicular systems.

Thomas took his Licentiate degree in May 2003 where he defended a probabilistic analysis method for the Controller Area Network (CAN) together with a method for server-based scheduling of CAN. During spring 2002, he was a visiting Jr. Specialist at the at the Department of Electrical and Computer Engineering, University of California, Irvine (UCI), Los Angeles, USA, and during autumn 2004 he was a visiting researcher at the Department of Computer Engineering and Telecommunications, University of Catania, Italy

Thomas is the PhD representative (doktorandombud) of all Ph.D. students at Mälardalen University since September 2003. Moreover, he is the M.Sc./B.Sc. Thesis Coordinator at the Department of Computer Science and Electronics (IDE) since October 2002. Prior to becoming Ph.D. student, Thomas has been an undergraduate student at IDE since 1997. He is a Student Member of IEEE.

Anders Pettersson is a Ph.D. Student at Department of Computer Science and Electronic (IDE) at Mälardalens University (MDH). Anders started his undergraduate studies in 1996, at MDH, and received his Master of Science in Computer Engineering, in August 2000. After receiving his MSc Anders become a Ph.D. student at MDH, doing research in the Tatoo Project at Mälardalens Real-Time Research Center (MRTC). In October 2003 Anders received his Licentiate degree. His licentiate thesis focused on testing and analysis for testing of multi-tasking real-time system. Anders main contribution in the thesis is an extension of a method for analysis of real-time systems. During 2004 Anders become a member of the LessBugs project and left the Tatoo project. The research focus for Anders in the LessBugs project is regression testing of multi-tasking real-time systems and analysis of such systems. Anders is a student member of IEEE.

Daniel Sundmark is a Ph.D. student at SDL. He received his MSc in Information Technology from Uppsala University in 2002. Daniel's current research interests include real-time system monitoring, testing and debugging, an area in which he in March 2004 presented his licentiate thesis. He also has about a year of industrial experience of software engineering in this field. Daniel gives a course in Operating Systems at Mälardalen University.

Larisa Rizvanovic is a Ph.D. student at SDL. She received an MSc in Computer Engineering from Mälardalen University in 2001. She has started with her graduated studies in 2004, when she was awarded a personal grant from the Faculty Board (MdH), "Meriteringsprogram för Kvinnor". Before that, she was working as research engineer at SDL. Her research interests are real-time architectures for networked multimedia streaming systems.

Ylva Boivie is research co-ordinator at MRTC. She received her MSc in Mechanical Engineering at the Royal Institute of Technology in Stockholm in1990, and has worked both in industry and academy since then.

Harriet Ekwall is executive administrator at SDL and MRTC. She is responsible for all travelling and personnel management and for maintaining and stimulating the good working environment.

Additional information about the members of SDL can be found at www.mrtc.mdh.se/sdl. E-mail addresses are on the form <first name>.<last name>@mdh.se.

4.7   National and international research co-operation

The following is a partial list of national and international research co-operation by SDL staff in 2004:

Gerhard Fohler and Hans Hansson participated (together with Ivica Crnkovic, SEL) in the European Thematic Network ARTIST (Advanced Real-Time Systems) which started in 2002. Additional partners in ARTIST include Verimag (F), INRIA (F), Technische Universitat Wien, Uppsala Univ., Universität des Saarlandes, PARADES (I), OFFIS (D), Aalborg University, Eindhoven University of Technology, University of York, CEA/Saclay (F), Lancaster University, Ecole Normal Superieure de Cachan, University of Twente, University of Pavia, Scuola Superiore S. Anna of Pisa, University of Cantabria, University of Aveiro, Technical University of Catalonia, University of Lisboa, and Universidad Carlos III de Madrid. Also, the follow up network ARTIST2 - a Network of Excellence in the 6th Framework Programme – started in 2004.

Mats Björkman

- is coordinator and leader of the EvaluNet and EvaluNet II joint research effort, involving MdH, SICS, Ericsson Research, TeliaSonera, Gatorhole AB, Netintact AB and Stiftelsen för internetinfrastruktur.
- is member of the steering group of the SSF program Winternet.
- is senior member of the CUGS national graduate school.
- is supervisor to two PhD students at the Swedish Institute of Computer Science (SICS).
- is assistant supervisor to Ph.D. students at Dept of Computer Systems at Uppsala University.

Gerhard Fohler

- coordinated the European IST project FIRST – Flexible real-time systems technology; partners University of York, UK, University of Cantabria, Spain, Scuola S. Anna, Italy.
- partner in EU IST project BETSY – Being on time saves energy, EU IST Project, partners including Philips Research, IMEC
- was involved in 2 proposals to EU 6th framework programmes (1 Network of Excellence, 1 STREPS)

Hans Hansson

- is co-ordinating the SAVE consortium doing research on Component Techniques for Safety-Critical Vehicular Systems. Additional partners in the consortium are RTSLAB Linköping Univ., Damek KTH, and the UppAal group Uppsala Univ.
- is co-ordinating the industrial graduate school SAVE-IT, which includes co-operation with LiU, KTH, and UU.
- was visiting Universitat de les Illes Balears for 3 months in 2004 to cooperate with Julian Proenza Arenas and Guillermo Rodriguez-Navas.

Henrik Thane

- received together with Hans Hansson a patent for BlackBox Replay debugging.
- has part-time worked in the industry during 2004 in the spin-off company ZealCore.
- initiated research collaboration with, Bombardier Transportation, and Level 21. Resulted in a research grant from KK foundation as well as funding from the industry in total exceeding 8 million SKr.

Mikael Nolin

- is coordinator for the national industrial graduate school SAVE-IT. SAVE-IT is supported by KKS and is a joint effort of MdH, UU, KTH and LiU. Participating companies include ABB, Arcticus Systems, Bombardier, Ericsson, Saab, and Volvo Construction Equipment.
- cooperated with KTH and Volvo Technology to contribute to the ITEA-project EAST/EEA.

SDL has concrete co-operations with the following national and international researchers and groups:

- Giorgio Buttazzo: Scuola Superiore S.Anna, Pisa, University of Pavia, Italy
- Pau Martin, Joseph Fuertes: Universitat Politecnica de Catalunya, Barcelona, Spain
- Carlos Pereira: Universidade Federal do Rio Grande do Sul, Brasil
- Martin Törngren, Jan Wikander: DAMEK group at KTH, Stockholm, Sweden
- Paul Pettersson, Wang Yi: The UppAaal-group at Computer systems, Uppsala University, Sweden
- Simin Nadj-Tehrani, Jörgen Hansson: RTSLAB at IDA, Linköping University.
- Per Gunningberg: CoRe group at Computer Systems, Uppsala University, Sweden.
- Bengt Ahlgren: CNA lab at the Swedish Institute of Computer Science (SICS), Stockholm, Sweden.

Virtually all members of SDL have been active in the ARTES/SNART national research networks, including participation in the ARTES postgraduate student conference and summer school.

4.8 Services to the scientific community

The following is a list of the most important services to the scientific community by members of SDL in 2004:

Mats Björkman

- was scientific evaluator for the KK foundation.
- was evaluator of applicant for one Lektor position at KTH.
- was on the grading committee at one PhD dissertation.
- was "opponent" at one litentiate presentation.
- is scientific advisor for a media technology educational program, Blekingetekniska högskola.
- was reviewer for several conferences and workshops.

Gerhard Fohler

- is Chairman of the Technical Committee on Real-time Systems of Euromicro, which organizes ECRTS, the major European Real-Time Conference
- is member of the Executive Board of the IEEE Technical Committee on Real-time Systems
- is member of the Executive Team of the IEE Professional Network on Real-time Systems
- was General chair of the 1st Workshop on Embedded Systems for Real-Time Multimedia (ESTIMEDIA)
- Co-program chair, 1st Workshop on Real-Time for Multimedia, Satellite Workshop of ECRTS 04
- was co-program chair of the real-time subtrack at Design, Automation and Test in Europe - DATE 05
- was on the programme committees for the Euromicro Conference on Real-time Systems (ECRTS), IEEE Real-time Technology and Applications Symposim (RTAS), European Dependable Computing Conference (EDCC-5), 2004, International Conference on Embedded Software (EMSOFT) 2004
- was European Publicity Chair, Real-Time Applications and Technology Symposium, 2005
- was participating in the Summer Research Institute, Ecole Polytechnique Federale de Lausanne, Switzerland, 2004

Hans Hansson

- is associate editor of Kluwer's Journal of Real-Time Systems
- is member of the International Advisory Board for the Embedded Systems Handbook, IEEE CRC Press
- was Programme Director for the national research programme ARTES and visiting professor at Uppsala University.
- is member of the steering-committee of the FLEXCON national research programme

- is Mentor for a software engineering research programme at Blekinge Institute of Technology (BIT).
- was on the grading committee at two PhD dissertations (Joakim Aidemark CTH, Cecilia Ekelin CTH)
- was scientific evaluator of the EU Fifth Framework Project NEXT-TTA
- was/is on the programme committee for: FeT 2005 - 6th IFAC International Conference on Fieldbus Systems and their Applications; 7th International Conference on Principles of Distributed Systems OPODIS-2004; IEEE Real-Time and Embedded Technology and Applications Symposium - RTAS 2004; The 7th IEEE International Symposium on Object-oriented Real-time distributed Computing - ISORC-2004; Embedded Real-Time Systems Implementation Workshop 2004; ETFA'2005 - 10th IEEE International Conference on Emerging Technologies and Factory Automation; RTCSA - Real-Time and Embedded Computing Systems and Applications Conference 2005.
- was external evaluator for the appointment of a Professor at KTH.

Mikael Nolin

- served at the programme committee of Real-time and Embedded Computing Systems and Applications Conference (RTCSA) Göteborg, Sweden, August 2004.
- served as the faculty opponent/reviewer the licentiate thesis "Maintaining Data Consistency in Embedded Databases for Vehicular Systems" by Thomas Gustafsson (Linköping University), November 10, 2004.
- was appointed as coordinator for the industrial graduate school SAVE-IT.
- acted as reviewer for (e.g.) The Computer Journal (British Computer Society), Journal of Systems and Software (Elsevier), IEEE Micro (IEEE).

4.9 Interactions with Society

The members of SDL are interacting with society in several ways, in 2004 including

Hans Hansson

- is member of the board of the national Embedded Systems initiative TEknIQ, which has a mission to make Swedish SMEs take full advantage of the rapid development in embedded electronics and real-time system technologies.
- participated in/co-organised an industrial seminar at Saab-Tech in Jönköping.
- participated in/co-organised a seminar on safety and security together with SecLink in Eskilstuna.
- was (as one of 8 Swedish scientists) invited to give a presentation at 10th anniversary of the Swedish research foundations.
- was invited to lecture at a course on scientific leadership organised by Vinnova, KKS and SSF.

Henrik Thane

- gave several short commercial courses on different aspects of real-time systems, safety and reliability directed to industrial engineers.
- participated in several industrial seminars as an invited speaker.
- received a Patent based on his Ph.D. thesis.
- Zealcore Embedded Solutions AB, a spin-off company established in 2001, got venture capital during 2004.

5 The Computer Architecture Laboratory (CAL)

Lab leaders: **Lars Asplund and Mohammed El Shobaki**

The research objectives for the Computer Architecture Laboratory are to perform research in the areas of scalable hardware platforms for embedded systems and development of architectures and tools for Safety Critical Systems. Special emphasis is on system-on-chip solutions.

There is additionally an initiative where the laboratory cooperates with other departments, industry and society to establish an internationally recognised activity in robotics. This activity covers undergraduate education, graduate education and research. This research is for this CAL based on current research, such as System-on-Chip and Safety Critical Systems, and applications will be selected in Robotics specific areas. A typical example is ChipVision, a complete system for image analysis that has been implemented on a single chip – output from a video camera is directly connected to the chip, which not only does the image analysis, but also includes a CAN-controller, and motor controller.

The laboratory is also responsible for giving courses in the area to undergraduate students and engineers active in industry.

CAL has a staff of two senior researchers, five lecturers, whereof three conduct part-time Ph.D.-studies, four industrial Ph.D. students, three full-time Ph.D. students, and three research engineers.

5.1 Focus

CAL is currently focusing on

- Computer architectures, with special emphasis on scalable multiprocessor systems,
- Innovative architectures for system-on-chip designs,
- Evaluating the effect of moving traditional software functions into hardware,
- Using and taking part in the development of latest technology and methods for hardware design,
- Hardware architectures for Safety Critical Systems, and
- Robotics sensory systems based on innovative hardware architecture designs en general and vision in particular.

The research is performed in close co-operation with industry and undergraduate education.

5.2 Education

CAL is responsible for the computer- and system architecture courses at the department, and the laboratory is also responsible for courses in electronic design given to industry and other universities. The courses given are:

Computers in Products 5p. The course is given for students that do not have computer science or engineering as a major. Students are given an insight in how embedded computers can be used to increase the competitiveness of commercial products. The course has a great strategic importance for Swedish industry by presenting new ways for using computers. The students is also shown how companies' way of working and organisation is influenced by new technology.

Micro Computers, 5p. The students are given an understanding of the basic operations and building blocks of a microprocessor, how to program it at a low level (micro-coding and assembly language), and how to write interfaces to high-level languages.

Systems architecture I, 5p. The course gives the students knowledge about hardware design, and a hardware description language. As a project in the course the students make a real implementation of a microprocessor including an interface to external memory and I/O.

Computer architecture, 5p: The course focuses on advanced issues in modern microprocessors, such as caches, pipelines, branch prediction, superscalars, multithreading, etc.

Complex Systems, 10p. This is a project course, where students from different programs in their third or fourth year work in teams of 10-14 students. They are given a requirements specification – for building a complete robot or a subsystem to a larger robotics system.

Robotics, 20p. This is a new course similar to Complex Systems, but the level is higher (D-level) and the length of the course is doubled, giving enough time to finish substantial projects. The course is a multidisciplinary course with content of mechanics, sensors, electronics, real-time operating systems, programming, and control algorithms. The students use the knowledge to construct an autonomous robot, and at the end of the course there is a competition between the robots built by the students and similar robots built by other universities. See www.robocup.org

Parallel systems, 5p. The focus of the course in on parallel computer architectures and how to program these machines efficiently.

HW/SW Design of Embedded Systems, 5p. The course focus on open-ended design problems using the latest CAD tools and the most advanced IP to provide students with experiences in creating and integrating IP to a complete SW/HW platform in embedded systems. The course also provides more constrained problems which involve a mixture of hardware and software, thereby giving students experience integrating existing IP with a limited amount of time devoted to creating new IP. Other course objectives are to develop human communication skills via a team project requiring both written and oral reports.

CAL is also responsible for a graduate course in advanced multiprocessor systems. This is a self-study course that allows the participants to have in-depth analyses of a selected topic within the multiprocessor field.

In addition to the courses, CAL has initiated two undergraduate programs; a new MSC/Engineering program ("civilingenjörsprogram") in Robotics (180 Swedish credits, 270 ECTS credits), and an International Master program in Robotics (40-80 Swedish credits, 60-120 ECTS credits). Both these programs started their first semesters in the autumn of 2004.

5.3   Research

The research at CAL is organised in two main areas:

Scalable Architecture for Real-time Applications (SARA). Within the framework of SARA several subprojects are defined. The common denominator for these projects is the hardware accelerator for real-time operating systems (RTU)

Safety Critical Systems for Embedded Systems (Safety Chip). This area includes activities in hardware design as well as formal modelling and verification of safety critical systems. The research is in cooperation with the department for Astro and Aeronautics at MIT, Boston

More information can be found at http://www.mrtc.mdh/cal

5.3.1   SARA - Scalable Architecture for Real-time Application group

Project leader:	Lennart Lindh
Project members:	Lennart Lindh
	Susanna Nordström
	Peter Nygren
	Mohammed El Shobaki
	Raimo Haukilahti
	Stefan Sjöholm
	Andreas Löfgren
	Stefan Stjernen
Partners:	Georgia Institute of Technology, USA
	MENTOR GRAPHICS
	XILINX
	Altera

Area description

The project is based on a previous project sponsored by the KK-foundation, industry and the university. The project originated from a design of a hardware accelerator for real-time operating systems (the Real-Time Unit – RTU) for single and multiprocessor systems. In recent years the research group has worked with hardware design methodology and successful industrial projects. The main motivation for the research project is to develop flexible and scalable parallel platforms for complex real-time systems

The new approach is defined by the following design goals:

Predictability: The software and hardware should be partly predictable. In a complex system, often 80-90 % of the tasks have soft deadlines (non-critical) and 10 % have hard deadlines (critical tasks).

Observability and controllability: The verification requires 50-75% of the total development time. Easy debugging and performance monitoring is also an important goal to reduce the development time.

Low Hardware and Software Overhead (simplifications): The non-productive software and hardware should be minimised. Simple solutions are important aspects when the design decisions are taken. The base system and the hardware platform should be as simple and small as possible.

Component oriented design: Component design is one important goal for decreasing the development time. The system should easily handle components, i.e. software or hardware components. The design paradigm will rest on an object-based software/hardware design and a priority inheritance based communication protocol.

Fault Tolerance: Many real-time applications are safety critical. They must function at least partially under severe disturbance conditions. Reliability and a high degree of availability are crucial in meeting today's quality requirements. In addition, software reliability and robustness with respect to third-party software are required. Problems as overload and failures must be handled in a dynamic, adaptive way.

The SARA system architecture

The SARA system architecture includes a design paradigm and a verification environment. The system is based on an application, a base system and a hardware platform. The application is designed with an object-based approach, and the objects are divided into three classes; shared, server and base object. The base system is a collection of communication/synchronisation systems for the application, verification/analyse system and resource/time handling. The base system is implemented in a hardware platform, but there also exists corresponding software classes.

RTU - a class in the base system

To improve the performance of a real time control system, the processor clock frequency can be increased. Sometimes this is not sufficient and so a co-processor can be used instead. The co-processor (RTU) is a special purpose hardware performing real time operating system functions. Different real time operating system functions have successfully been implemented into hardware the last 10 years. The scheduling algorithm of the RTU is priority based, and supports preemptive and non-preemptive schemes. The scheduler algorithm of the RTU can also balance the load among the processors in the system.

IPC - a class in the base system

The application software (task or server class) connects to an IPC (Inter Process Communication) bus, it can be seen as a virtual bus. The IPC bus contains 32 slots and each slot has a priority based queue for 32 messages. The queue is FIFO with priority inheritance. A slot can be owned by a task (we call it a server object). The slot of the processors can be allocated in two ways:

- One slot is allocated to one processor
- One slot is allocated to two or more processors, which means it is scheduled between the processors.
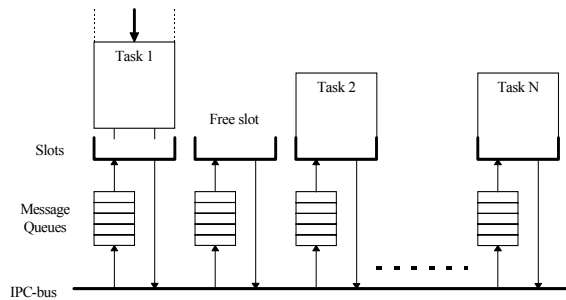
Figure 1 The IPC bus model.

A sender task can use time-out constraints on full queues, and a receiver task can do the same on empty queues, e.g. a receiver task can be set to wait a specified time for a message.

Examinations 2004

Licentiate theses by Peter Nygren and Mohammed El Shobaki

Licentiate Thesis No33, *An Application Programming Interface for Hardware and Software Threads*, published at the Department of Computer Science and Engineering, Mälardalen University, September 2004.

Licentiate Thesis, *On-Chip Monitoring for Non-Intrusive Hardware/Software Observability*, published at the Department of Information Technology, Uppsala University, September 2004.

Publications 2004

- Stefan Stjernen, Andreas Löfgren, Stefan Sjöholm, *A new PSL-based formal method for improved HDL-design verification*, Euromicro Symposium on Digital System Design '04, France.
- Stefan Sjöholm, Stefan Stjernen , An analysis of the embedded system design space and two case studies, replacing uP's with an FPGA, NORCHIP, Oslo, 2004.
- Arseni Vitkovski, Raimo Haukilahti, Axel Jantsch, and Erland Nilsson. *Low-power and error coding for network-on-chip traffic.* In Proceedings of the IEEE NorChip Conference, November 2004.
- Raimo Haukilahti, Zoran Paunovic, David Borgedahl. Mälardalen university *Dynamic Voltage Scaling for FPGA:s*, Technical Report.
- Mohammed El Shobaki, Jeroen Heimanns, *MAMon - A Multipurpose Application Monitor,* MRTC Report, ISSN 1404-3041, ISRN MDH-MRTC-121/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, September 2004.

Workshops

Organized two workshops in Västerås; "Intellectual Property Based FPGA SOC Design" and FPGAworld (fpgaworld.com). The workshop provides a link between the research group and industry in Sweden. The research groups are addressing many similar problems, but with different backgrounds and approaches. The workshop intended to provide a forum where the researchers and industry can interact. Results can be better reviewing, education, corporation, writing papers etc.

Subprojects

The current research in SARA is performed in the following sub-projects:

An Application Programming Interface for Hardware and Software Threads

Project members: Peter Nygren
                          Lennart Lindh (supervisor)

Project description

This research in Hardware Software Co-design has its main focus on different types of interface. The Co-design flow is divided in two main parts. The first is system-level design, and it includes functionality specification, which is the task of describing the desired system behaviour in some form. The second is system design, which is the task of implementing this functionality with system components such that design constraints are satisfied. The result of system design is a set of system components, each with its own functional specification.

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Examples of system components include standard processors and micro-controllers, memories, buses and custom designed ASICs. A key aspect of the synthesis of embedded systems is the automatic integration of systems components. This entails the derivation of both the hardware and software interfaces that will bind theses element together and permit them to communicate correctly and efficiently.

Research summary

Our objective is to develop a communication interface at the thread level and to introduce the possibility of transforming the system tasks to either a hardware or software thread containing the interface (VCB). The interface is to provide a uniform independent message-passing mechanism using a specified application programmable interface (API).
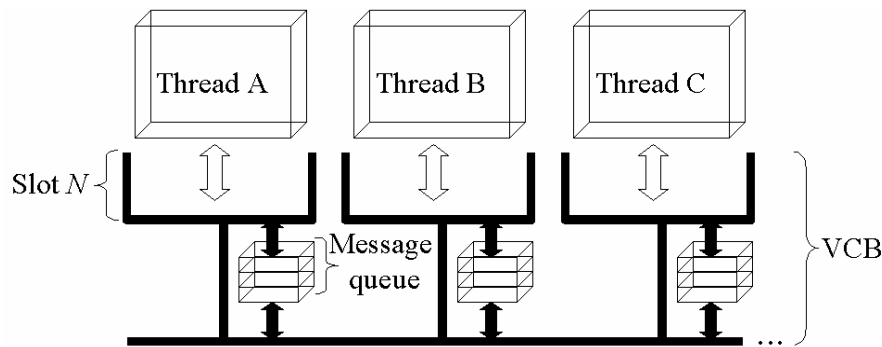
Figure 1 System architecture

The current system architecture includes a software processor kernel CPU from Xilinx, which runs the different software threads. One real time unit accelerator manages the software thread scheduling, interrupt and semaphore handling as well as time management. The system also includes a VCB-core, manager the different system calls from the API-interface.
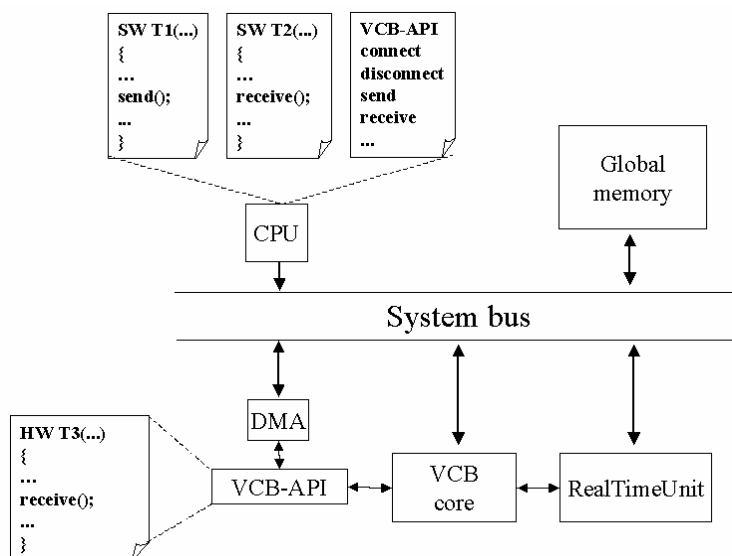
Figure 2 Hardware and Software architecture

Every device in the system is connected through the IBM Core-Connect bus. The on-chip peripheral bus (OPB) is designed for easy connection of on-chip peripheral devices. The OPB is a fully synchronous bus, which functions independently at a separate level of bus hierarchy. The processor core can access the slave peripherals on this bus through the processor local bus (PLB) to OPB bridge unit, which is a separate core.

Publications

- Licentiate thesis No33 "An Application Programming Interface for Hardware and Software Threads" published at Department of Computer Science and Engineering Mälardalen University.

MAMon - Multiprocess Application Monitor

Project members: Mohammed El Shobaki
                                         Lennart Lindh (supervisor)

Project description

The MAMon project is part of the research taken within SARA. The aim of the project is to develop non-intrusive monitoring hardware for single- and multi-processor applications based on Real-Time Kernels in hardware (RTU).

Monitoring is a necessity for testing, debugging and performance evaluations of real-time computer systems. Most research into monitoring of real-time systems has been devoted to minimising the execution interference imposed by the monitor. One approach to this has been the use of hardware support to extract software execution traces by probing the external processor (or system) busses. However, the use of cache memories on various levels, and the increased integration of system components on-chip (SoCs) in addition to limited chip-package pins, severely obstructs traditional hardware monitors from probing processor signals and busses. For real-time systems built on these premises there is a need to access execution information residing on-chip, as well as to avoid interference with the system's execution behaviour.

In this project we propose an architecture (see figure below) for on-chip monitoring of single and multiprocessor real-time systems that are based on hardware-accelerated operating systems (i.e. like the SARA platform). The monitor, called MAMon, probes a hardware-implemented Real-Time Kernel (RTK) using a Probe Unit integrated as an IP-block at the VHDL-level. The hardware RTK implements traditional (software) RTOS functions, such as scheduling algorithms, process management and communication, in hardware. Operating at the system-level the Integrated Probe Unit detects and collects events regarding process' execution, communication, synchronisation, and I/O interrupt activities. The collected events are time-stamped with the resolution of the system clock frequency and then transferred, via a high-speed parallel port link, to a separate host computer system. At the host the events are stored in a database which constitutes the heart of a monitoring application framework featuring event analysis and debugging (searching, filtering, and graphing), performance evaluations, and more. Monitoring occurs mainly at the system-level, but lower abstraction-levels are supported too by allowing instrumentation code to write to dedicated probe registers in the monitor hardware.
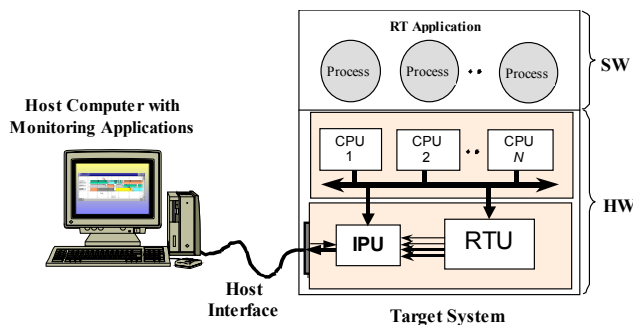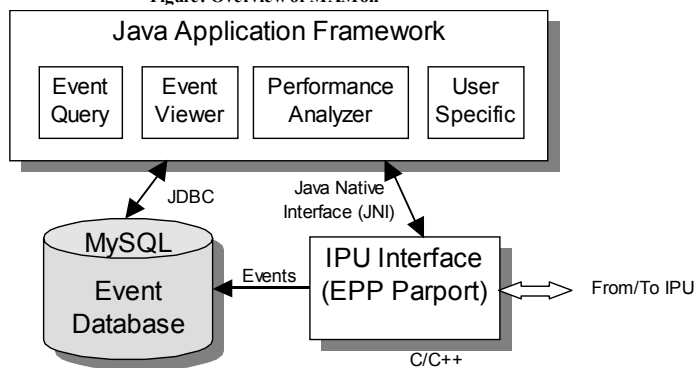

Figure: Overview of MAMon

Figure: Monitoring Application Environment on the Host

Industrial co-operation

We have a strong co-operation with two industrial partners; RealFast Systems AB who are interested in developing products based on our ideas, and ABB Automation Products (Leif Enblom) who provides us with a real test-case.

Results and achievements in 2004

As a result of the MAMon-project one Licentiate thesis was published.

▪ Licentiate Thesis, On-Chip Monitoring for Non-Intrusive Hardware/Software Observability, published at the Department of Information Technology, Uppsala University, September 2004.

Future plans

Planned concrete developments include the following:

- Integrate the earned knowledge and techniques in the course HW/SW Design of Embedded Systems, 5p (advanced level).
- Assist our industrial partner (RealFast Systems AB) in developing further the MAMon concept for use in real industrial products. This is to be investigated further, since such co-operation must be integrated with the research project.
- The next research steps will focus on developing the MAMon platform for a wider range of RTOS-based systems, i.e. so as to generalise the concept of run-time monitoring of SoC-based real-time system.

Low Power Techniques for Real Time Operating Systems

Project members: Raimo Haukilahti (Ph.D student)
Lennart Lindh (advisor)
Axel Jantsch (KTH, supervisor)

Project description

To achieve an energy-efficient device, sufficient techniques must be adopted at all levels of abstraction and also for every component in the system, including the Real Time Operating System. There exists several implementations of operating systems where parts of the operating system are implemented in hardware, but their energy efficiency is not yet investigated. This project will investigate the energy savings when using special purposed hardware for the RTOS. The in house developed Real Time Kernel will be used as a case study. Moreover, we study the effect of the RTOS scheduling strategies on the overall energy consumption. Efficient power-saving techniques for FPGAs and Networks-on-chip will also be investigated.

Results and achievements in 2004

▪ Arseni Vitkovski, Raimo Haukilahti, Axel Jantsch, and Erland Nilsson. *Low-power and error coding for network-on-chip traffic*. In Proceedings of the IEEE NorChip Conference, November 2004.

▪ Raimo Haukilahti, Zoran Paunovic, David Borgedahl, *Dynamic Voltage Scaling for FPGAs*, Technical report , Mälardalen university.

Validating Hardware Components

Project members: Stefan Stjernen
Lennart Lindh (supervisor)
Stefan Sjöholm (advisor)

Project description

The main focus for this project was to create test stimuli's and make models (in VHDL) for the testing of the FPGA. The FPGA is designed to communicate with a CPU over a PCI target interface between the local PCI bus and the FPGA. A model of the CPU was created in VHDL. All of the PCI calls from the CPU to the FPGA was initiated from the 'VHDL' CPU model and then sent to the FPGA over the PCI bridge.

Replacing Software with Hardware

Project members: Stefan Sjöholm
Lennart Lindh (supervisor)

Project description

The research is how and when software (uP) should be replaced by hardware (FPGA).

Several case studies will be presented. The goal of the case studies is to show how an uP can be replaced by an FPGA in different IO-board applications, to not only improve performance, but also to reduce cost, time to market and other important constraints. In the case studies the FPGA design will include a behavioural controller. The behavioural controller is a design technique to be used when replacing uP with FPGA. The behavioural controller(s) is designed in VHDL at RT-level to handle all scheduling, allocation and different forms of pipelining in the FPGA. This method has the potential to result in a very small (cost efficiency) FPGA but still with high performance.

Results and achievements in 2004

- Stefan Stjernen, Andreas Löfgren, Stefan Sjöholm, *A new PSL-based formal method for improved HDL-design verification*, Euromicro Symposium on Digital System Design '04, France
- Stefan Sjöholm, Stefan Stjernen , An analysis of the embedded system design space and two case studies, replacing uP's with an FPGA, NORCHIP, Oslo, 2004

System-on-Programmable-Chip

Project members: Andreas Löfgren
Lennart Lindh (supervisor)

Research Summary

Recently initiated research in the area of System-on-Programmable-Chip and how to design and reuse Intellectual Property components in programmable logic. Focus is on logic-centered SOC architecture and how to implement this complex architecture in a FPGA. A number of existing IP components, such as OS, memory controllers and CPU will be used.

Results and achievements in 2004

- Stefan Stjernen, Andreas Löfgren, Stefan Sjöholm*, A new PSL-based formal method for improved HDL-design verification,* Euromicro Symposium on Digital System Design '04, France

Utilizing Hardware Parallelism to Optimise Cost and Performance for Real-Time Kernels

Project members: Susanna Nordström
Lennart Lindh (advisor)
Denny Åberg (supervisor)

Research Summary

The licentiate thesis task will focus on analysis and co-design implementation of real-time operating system (RTOS) accelerators for system-on-chip (SoC) in single processor systems in field programmable gatearrays (FPGAs). Analysis of different RTOS and different structures of RTOS will result in a general method of how to adapt hardware support in order to perform optimised hardware acceleration for best performance and smallest footprint in hardware and software. The analysis will also cover configuration of HW/SW system on FPGAs, the protocol between SW and HW, and what parts in an RTOS that result in most speed up and/or footprint optimisation, i.e hardware or software implementation. An

implementation of this will be done in one commercial RTOS and integrated HW/SW tools with this developed method. After licentiate degree, focus will be on heterogeneous multiprocessor systems.

5.3.2 Safety-Critical Systems group

Project leader: Lars Asplund
Project members: Johan Furunäs
                                  Gustaf Naeser

The research is within the SafetyChip project, which is a co-operation between Mälardalen University and MIT, Boston. The project aims at developing a framework supporting the development of safety critical systems at the highest safety level. The development process using this framework starts with a tool that can generate a formal model, Intermediate-Model, from source code. This Intermediate-Model is not intended to be used directly for verification, it is intended for further transformation into formally verifiable notations. It is, however, very important that the Intermediate-Model is highly readable by programmers, i.e. it should be easy to validate its source-code conformance. The generation of the Intermediate-Model is automatic, but to ensure the correctness of the transformation, human interaction is required. Currently the Intermediate-Model is transformed into timed automata and verified using the UPPAAL tool. This transformation from the Intermediate-Model to the target model is fully automated and does not require any human interaction. The correctness of this transformation should be by mathematical proofs.

The applications Intermediate-Model is also the basis for the generation of a SafetyChip. The SafetyChip is a device that monitors and policies the execution of an instrumented program, running in a hardware implemented Run-Time Kernel.

The project has been defined as the following work packages, presented below:

1. Tool for translating VHDL into Automata (has been completed at MIT)

2. Tool for translating the Ada-95 Ravenscar profile into Automata (has been completed at MRTC)

    Transformation of Ada is by means of ASIS (Ada Semantics Interface Specification). The translated code currently allows a larger set of instructions than the intended set restricted by the Ravenscar profile. The output generation is shared with the VHDL translation tool and UPPAAL automata is generated. Intermediate code which shows the control structure of the source code can also be generated.

3. Semantics of the Intermediate-Model (has been completed at MRTC)

    Typical constructs or temporal building blocks that are used in target applications have been identifed and used to formulate a notation. In the model there is a special notion of priority and process identification, and labelling with BCET and WCET.

4. Readability/GUI (MIT)

    This part of the framework aims at studying the non-functional properties of the Intermediate-Model.

5. Translation of the Intermediate-Model into timed automata (has been completed at MRTC)

6. Translator from our model into any Model Checker-syntax based on a description of the Model Checker (MIT)

7. A new dedicated model checker (MIT)

8. Generation of code for the SafetyChip (Completed to 50% at MRTC)

    The Intermediate-Model describes the complete system, and all transitions and times for BCET and WCET are given. Using this information the necessary VHDL code for the FPGA-based SafetyChip can be generated. As a starting point the UPPAAL model can be used as formal model. In this stage a manual transformation is used. After the gurkh-formalism has been designed, an automatic tool can be designed to do the transformation.

9. Development of a formally modeled and verified Multi-Pro Kernel (Completed at MRTC)

   The Kernel that has been modeled and verified supports dynamic priorities, preemption, delays, interrupts, multiple hetereogeneous CPU's, and Protected Objects.

10. Run-Time Kernel in VHDL (Completed at MIT and and an improved version under development at MRTC; completed to 50%)

    The software is translated to object-code and run on a single or multiprocessor machine. The run-time kernel (RTK), which is already described in a formal language, can be implemented in software or hardware. This project aims at the hardware implementation of the RTK. The formal model is today based on a single CPU machine, and a natural extension of this model is to allow several processors. A first prototype of a kernel has been run on the FPGA. Different kernel component implementations have been investigated formally and in hardware, in terms of area utilizations and timing behaviours.

11. SafetyChip in VHDL (Completed as a joint venture between MRTC and MIT)

    The SafetyChip is a hardware unit with built in timers that monitor all clocks given in the formalism used to describe the application. The SafetyChip monitors that the transitions of the RTK conforms to the schema derived from the Intermediate-Model. At each transition timers are checked versus the limits set by BCET and WCET. In the case of timer overflow versus WCET or underflow compared to BCET an error flag is raised with a severity level that is defined by the user. Interrupts are generated when deviations from the schema are detected.

Hardware platform

The project has developed a hardware platform based on one of the chips from Xilinx (with an integrated PowerPC and an FPGA-area). The platform contains this chip (as a donation from Xilinx) a smaller FPGA (a service FPGA) RAM and Flash EPROM and two USB ports. An expansion connector makes it possible to add various IO-boards. Not only will this platform be used in this framework, but it is also used as the main processor for the Aros robot (http://www.idt.mdh.se/rc/aros).

5.4   Theses

Two Licentiate theses were presented in 2004 by CAL researchers:

Mohammed El Shobaki, *On-Chip Monitoring for Non-Intrusive Hardware/Software Observability*, Licentiate thesis ISSN 1404-5117, ISSN 1404-3041 ISRN MDH-MRTC-120/2, Department of Information Technology, Uppsala University, Sweden, September 2004.

The increased integration of hardware and software components in today's state-of-the-art computer systems make them complex and hard to analyse, test, and debug. Moreover, the advances in hardware technology give system designers enormous possibilities to explore hardware as a means to implement performance demanding functionality. We see examples of this trend in novel microprocessors, and Systems-on-Chip, that comprise reconfigurable logic allowing for hardware/software co-design. To succeed in developing computer systems based on these premises, it is paramount to have efficient design tools and methods.

An important aspect in the development process is observability, i.e., the ability to observe the system's behaviour at various levels of detail. These observations are required for many applications: when looking for design errors, during debugging, during performance assessments and fine-tuning of algorithms, for extraction of design data, and a lot more. In real-time systems, and computers that allow for concurrent process execution, the observability must be obtained without compromising the system's functional and timing behaviour.

 In this thesis we propose a monitoring system that can be applied for non-intrusive run-time observations of real-time and concurrent computer systems. The monitoring system, designated Multipurpose/Multiprocessor Application Monitor (MAMon), is based on a hardware probe unit (IPU) which is integrated with the observed system's hardware. The IPU collects process-level events from a hardware-implemented Real-Time Kernel (RTK), without perturbing the system, and transfers the events to an external computer for analysis, debugging, and visualisation. Moreover, the MAMon concept also

features hybrid monitoring for collection of more fine-grained information, such as program instructions and data flows.

We describe MAMon's architecture, the implementation of two hardware prototypes, and validation of the prototypes in different case-studies. The main conclusion is that process level events can be traced non-intrusively by integrating the IPU with a hardware RTK. A subsidiary conclusion, but yet relevant, is that the IPU's small footprint makes it attractive for SoC designs, as it provides increased system observability for a low hardware cost.

Peter Nygren, An Application Programming Interface for Hardware and Software Threads

Licentiate thesis 33, Mälardalen University Press, September 2004.

Modern embedded computer systems contain an increasing number of software and hardware components. The most common way to communicate between these components is to interrupt the processor (CPU) and let the operating system manage the communication. In almost any operating system, the arrival of an interrupt event causes the execution of a service routine (which could be a device driver handling some external I/O). The advantage of this method is that it encapsulates all hardware details of the I/O device. In many cases these interrupt driven service routines interfere with the real-time behavior. In cases where the interrupt routine is not handled properly, priority inversion and unbounded delays of process execution can be introduced. The real time problem with software device drivers and the development of Field Programmable Gate Array (FPGA) technology motivate research on communication and synchronization between hardware and software components. This thesis presents an application interface called VCB (Virtual Communication Bus), which provides a standardized interface for communication and synchronization between hardware and software without the need to execute any driver software. The interface provides six different system calls; connect, disconnect, send, receive, send&wait, and broadcast. The VCB also has functions to avoid priority inversion problems. The interface is fully implemented in hardware, meaning that no software is used during communication and that several system-calls can be made simultaneously. This makes the system easier to analyze and design. The thesis presents the VCB concept, its implementation architecture and definition of hardware threads. Furthermore, the VCB is demonstrated and evaluated in a case study with device drivers that manage a Universal Asynchronous Receiver Transmit (UART). The two main contributions of this research are (1) that it shows that it is possible to design a uniform interface for communication between hardware and software threads, and (2) that this interface can be used to design device drivers in hardware that introduce almost zero overhead for the software system to manage the external device.

5.5 Industrial co-operation

There is a strong tradition within CAL to conduct applied research in close co-operation with industry. Our industrial partners include:

- ABB Automation Products (1996-, 1999-) – supports two industrial Ph.D. student
- Ericsson Radio Systems AB (1999-) – supports one industrial Ph.D. student
- Protang AB (1999-) – supports one industrial Ph.D. student
- XILINX (1998-) – supports hardware circuits
- ABB Robotics (1997-) – provides industrial case studies
- Ericsson Utvecklings AB (1998-) – provides industrial case studies
- Saab Avionics (2002-) provides industrial partnership
- Saab Aerospace (2003-) provides industrial partnership
- Hectronic AB (2002-) supports one industrial Ph.D. student
- Rolls Royce (2003-) provides industrial partnership
- SenseBoard Technologies AB (2001) supports two extended MSc students

5.6   Staff

Joakim Adomat has been working at Mälardalen since 1994. He started as a research engineer, and is currently a lecturer/Ph.D. student. Main areas of interest are SoC architecture, FPGA rapid prototyping, digital design and PCB. The future research ambition is to explore and improve systems for graphics rendering.

Lars Asplund is professor in computer systems at Mälardalen University since 2001, and from 2002 lab-leader at CAL. He received a Ph.D. in Physics at Uppsala University in 1977. In the last twenty years his research has been in real-time systems, distributed systems, learning systems, and most recently in safety critical systems. He has written nine textbooks. His current research interests are safety critical systems, system on chip and Robotics.
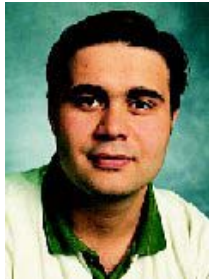
Mohammed El Shobaki is a Ph.D. student at the Computer Architecture Laboratory. He received his Bachelor of Science in Computer Engineering from Mälardalen University, Sweden (1997). His current research is focused on run-time debugging and monitoring of hardware and software in embedded real-time systems. Other interests include (but are not limited to) multiprocessors, systems-on-chip, and algorithms into hardware.

Johan Furunäs is a Ph.D. Student at CAL. Finished his Licentiate thesis "Interprocess Communication Utilising Special Purpose Hardware" December 2001 and received a Licentiate of Philosophy in Computer Systems from Uppsala University. Received a Bachelor of Science in Computer Engineering from Mälardalens University, Sweden (1995). Have been working with operating system co-processors since 1995 at Mälardalen University and Realfast for Ericsson UAB. His main research interest is interprocess communication utilizing co-processors, and he has joined the SafetyChip-project in 2003.

Raimo Haukilahti received his BSc in electrical engineering and MSc in computer engineering in 2000 with the master thesis titled *SoCrates -A Multiprocessor System-on-Chip for Real-time Systems*. He has earlier been teaching analogue electronics and assisted several labs in computer engineering and electrical engineering courses. Since Jan 2001 he has been a Ph.D student focusing on Low-power Techniques for Real-Time Operating Systems.

Lennart Lindh. Lennart Lindh graduated from Lund Technical University 1980 with the MSc degree in Electrical Engineering. After five years at ABB Robotics, Västerås, as a system engineer, he was appointed a senior lecturer at Mälardalen University, Västerås in 1985. His main focuses are implementation of complex functions in hardware, Real-Time operating systems and flexible multiprocessor systems. He is today responsible for the guidance of Ph.D. candidates, PC member in some academic workshops/conferences and board member in Euromicro (European academic organisation). He is today dividing his time between Mälardalens University and the company RealFast AB.

Anders Martinsen is lecturer at CAL. He received a Master of Science at the University of Linköping 1973. He teaches mainly in computer architecture and digital electronics. He also work as project leader in a national program - called "Embedded system" (see www.tekniq.nu).

Gustaf Naeser is a Ph D student at MdH since March 2001. He is active in the SafetyChip-project, and his special interest is in translation of software into a formal description, and formal verification of integrated models of hard- and software.

Peter Nygren is a postgraduate student at CAL since August 2000. His current research is focused on transparent interface between software and hardware communication with possibility to integration of custom specific hardware. However, his interest profiles cover much broad area in hardware software co-design. Hi is also involved in the project Scalable Architecture Real time Application (SARA) at CAL.

Filip Sebek is a lecturer and director of undergraduate studies with focus on quality and pedagogic issues. He received his Bachelor of Science in Applied Computer Engineering from Mälardalen University, Sweden (1995) and his Licentiate thesis with the title "Cache Issues in real-time systems" was defended in October 2002.

Stefan Sjöholm is industrial Ph.D. student. His research is targeted at industrial hardware design methods, and their suitability for VHDL. The research is conducted in corporation with ABB Automation Systems and RFHC RealFast hardware Consulting AB, Västerås, where the case studies are performed.

Johan Stärner is lecturer and Ph.D. candidate at the computer architecture lab. He received his bachelor of science in applied computer engineering from Mälardalen University in 1994. His current research interests include prefetching techniques, real-time operating systems, and computer architecture with emphasis on multiprocessor systems.

Susanna Nordström is an industrial Ph D student of the Industrial Research School since April 2004. Her research interest is hardware support for real-time operating systems in order to enhance system performance and predictability. The research is conducted in corporation with RealFast Intellectual Property, Västerås. The company has a new paradigm for real-time operating system implementations.

5.7   National and international research co-operation

CAL has a very active co-operation with Professor Vincent Mooney from the School of Electrical and Computer Engineering at Georgia Institute of Technology, Atlanta. The co-operation is aimed at real-time kernels and system-on-chip. Close co-operation with the department for Astro and Aeronautics at MIT, Boston (Prof Kristina Lundquist) is on-going in the SafetyChip-project.

At the national level, we have established collaboration with the Electronic Design Department at KTH within the area of low-power techniques and real-time systems. As part of this collaboration we have a Ph.D. student sharing his time between CAL and KTH.

5.8   Services to the Scientific Community

Lennart Lindh was program committee member of EUROMICRO Digital Systems Design, CAD&CG (Asia), and different Swedish workshops, such as SNART

Lars Asplund was member of the Program Committee of 9th International Conference on Reliable Software Technologies - Ada-Europe 2004, and reviewer for Journal of Real Time Systems

Also, the laboratory organised two workshops in Västerås together with Vincent Mooney from Georgia institute of Technology.

5.9   Interactions with society

Lennart Lindh gave a number of tutorials on FPGA-circuits in embedded systems for industry and at conferences.

Anders Martinsen is a project leader within "Expertkompetens – inbyggda system" (see http://www.tekniq.nu). This project mission is to increase the competence of embedded systems in Swedish industry.

Lars Asplund has taking an active part in the creation of Robotdalen (www.robotdalen.org), which is an initiative to make Mälardalen internationally very strong in academic research and industrial development in the robotics area. The initiative involves two academic institutions MdH and Örebro University, major companies such as Volvo CE, ABB Robotics, Atlas Copco, SMT Tricept, and official representatives from the regions Örebro, Eskilstuna, Västerås, Västmanland, and Södermanland.

One important activity in Robotdalen is to create a larger interest for technology in general and robotics in particular. There will in the future be several external activities to achieve this goal. To mention a couple, there will be different robotics competitions for younger people. For children in the age between 10 and 16 there will be the First Lego League. "An international program for children ages 9-14 (9-16 in Europe) that combines a hands-on, interactive robotics program with a sports-like atmosphere. Teams consist of up to 10 players with the focus on such things as team building, problem solving, creativity, and analytical thinking." People at CAL have been involved in arranging one of the Scandinavian FIRST LEGO LEAGUE semi-finals. Sixteen teams participated and about 1000 spectators followed the competition that was held in Västerås.

The Sumo competition that traditionally has been for students at MdH will in 2005 be open for participants studying at high schools (Swe gymnasier).

Several companies have been established as a result of the research in CAL (see http://www.realfast.se for more information).

- RF RealFast AB was established in Västerås 1994 (Technology Park 1998). Its mission is to develop and produce state of the art hardware accelerators and multiprocessor architecture for different Real-Time Operating Systems Vendors and end-user and by applying hardware accelerator techniques to our partners Operating System, thereby solving performance, robustness and functional problems for the end-users.

- RFE RealFast Education AB's mission is to provide continuing education support and post-graduate specialisation courses to managers, developers and professionals involved in Electronic, Software & Real-Time Technology activities.
- RFO RealFast Operating Systems mission is to support industry in the operating systems and hardware support area.
- RFHC RealFast Hardware Consulting AB mission is to support industry in the hardware area.
- RFSC RealFast Software Consulting AB's mission is to support industry in the software area.

Also, several articles have been published in the popular press about our work on real-time operating system kernels and hardware design and Robotdalen.

6 Nat'l Grad Schools and MSc pgms

In this section, two special educational programmes with strong relations to the MRTC research are presented, together with information about our international MSc-programmes there were launched in 2004.

During 2004 the concept of the Industrial Lic School was incorporated into the KK-founded industrial graduate school SAVE-IT which is presented in chapter 1.

6.1 National Graduate School in Computer Science (CUGS)

In 2001 the Swedish National Graduate School in Computer Science (CUGS), based in Linköping, was launched. MRTC participates as one of four nodes in the school. (The others, besides Linköping University, are University of Örebro and University of Skövde. Jönköping University, Lund University and Växjö University are associated members.)

The goal of the school is to produce PhDs that are well-educated in the central parts of core computer science and computer engineering. CUGS puts an emphasis on programming languages, algorithms, software engineering, also including related areas of autonomous systems, real-time systems, embedded systems, knowledge-based systems and artificial intelligence.

The CUGS curriculum consists of a core curriculum, intended to give a both broad and deep understanding of basic computer science and computer engineering at graduate level, and a selection of advanced courses that can be chosen quite freely. 60 course credits are required for a Ph.D. degree, in addition to the thesis. The students are formally enrolled at their home universities, but are also members of CUGS and will receive a special proof of this when obtaining their respective degrees.

Students are selected to CUGS by the respective participating departments. Each department is allocated a number of modules in competition with the other departments. The modules consist of two graduate students plus associated supervising faculty. Currently, MRTC has two CUGS modules – one led by Björn Lisper, the other by Mats Björkman – with the following PhD students:

- Jan Carlson (High-level languages for hard real-time systems)
- Baran Cürüklü (Modelling and simulation of biological neural networks)
- Adam Dunkels (Networks of sensors, embedded systems, and IP networks)
- Jonas Neander (Proxy support for small embedded communicating devices)

6.2 The ARTES++ national graduate school

In 2003, the Swedish Foundation for Strategic Research (SSF) decided to extend the funding of the ARTES national research initiative (www.artes.uu.se) with 7 MSEK. The extension of the programme is in the form of the ARTES++ graduate school. This school admits 20 students annually during a three year period 2004-2006. The following students from MRTC were admitted in January 2005 (in addition to the seven MRTC graduate students that were admitted in January 2004):

- Erik Olsson
- PengPeng Ni
- Ewa Hansen
- Christer Gerdtman
- Daniel Flemström
- Johan Eriksson

ARTES++ will organise graduate courses, annual summer schools and PhD-student conferences. In addition, admitted students will be provided support for conference trips and a longer international visit, as well as for spending some weeks at a company. Funding for student employments are not provided by ARTES++.

6.3   International MSc-programmes in 2004

All international master years are one-to one and a half year programmes for special education of students towards research in one of the subjects defined by the programme. Closely connected to the department research, the students receive special guidance to be well prepared for research in scientific and industrial environments. The former MSc programmes (magister year) in Real-Time Systems and Computer Science have been included and integrated in the international MSc programmes.

The MSc students have access to all the facilities at the departments and are provided their own workspace. The program consists of one semester of course work and one semester of thesis work. All lectures are given by researchers in the field, and individual assignments are given to improve practical "learning by doing". The courses are mainly on D-level.

In 2004 we offered the following international MSc-programmes within the newly established Mälardalen International Master Academy (MIMA):

Artificial Intelligence

In this program the student may chose the length of his/her studies depending on how much he/she wants to penetrate the subject. During the last semester the student will carry out and write a Master degree project. The project may even last for one and a half semester. The degree project can specialize on e.g., intelligent systems, decision support system, embedded AI, AI in games, intelligent agents or in some field or application you have special interest in. The project is typically carried out within the research group of AI, some of the other research groups or at some company the department and AI group collaborates with - there are several companies in the region with applications where AI is essential - ABB, Volvo, Bombardier, Ericsson to mention some. The courses can be selected and combined in different configuration to give the profile the student prefers and courses from other programs may also be selected.

Computer Science with Programming and Specification Languages

This is a program in Computer Science that specialises in Programming and Specification Languages. The students will work close to the research group in Programming and Specification Languages, which currently runs research projects in execution time analysis, data cache analysis, dimensional inference for modelling languages, and event algebras for high-level programming of embedded systems. Following a course in Research Methodology in Computer Science, you will take advanced Computer Science courses and write a Master degree project. The project is typically carried out within the research group in Programming and Specification Languages, but it could also be done within some other research group at the department or at some company having research cooperation with the department.

Computer Science with Software Engineering

This program specialises in Computer Science and Software Engineering. Following a course in research methods for computer science, you will take advanced courses in computer science and write a Master degree project. Experts within the field will give the lectures. The degree project can be performed within one of the research areas of the department, in close co-operation with researchers and graduate students. Another possibility is to perform the project at some of the companies with which the department has active co-operation, for example ABB or Ericsson.

Real-Time Systems

The master's year in real-time systems provides education for students to pursue further careers in real-time areas, both academic and industrial. It provides a comprehensive set of introductory courses, forming a basis for real-time research, including real-time systems, hardware aspects, and safety critical systems. Furthermore, training is given for scientific methodology, to keep track of rapid developments in the field and prepare for conference publications and presentations. A master's project provides further insights in a specific area by working on a state-of-the-art research project.

Robotics

The programme runs over three semesters mainly due to a philosophy to start with theory and later in the programme specialize in one area, with an experimental approach. In a larger project course students with different specialization work together to design and build complete robots or complete subsystems to a robot. Examples of projects in the past has been mid-size robots (F2000) for robocup. There are two different profiles, Electronic Control and Computer Architecture and System on Chip.

7 Seminars, the Industrial day, and other events

A number of seminars and lectures were held at MRTC providing a forum for presentation and discussion of research within in MRTC as well as lectures by external scientists. Additionally, MRTC organised several workshops and schools with both external industrial and academic participation.

7.1 MRTC Seminars

The MRTC seminars are on topics of general interest to the Computer Science community, with a slight bias towards real-time systems. We also have more focused research talks organised by our different labs (CAL, CSL, SEL, and SDL).

Internal Speakers

1) Licenciate thesis Proposal by Johan Andersson

2) PhD defense by Xavier Vera – Cache and Compiler Interaction

3) PhD defense by Magnus Larsson - Predicting Quality Attributes in Component-based Software Systems

4) Licentiate Thesis defense by Daniel Sundmark - Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components

5) Licentiate Thesis defense by Joakim Fröberg - Engineering of Vehicle Electronic Systems: Business requirements reflected in Architecture

6) Licentiate thesis defense by Markus Bohlin - Design and Implementation of a Graph-Based Constraint Model for Local Search

7) Licentiate thesis defense by Markus Nilsson - A case-based approach for classification of physiological time-series

8) Licentiate thesis defense by Jan Carlsson - An Intuitive and Resource-Efficient Event Detection Algebra

9) Seminar led by Andreas Löfrgren - Safelogic - Formal Property Checker Tool

10) Licentitate thesis defense by Mohammed El Shobaki - On-chip monitoring for non-intrusive hardware(/software observability

11) Licentiate thesis defense by Peter Nygren - An Application Programming Interface for Hardware and Software Threads

12) Licenciate thesis Proposal by Rikard Lindell

13) Licentitate thesis defense by Mikael Sollenborn - Clustering and Case-Based Reasoning for User Stereotypes

14) Licenciate thesis Proposal by Jonas Neander

15) Licenciate thesis Proposal by Adam Dunkels

16) Interinstitutionellt genusfroum led by Gordana Dodig-Crnkovic

17) PhD proposal by Dag Nyström

18) Docentföreläsning by Mikael Nolin – Engineering of Real-Time Systems using Advanced Analysis Techniques

19) Licentitate thesis defense by Rikard Lindell - new Interaction - a content centric data surface approach

20) Licentitate thesis defense by Goran Mustapic - Architecting software for complex embedded systems

21) PhD proposal by Jukka Mäki-Turja

22) PhD defense by Damir Isovic - Flexible Scheduling for Media Processing in Resource Constrained Real-Time Systems

External Speakers

The following talks were given by external speakers at MRTC in 2004:

1) Programming with time-constrained reactions by Johan Nordlander, LuTH

2) The Philosophy of Information as a New Field of Research by Luciano Floridi, University of Oxford

3) Predictable assembly of software components by Kurt Wallnau SEI/CMU

4) Medicin och Artificiell Intelligens: En psykofysiologisk ansats för identifiering av symptom, diagnos och effektiv behandling by Bo v Scheele, Stressmedicin AB, Peter Funk MdH

5) Robust Open Component Based Software Architecture by Michel Chaudron, Technical University Eindhoven

6) IT och artificiell intelligens(AI)/intelligenta system för diagnos, stressprevention och behandling av stress, Söderhamns TeknikPark, Stressmedicin AB samt MdH

7) Component-based software architecture by Paula Inverardi, Computer Science Department at University of L'Aquila

8) Overview of the Bound-T WCET tool by Niklas Holsti, Tidorum Ltd

9) Fri och öppen programvara - en ny strategisk inriktning

10) Fallstudiemetodik by Per Runesson, LU

Soft Real-Time Aspects in Ericsson's Telecom Systems

During 2004 MRTC also arranged a seminar day: **Soft Real-Time Aspects in Ericsson's Telecom Systems**. The programme included the following topics:

- Soft real time and high availability by Mike Williams (Ericsson/TSP)
- How the AXE System Implements Soft Real Time by Åke Nyberg (Ericsson/AXE)
- Carrier Class Telecom Server Platform by Alexander Larruy (Ericsson/TSP)
- Erlang Open Telecom Platform by Ulf Wiger (Ericsson/AXD)
- Characteristics of AXE under extreme overload during a catastrophe by Lars-Åke Johansson Ericsson/AXE)
- Parallel PLEX Project by Björn Lisper

7.5   *MRTC Industrial Day*

The MRTC Industrial Day is an annual event organised in spring each year. The purpose of the industrial day is to present and discuss our achievements, with a special emphasis on industry relevance and impact.

Our co-operation partners, other industry, national academia, and students are invited to participate in this event, which in addition to MRTC presentations features invited speakers, typically world-leading researchers or industrialists.

Since one day is not enough to present all the multitude of projects and activities at MRTC, each industrial day has a special focus corresponding to a specific research direction.

Industrial Day 2004

This years traditional Industrial Seminar focused on development of large complex embedded sytems. Swedish industry has a tradition in being excellent in these systems with high reliability and availability requirements, such as telecom systems, automation systems, aeroplanes, and vehicles. The systems become increasingly complex, while at the same time the global competition becomes tougher and tougher. To remain competitive we must both understand where the complexity origins and how to handle it efficiently.

In this year's seminar these issues were addressed by providing talks from two world leading researchers, Kurt Wallnau Software Engineering Institute, CMU, USA and Jeff Voas, Cigital, USA. They both addressed design and verification issues when developing complex systems. Further, a talk addressing complexity issues in system development was given by Jakob Axelsson from Volvo Cars.

From the programme:

- Welcome and brief presentation of MRTC, Hans Hansson, MdH
- Softwares Inoperable Interoperability Problem, Jeff Voas, Cigital, USA
- Component-based architectural specifications that enhance predictability of quality-attributes, Kurt Wallnau,CMU, USA
- Complexity Issues in System Development: Examples from Automotive Electronics, Jakob Axelsson, Volvo Cars/MDH

The day was finished with a panel discussion with Prof Christer Norström as moderator, and participation from the speakers and from Per Skytt (ABB Corporate Research).

This year's edition also opened for further informal discussions after the panel while the participants enjoyed a beer and a sandwich.

Industrial Day 2003

The focus on 2003 years edition of MRTC Industrial Seminar was on Robotics, both from an industrial and academic perspective. One of the highlights was a talk by Erik Sandewall from Linköping University on "The WITAS Unmanned Aerial Vehicle Project".

Additional items on the agenda:

- Welcome and brief presentation of MRTC (Hans Hansson)
- Learning systems and autonomous robotics at AASS (Tom Ducket, Örebro University)
- Industrial Robotics – pas, now and in the future (Torgny Brogårdh, ABB Robotics)
- The Robot Valley Initiative and Robotics at MRTC (Lars Aspund)
- Panel: Robotics in Society (Panellists: Tom Duckett, Erik Sandevall, Torgny Brogårdh, Lars Asplund; Moderator: Christer Norström)

Industrial Day 2002

The Industrial seminar in 2002 had a focus on Safety-Critical Systems, with a much appreciated tutorial on "Safety-Critical System and Software Standards" given by Dr P.V. Bhansali, Associate Technical Fellow of The Boeing Company.

Additional items on the agenda:

- Welcome and brief presentation of MRTC (Hans Hansson)
- Automatic testing with fault injection (Håkan Edler, IVF)
- Poster Exhibit
- Multiprocess Application Monitor (Mohammed El Shobaki)
- Monitoring Hardware for Safety-Critical Systems (Lars Asplund)
- Componentization of industrial control systems (Frank Lüders)
- Research at Computer Science Laboratory 2001 (Ivica Crnkovic)
- Flexible Scheduling and Temporal Constraints in Embedded Control Systems (Gerhard Fohler)
- Enforcing Temporal Constraints (Kristian Sandström)

Industrial Day 2001

In 2001 the focus was on Industrial Software Engineering, with invited speaker Jeffrey Voas from Cigital, who gave the talk "Why Testing Under Expected Operational Scenarios is Not Sufficient".

Additional items on the agenda:

- Welcome and brief presentation of MRTC (Hans Hansson)

- Poster Exhibit
- Component-based Software Engineering - Promises and Challenges for Industrial IT (Ivica Crnkovic)
- Experience in Using Standard Technologies in Industrial Applications (Erik Gyllenswärd)
- Education goals at Department of Software Engineering and Mälardalen University (Elvy Westlund)
- Software Product lines – Flexible and Reusable Architectures (Anders Wall)
- Scalable Multiprocessor Platform for Industrial Control Applications (SARA) (Lennart Lindh, Leif Enblom)
- "Best Practice" of Academia & Industry Cooperation - Sveriges Verkstadsindustrier (Annita Persson Dahlqvist)
- Panel: Total global integration of real-time, safety-critical systems with non-real-time non-safety-critical information systems - utopia or reality? (Panellists: Jeffrey Voas, Hans Skoog, Christer Ramebäck, Annita Persson, Björn Lisper, Christer Norström; Moderator: Bengt Asker)

Industrial Day 2000

In 2000 the focus was on Real-Time Systems, with an invited presentation by Prof. Jack Stankovic from Univ. of Virginia: "Application Specific Operating Systems for Embedded Systems: A Component Based Solution".

Additional items on the agenda:
- Welcome and brief presentation of MRTC (Hans Hansson)
- Poster Exhibit
- Real-life Applications of Computer Science: Analysis of RT Systems and Industrial Software Engineering (Lisper/Crnkovic)
- Designing Safety Critical Embedded Systems (Hansson/Norström/Thane)
- Scalable Multiprocessor Platform for Industrial Control Applications (Lennart Lindh)
- Panel on "Real-Time Research for Industry" (Panellists: Bernt Ericsson, Hans Skoog, Peter Lidén, Göran Lundin, Christer Ramebäck, Jack Stankovic, Neeraj Suri, Jan Torin; Moderator: Bengt Asker)

8 Publications

8.1 Research publications

8.1.1 Books

1. Peter Funk, Pedro A González Calero (eds.): Further Advances in Case-Based Reasoning, Springer verlag, LNAI 3155 2004 ISBN: 3-540-22882-9

8.1.2 Journals

2. Ivica Crnkovic, Heinz Schmidt, Judith Stafford, Kurt Wallnau: 6th ICSE Workshop on Component-Based Software Engineering: automated reasoning and prediction, ACM SIGSOFT Software Engineering Notes, 29(3):1-7, ACM, May 2004.

3. Damir Isovic, Gerhard Fohler, Liesbeth Steffens: Real-time issues of MPEG-2 playout in resource constrained systems, International Journal on Embedded Systems, vol. 1(2), ISSN 1740-4460, Cambridge International Science Publishing, June 2004.

4. Erik Olsson, Peter Funk, Ning Xiong. Fault Diagnosis in Industry Using Case-Based Reasoning, Journal of Intelligent & Fuzzy Systems, vol. Vol. 15, ISSN 1064-1246, IOS Press, December 2004.

5. Anders Möller: A Simulation Technology for CAN-based Systems, CAN Newsletter, (4), CAN in Automation, December 2004.

6. Annita Persson-Dahlqvist, Ivica Crnkovic, Magnus Larsson: Managing Complex Systems - Challanges for PDM and SCM, Projects & Profits, IV-7(Rs 60):36-42, ICFAI Press, Panjagutta, Indien, July 2004.

7. Aleksandra Tesanovic, Dag Nyström, Jörgen Hansson, Christer Norström: Aspects and Components in Real-Time System Development: Towards Reconfigurable and Reusable Software, JOURNAL OF EMBEDDED COMPUTING, 1(1), Cambridge International Science Publishing, February 2004.

8. Xavier Vera, Nerina Bermudo, Josep Llosa, Antonio Gonzalez: A Fast and Accurate Framework to Analyze and Optimize Cache Memory Behavior, ACM Transactions on Programming Languages and Systems (TOPLAS), vol. 26(2) , ACM, March 2004.

9. Jingling Xue, Xavier Vera: Efficient and Accurate Analytical Modeling of Whole-Program Data Cache Behavior, IEEE Transactions on Computers, vol. 53(5), IEEE, May 2004.

8.1.3 Thesis

10. Damir Isovic: Flexible Scheduling for Media Processing in Resource Constrained Real-Time Systems, Phd Thesis, Mälardalen University Press, November 2004.

11. Magnus Larsson: Predicting Quality Attributes in Component-based Software Systems, Phd Thesis, Mälardalen University Press, March 2004.

12. Xavier Vera: Cache and Compiler Interaction (how to analyze, optimize and time cache behavior), Phd Thesis, Mälarden University Press, January 2004.

13. Markus Bohlin: Design and Implementation of a Graph-Based Constraint Model for Local Search, Licentiate Thesis, Mälardalen University, April 2004.

14. Jan Carlson: An Intuitive and Resource-Efficient Event Detection Algebra, Licentiate Thesis, Mälardalen University Press, June 2004.

15. Mohammed El Shobaki: On-Chip Monitoring for Non-Intrusive Hardware/Software Observability, Licentiate Thesis, Department of Information Technology, Uppsala University, Sweden, September 2004.

16. Joakim Fröberg: Engineering of Vehicle Electronic Systems: Requirements Reflected in Architecture, Licentiate Thesis, Mälardalen University Press, April 2004.

17. Rikard Lindell: Towards new Interaction - A Content Centric Data Surface Approach, Licentiate Thesis, Mälardalen University Press, December 2004.

18. Goran Mustapic: Architecting Software for complex embedded systems - Quality Attribute Based Approach to Openness, Licentiate Thesis, Mälardalen University Press, December 2004.

19. Markus Nilsson: A Case-Based Approach for Classification of Physiological Time-Series, Licentiate Thesis, Mälardalen University Press, May 2004.

20. Mikael Sollenborn: Clustering and Case-Based Reasoning for User Stereotypes, Licentiate Thesis, Mälardalen University Press, October 2004.

21. Daniel Sundmark: Deterministic Replay Debugging of Embedded Real-Time Systems using Standard Components, Licentiate Thesis, Mälardalen University Press, March 2004.

8.1.4 Articles in collection

22. Goran Mustapic, Johan Andersson, Christer Norström, Anders Wall: A Dependable Open Platform for Industrial Robotics - A Case Study, in Architecting Dependable Systems II Editors: Rogerio de Lemos, Cristina Gacek, Alexander Romanovsky, LNCS 3069, Springer Verlag , 2004.

8.1.5 Conferences and workshops

23. Johan Andersson, Anders Wall, Christer Norström: Decreasing Maintenance Costs by Introducing Formal Analysis of Real-Time Behavior in Industrial Settings, Proceedings of the 1st International Symposium on Leveraging Applications of Formal Methods (ISoLA '04), Paphos, Cyprus, October 2004.

24. Johan Andersson, Anders Wall, Christer Norström: Validating Temporal Behavior Models of Complex Real-Time Systems, Proceedings of the Fourth Conference on Software Engineering Research and Practice in Sweden (SERPS'04), Linköping, Sweden, September 2004.

25. Marcus Bengtsson, Erik Olsson, Peter Funk: Technical Design of Condition Based Maintenance Systems - A Case Study using Sound Analysis and Case-Based Reasoning, MARCON (Maintenance and Reliability Conference), pages 12, Knoxville, TN, USA, May 2004.

26. Jan Carlson, Björn Lisper: An Event Detection Algebra for Reactive Systems, Fourth ACM International Conference on Embedded Software (EMSOFT'04), pages 147-154, Pisa, Italy, ACM, New York, September 2004.

27. Ivica Crnkovic, Magnus Larsson: Classification of quality attributes for predictability in component-based systems, DSN 2004 Workshop on Architecting Dependable Systems, Florence, Italy, IEEE, June 2004.

28. Ivica Crnkovic: Component-based approach for Embedded Systems, Ninth International Workshop on Component-Oriented Programming, Oslo, June 2004.

29. Baran Çürüklü, Anders Lansner: A Model of the Summation Pools within the Layer 4 (Area 17), Proceedings of the Computational Neuroscience Meeting, Baltimore, USA, Elsevier, July 2004.

30. Baran Çürüklü: Early Stages of Vision Might Explain Data to Information Transformation, Proceedings of the Turkish Symposium on Artificial Intelligence and Neural Networks, Izmir, Turkey, June 2004.

31. Radu Dobrin, Gerhard Fohler: Reducing the Number of Preemptions in Fixed Priority Scheduling, 16th Euromicro Conference on Real-time Systems (ECRTS 04), Catania, Sicily, Italy, July 2004.

32. Gordana Dodig-Crnkovic, Sandra Irobi Ijedma: Model Validation, Evolutionary Systems and Semantics of Information, Model-Based Reasoning In Science And Engineering Abduction, Visualization, And Simulation, Pavia, Italy, December 16-18, 2004, (editor(s):L Magnani), December 2004.

33. Gordana Dodig-Crnkovic: On the Importance of Teaching Professional Ethics to Computer Science Students, Computing and Philosophy Conference, E-CAP 2004, Pavia, Italy, (editor(s):L Magnani), November 2004.

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