MRTC

MÄLARDALEN REAL-TIME RESEARCH CENTRE

www.mrtc.mdh.se

Annual Report 2003

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 and software engineering and dominating focus on real-time systems.

With a strong application focus on computers and computing in products and production systems (of various types), research is conducted – in many cases in close co-operation with industrial partners – in the disciplines of real-time and embedded systems, industrial software engineering, data communication, intelligent systems, and robotics (a new direction currently being established).

This report presents the organisation, projects and achievements of MRTC in 2003, a year of continued growth with the following high-lights:

- One Ph.D. thesis (Anders Wall) was successfully defended.
- Twelve Licentiate theses (Thomas Nolte, Dag Nyström, Tomas Lennvall, Radu Dobrin, Rikard Land, Anders Pettersson, Thomas Larsson, Joel Huselius, Leif Enblom, Christina Wallin, Frank Lüders, and Baran Çürüklü) were successfully defended.
- 7 new Ph.D.-students have been enrolled (2 of which are industrial PhD-students).
- 26 MSc-theses and 100 publications, many presented at leading conferences world-wide.
- Support with 100MSEK was decided by Vinnova for the Robotdalen regional initiative. Robotdalen aims at during a ten year period establish Mälardalen as a world leading region in Robotics. Robotdalen includes academic cooperation with Örebro University and KTH, industrial cooperation, and cooperation with schools, municipalities and hospitals. Matching support will be provided by participating organisations.
- Support with more than 20 MSEK was by the KK-foundation decided for the industrial graduate school SAVE-IT. During a period of 6 years, 15 industrial PhD students will be involved in research and graduate education in conjunction with the research programme SAVE. Matching support will be provided by participating industries
- Support with 9 MSEK was granted by the strategic foundation (SSF) for the research project ExAct, coordinated by Peter Funk (CSL). Together with participating industries, that will provide an additional 15.5 MSEK, an intelligent and flexible framework for information-sharing will be developed.
- MRTC organized the following workshops and conferences in or in the vicinity of Västerås:
    - RTiS, Real-time in Sweden, August 18th-19th, Västerås
    - ESSES, European Summer School on Embedded Systems, July-October, Västerås
    - MRTC Industrial Day, March 31st, Västerås
    - 2 IPIS workshops, Intellectual Property Based FPGA SOC Design Västerås

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 grant from the KK-foundation and a focused effort on real-time related research since 1987 at the Department of Computer Science and Engineering (IDt).

Looking back at 2003, there are a few important breakthroughs and developments which I believe in a longer perspective will be considered major milestones in the development of MRTC

- This was the year of the "Ketchup-effect" in graduate degrees. We reached a new higher level in the production of graduate degrees. Previous years 3-5 degrees were produced, but in 2003 13 graduate degrees (1 PhD + 12 Licentiates) were completed. What is even more satisfying is that this is not a single peak; instead we are expecting even more degrees in 2004 (our most optimistic forecast indicates 8 PhDs and 24 licentiates; even the more realistic estimate of reaching half of these numbers would be an outstanding achievement!).
- Our involvement in European activities increased, by involvement in a number of proposals for projects and networks within the EU 6th Framework Programme: including ARCHON, ARTIST 2, UFL, BESTY, Coconet, Rewind, Structure, and Vian. This is in addition to involvement in the current (FP 5) activities: FABRIC, DOTS, and ARTIST.
- The Robotdalen ("Robot Valley") initiative was launched; involving academic cooperation with Örebro University and KTH, as well as industrial cooperation, and cooperation with schools, municipalities and hospitals. As a result a couple of senior industrial robotics engineers are now working at the department, our contacts with schools have increased, we are about to launch an engineering programme in robotics, we are recruiting a (part-time) professor in robotics, and robotics have been identified as a priority area.
- In addition to the SAVE-IT industrial graduate school which in 2004-2005 will lead to some 10 additional industrial graduate students at MRTC, six of our students were admitted to the ARTES++ national graduate school in real-time and embedded systems. ARTES++ will organise graduate courses, and provide support for mobility (both international and for industry visits).
- The ExAct-grant clearly indicates the maturity of our intelligent systems group, as well as the success of the profile grant, which has been instrumental in establishing this group.
- Research co-ordinator Ylva Boivie was recruited. The benefits from having a person dedicated to "high-level" support for research activities and administration is (and will) allow us to become even more professional in how we run and further develop MRTC.
- A major effort was undertaken to formulate plans for the future development and funding of MRTC. Concretely, this work resulted in an application for establishing a new profile in Software Engineering (MISEC). Despite positive feedback, the application only survived the first round of evaluation by the KK-foundation. Unfortunately, the proposal was considered to be too close to the MRTC-profile. The work invested in formulating visions and long term plans for the research is however well invested, and will continue in 2004.
- A decision to move into the new university building was taken. The move, which is planned for in September 2004, will facilitate closer contacts with other university departments, and in particular our cooperation with the Electronics departments (IEl) will be intensified.

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 2004.

Hans Hansson
Director MRTC

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1 Mälardalen Real-Time research Centre (MRTC)

Mälardalen Real-Time research Centre (MRTC[1]) 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[2].
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] Note that we use the brand-name MRTC (Mälardalen Real-time Research Centre) to denote all research at the department of Computer science and Engineering (IDt), even though the majority of research activities at IDt are funded by other sources than the MRTC grant from the KK foundation. For a specific presentation of this grant, please consult Section.1.9

[2] Licentiate is an optional intermediate postgraduate degree approximately halfway to a PhD. About one year of course work and writing a licentiate thesis is required.

1.1 Industrial co-operation

One of the cornerstones of MRTC is the close industrial co-operation. Almost all our projects and activities include industrial partners. To further develop our interactions with industry we are establishing more long-term bilateral co-operations with some of our main industrial partners:

- ABB Research – A strategic cooperation with ABB research has been established. The cooperation includes common projects, several industrial PhD students and, master students, participation in courses, common works on different applications, etc. In 2003 the following concrete results have been achieved:
    - ABB CRC has selected as MRTC as a strategic partner for research in Software Engineering
    - Three ABB CRC employees work 50% as industrial PhD students on their research. One (Christina Wallin) has obtained her Licentiate. Thesis and one (Magnus Larsson) will obtain his PhD in Q1 2004.
    - MRTC and ABB CRC were 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 by ABB and MRTC together
    - About ten papers were published and presented together at international conferences
    - MRTC, ABB CRC and Software Engineering Institute at Carnegie Mellon University have a successful cooperation in several years

  Common research policy and building a portfolio of common research activities are periodically discussed and updated. Dr. Fredrik Ekdahl from ABB CTC 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 2003, the portfolio consisted of:
    - two research projects REMODEL and OpenController which is 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.
    - participating in a EU Network of excellence (ARTIST-2)
    - organisation of several workshops
    - two courses, real-time systems and safety critical systems, which have been given at ABB Robotics.
    - several master theses that have been conducted at ABB Robotics by MdH students.
    - more than 20 trainee positions have been provided for MdH students at ABB Robotics.
    - two persons from ABB that now temporarily is working for MdH.
    - two PhD students which have been participating in a development projects to get insight into the development of complex systems.

  The portfolio is evaluated four times per year. Essential for the success of a portfolio of this size, are long term goals and mutual benefits for both partners, as well as persons maintaining the portfolio. In the case of ABB Robotics, the portfolio is managed by Staffan Elfving, ABB

Robotics and Christer Norström, MdH that together owns the portfolio. We believe that this way of working together is a model for the future.

- Bombardier Transportation – We are extending this type of co-operation also to other industries, as well as establishing co-operation with groups of companies in specific areas. One such example being Ericsson Microwave where cooperation in the area of information systems – product data management and software configuration management is established.

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 2003 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 the graduate education for 15 graduate students employed by participating companies, as well as promoting increased co-operation and exchange between all participating organisations.

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 ExAct

The purpose with the ExAct project is to exploit methods and techniques from artificial intelligence (AI) to enable semi-automatic and automatic experience sharing in organizations. The project is funded (9 MSEK during a three-year-period) by the Swedish Foundation for Strategic Research (SSF, ProViking). It is a collaboration between IDt, IDP, Stockholm University and KTH. Industrial participants are ABB robotics, SKF, Volvo CE and SCEMM with 70 member companies.

The main goal for the ExAct project is to build the foundation for a framework that enables humans and computer systems to share and reuse experience. How to give the system intelligent features such as being proactive, learn from mistakes, improve its performance and ability to collaborate with other systems and humans will be explored. This will be made with a number of case studies and pilot projects together with industry, carried out during 2004, 2005 and 2006.

The value and benefits for industry and also the health care sector is large. Up to 60 % of an organization's experience is said to be inside peoples heads and difficult to share and reuse. Also data collected automatically with sensors captures valuable experience rarely reused to its full extent in industry. The research will enable the construction of "flexible and intelligent experience sharing" systems. Methods and techniques from artificial intelligence are key components to achieve this goal.

Standardization issues are also explored as well as condition based maintenance, intelligent diagnostics, automated intelligent support system, flexible production processes and industrial robots that learn and adapt to new situations.

Dr. Peter Funk is project leader and coordinator of the project.

1.2.3 LESS BUGS

Funding for LESS BUGS of 3.8 MSEK during a three year period was decided by the KK-foundation in December 2003. In addition, the industrial partners ABB Corporate Research, Bombardier Transportation and Level Twentyone, will contribute with efforts (including 2 industrial PhD students) valued to 5.5 MSEK.

LESS BUGS is focused 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.

In LESS BUGS we will elaborate and expand on that work and add real industrial 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.

1.2.4 EvaluNet II

EvaluNet - Steg II is a three-year project supported by KKS with a 2.0 MSEK grant, to which should be added efforts by Ericsson Research, TeliaSonera AB and Gatorhole AB. The project is lead by MdH, and the active participating organizations are MdH, Ericsson Research, TeliaSonera AB and Gatorhole AB, with the following additional partners:

- SICS AB
- Netintact AB
- Stiftelsen för internetinfrastruktur.

The main goal of EvaluNet - Steg II is to develop tools for end-to-end characterization of computer network paths, focusing on available bandwidth and delay.

One of the main activities in EvaluNet - Steg II is to actively cooperate with Gatorhole AB in the development of future versions of the TPTEST tool, developed by Gatorhole AB and provided by Konsumentverket, Post- och telestyrelsen and Stiftelsen för internetinfrastruktur.

1.2.5 PLEX

Since 1998, collaboration between Ericsson and MRTC, around methods and tools for analysis of PLEX programs, has taken place. This has been 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 will be recruited in early 2004. The project is expected to run for at least two years. It will be co-funded by Ericsson and ASTEC.

1.2.6 MultEX

In MultEx MRTC and Arcticus Systems AB 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.

This project was launched in Q4 2003 and started with a test implementation of, so called, single shot execution (SSX) tasks in Arcticus' real-time operating system Rubus. The result was a proof of concept that Rubus allows easy implementation of new execution paradigms, in that SSX tasks was implemented using a resource effective shared stack. The long term goals of the project, encompassing 3 years of activities, will generate one licentiate and one PhD degree. Together with Arcticus Systems new techniques will be implemented in their software engineering tools.

1.2.7 ESSES

During a three month period (July 14th- Oct 10th) MRTC arranged and hosted the European Summer School on Embedded Systems (ESSES). The objective of ESSES was to provide a forum for PhD students and early-career researchers in low-power, embedded, and real-time research areas to learn up-to-date research from masters in the three strongly inter-related research areas and to foster their own research network. In order to achieve this more than 45 world-class lecturers were invited and gave lectures on their research field to more than 80 international students. The networking was supported by the many social activities, ranging from Swedish cray-fish party and Korean barbeque, to descending into an old silver-mine. The summer school also made visits to relevant industry, such as ABB Robotics, Ericsson, CC-systems.

The summer school was sponsored by BK21 (Korea), ARTIST (EU-network), Ciss (Denmark), Artes (Sweden), and MRTC.

1.2.8 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.

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.

1.2.9 MISEC

In September 2003 an application was sent to KK-foundation proposing establishing Mälardalen Industrial Systems Engineering Centre (MISEC) to make the Mälardalen region world-leading in engineering of industrial computer-based systems. Associated companies would through MISEC get access to the best competence in the world in research and education, together with an industrial-academic network in development of industrial computer-based systems.

The centre would specifically focus on predictability in engineering of 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 realisation of this vision in this extremely complex area required that MISEC began from a high level of competence in both academic research and education, together with a thorough understanding of the needs of industry. Further, an existing active collaboration with industry was required.

MISEC was strongly supported by ABB (3 divisions), Bombardier Transportation Systems, CC Systems, CompFab, Ericsson, Volvo Car, Volvo CE, Tieto Enator and ÅF. The participating companies indicated a total support of 34 MSEK.

The application was considered very well written and a proposed a very good concept but was unfortunately rejected because it was considered to resemble MRTC too much.

1.2.10 European FP6 Proposals

During 2003 members from MRTC were active in the following proposals for the European 6th Framework Programme. The list indicates the project acronym, type of instrument (STREP, Specific Targeted Research Project; NoE, Network of Excellence; IP, Integrated Project)

a) ARCHON, STREP coordinated by University of Cyprus
b) ARTIST 2 Embedded Software and Systems (NoE), Laboratoire VERIMAG /Université Grenoble Joseph Sifakis, France
c) UFL, STREP, coordinated by MdH skall tas bort? Rejection"!
d) BESTY, STREP, coordinated by Philips research
e) Coconet- "CONTROL METHODS FOR COMMUNICATION NETWORKS", IP coordinated by Université Henri Poincaré
f) Rewind, STREP, coordinated by Siemens Business Systems
g) Structure, STREP coordinated by Philips research
h) Vian, IP, coordinated by TU Vienna (Thilo Sauter)

1.2.11 International Master of Science Programmes

The department has committed upon a strong effort to market our Master's programs internationally. The programs will be marketed through MIMA – Mälardalen International Master Academy – and thus via the ECTS catalogue, the Swedish Institute, and our web pages. The programmes are intended for students with a Bachelor of Science in the appropriate subject, and are all given in English.

The programmes offered for 2004 are:

- Master's Program in Computer Science with Software Engineering Profile (1- 1.5 years)
- Master's Program in Computer Science with Artificial Intelligence (AI) Profile (1-2 years)
- Master's Program in Computer Science with Programming and Specification Languages profile (1 year)
- Master's Program in Robotics (1.5 year)
- Master's Year in Real Time Systems (1 year)
- Preparatory Module for Master's Year in Real Time Systems (0.5 - 0.75 year)

1.2.12 teknIQ – Expert Competence Intelligent Products

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 CAL is responsible for one of five regions (Mid-Sweden), as well as the teknIQ training program. During 2003 researchers and students at MdH/MRTC have been increasingly involved in teknIQ, including:

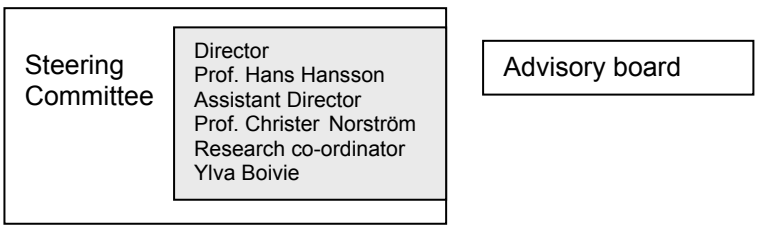
- Student work in actuators for applications in distributed systems in trucks and Bluetooth for steering an electrical engine.
- Starting a project with an industrial researcher in the AI area
- Organisation of seminars where new innovative ways of possibilities are presented and discussed. Examples of seminars in 2003 include Embedded Internet Systems, LonUserday 2003 in Stockholm, Wireless Arena 2003 in Ronneby, Bluetooth in industrial environment and Communication in industrial applications with ProfiBus. The seminars were successfully completed with totally more than 700 participants.
- Course offerings and development, including courses on
    - ❖ Mechatronics (CAL)
    - ❖ Electronic design (CAL)
    - ❖ Communication with CAN (CAL)
    - ❖ Embedded systems (CAL)
    - ❖ Electrical machines (CAL/IEL)
    - ❖ DSP – technology (CAL/EmbeddedArtists)

  The total number of SMEs was about 40 for these courses in 200
- Complete a new course "Products with embedded systems"- 5points, intended for students at the department of Innovation, Product development and Design (IDP) at MdH, but also for students in different kind of electronics and computing program.

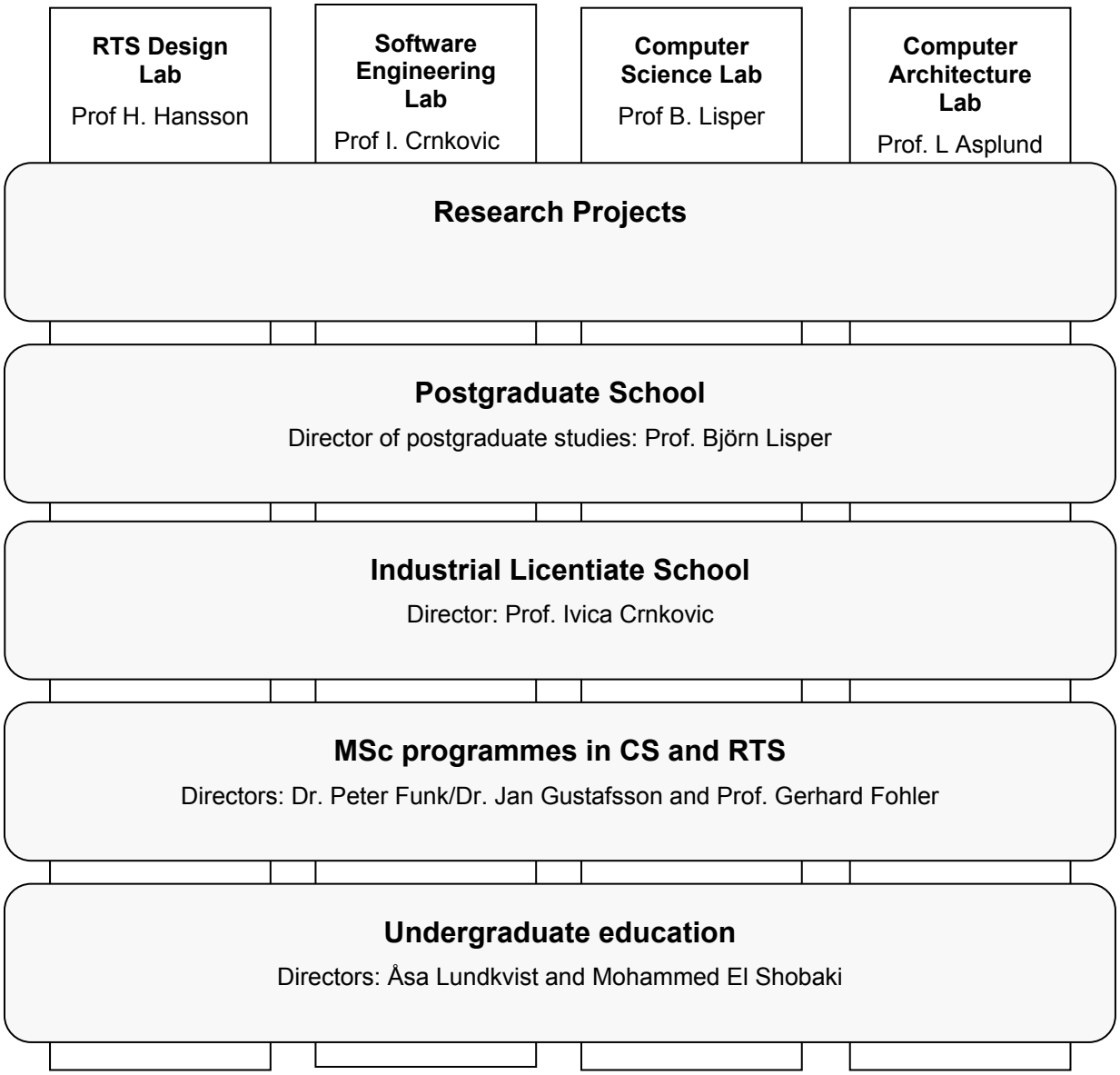
More information is available at www.tekniq.nu

1.3 Organisation

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



Research laboratories



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 licentiate school 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.

Within the laboratories, the actual research is performed by research groups, which all 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. The groups are in several cases co-operating, as they are all dealing with different (complementary) perspectives on embedded real-time systems.

a) **Industrial Software Engineering group** – headed by Prof. Ivica Crnkovic; 7 graduate students; 3 licentiates in 2003 and 1 PhD early 2004; focusing on Software Engineering for industrial systems (e.g. for automation systems); funding from ABB, SSF, EU, KKS, and MdH.
b) **Embedded Systems Software Engineering group** – headed by Prof. Christer Norström; Senior Lecturer Dr. Kristian Sandström; 6 graduate students; 2 licentiates and 1 PhD 2003; focusing on Embedded Systems Software Engineering (e.g. for automotive systems); funding from SSF, ABB, KKS, and MdH.
c) **Predictably Flexible Real-Time Systems group** – headed by Prof. Gerhard Fohler; 3 graduate students; 2 licentiates 2003, 1 PhD planned 2004; focusing on static and dynamic real-time scheduling, combining flexibility and predictability; funding from EU, SSF, and MdH.
d) **Communication Performance Predictability and Analysis group** – headed by Prof. Mats Björkman; Researcher Dr. Bob Melander; 4 graduate students; 2 licentiates planned for 2004; focusing on communication for small embedded devices, and traffic measurement and analysis; funding from VR, Vinnova, KKS, CUGS, and MdH.
e) **Monitoring and Testing group** – headed by Dr. Henrik Thane; 4 graduate students; 3 licentiates in 2003; focusing on monitoring, testing, and debugging of real-time systems; funding from SSF, KKS, and MdH.
f) **Real-Time Systems Design group** – headed by Prof. Hans Hansson; Researcher Dr. Mikael Nolin, 4 graduate students; 1 licentiate in 2003; focusing on design methods, architectures and communication for real-time systems; funding from SSF, Vinnova, KKS, EU, and MdH.
g) **Safety-Critical Systems group** – headed by Prof. Lars Asplund; 4 graduate students; 2 PhDs planned for 2004; focusing on hardware architectures for safety-critical systems and robotics sensory systems; funding from KKS and MdH.
h) **Scalable Architecture for Real-time Application (SARA) group** – headed by Prof. Lennart Lindh; 7 graduate students; 3 licentiates in 2003; focusing on scalable multiprocessor systems, system-on-chip, and moving software functions into hardware; funding from KKS and MdH.
i) **The Programming Languages group** – headed by Prof. Björn Lisper; Senior Lecturer Dr. Jan Gustafsson and Researcher Dr. Andreas Ermedahl; 7 graduate students; 2 licentiates in 2003 and 1 PhD early 2004; focussing on worst-case execution time analysis, and design and analysis of languages for real-time and embedded systems; funding from Vinnova, VR, KKS, CUGS, and MdH.
j) **The Intelligent Systems group** – headed by Docent Peter Funk; 4 graduate students; 2 licentiates in 2003 and 2 licentiates planned 2004; focusing on applications of artificial intelligence techniques (in particular case-based reasoning); funding from SSF, KKS, and MdH.

1.4 Scientific Achievements

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 projects. 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 managing 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 and 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
    - ❖ Vice President Research and Innovations Bernt Ericson, 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, Chalmers
    - ❖ 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).

1.5 Funding

MRTC was established as the result of a grant of (up to) 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 (up to) 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.

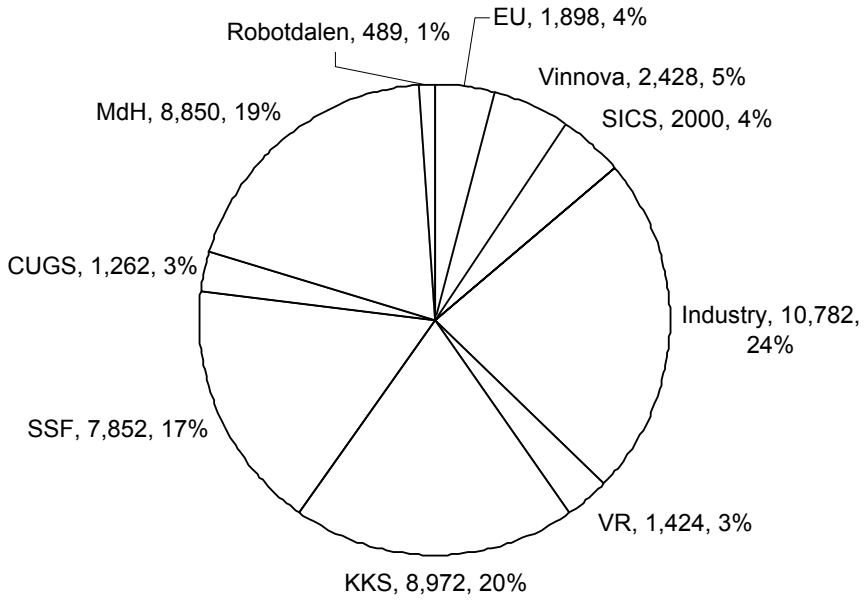
In addition to the above, MRTC is also funded by more traditional competitive sources of funding, including grants from

- 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), and
- The European Union, via Fifth Framework projects and networks.

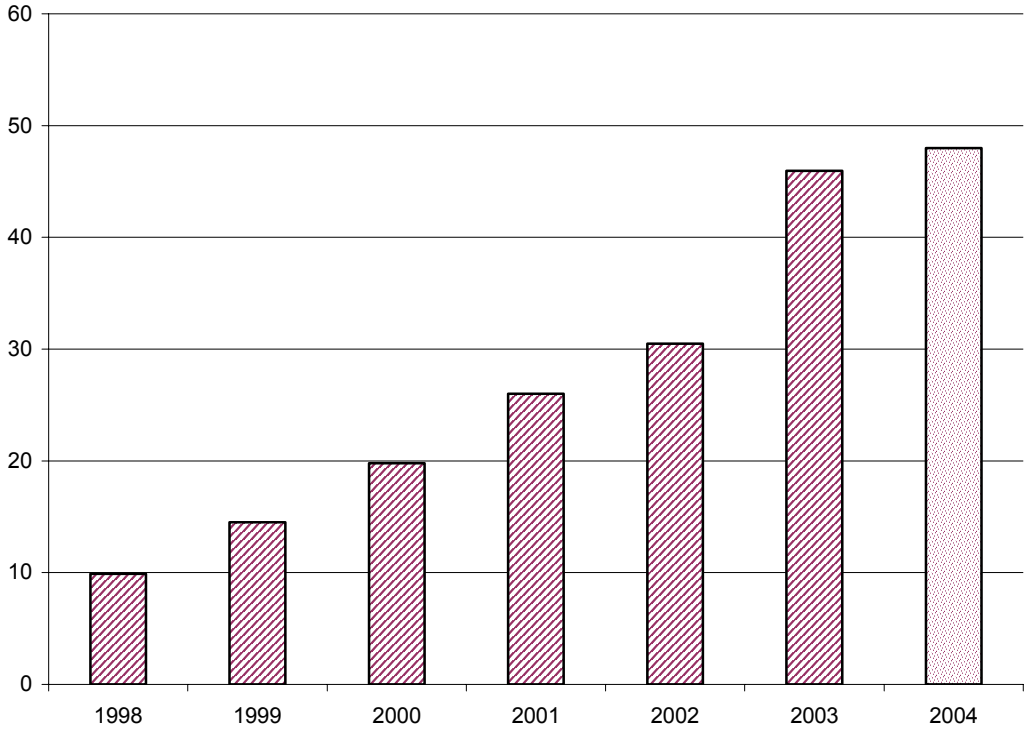
All research is performed in projects with specific goals with respect to achievements, publications, collaborations, and prototype tools. Each project includes both senior researchers and postgraduate students. A project typically has elements of both basic and applied research. The project leader is 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 2003, more than 80% of the funding was external, the majority from the KK-foundation (KKS), Industry (both via donations and direct involvement in projects), SICS, SSF, Vinnova, the Swedish Research Council (VR) and the European Union (EU). The diagram below summarises the MRTC funding in 2003 (for each source, name, amount and percentage are indicated). It should be noted that the majority of the included SICS and Industry funding is in terms of participation in research projects and does not represent direct monetary funding of MRTC.



MRTC funding 2003, total amount 46 MSEK

The following chart, showing the funding levels in MSEK for the years 1998-2004 (amounts in MSEK; budget value for the latter year), gives an illustration of the rapid development of MRTC.



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 more than 50 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 some 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 2003, 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.

A major event in our postgraduate education during 2003 was the European Summer School on Embedded Systems, an international summer school hosted by MRTC and arranged in collaboration with Korean researchers. This summer school stretched over nearly three months (!): it featured a number of prominent international speakers and attracted many international graduate students, mostly from Korea but also a number of other countries.

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

Courses

During 2003, MRTC has offered 7 postgraduate courses:

- Real-Time and Embedded Systems (spring, CUGS)
- European Summer School on Embedded Systems, (summer-fall)
- Research Methodology for Computer Science and Engineering (fall)
- Planning of research projects (fall, Licentiate School course)
- Component Technologies (fall)
- Concurrency Theory and Time (fall)
- Advanced Functional Languages (self-study course, no fixed period)

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 2003 the following Computer Science and Engineering D-level courses were given by MRTC-staff at MdH:

- Computer Graphics, advanced course, 5p
- Case-based Reasoning, 5p
- Real-Time Systems, advanced course, 5p
- Safety-Critical Systems, 5p
- Semantics of programming languages, 5p
- Logic Programming, 5p
- Parallel Systems, 5p
- Artificial Intelligence, in Depth, 5p
- Component-based Design of Single-Chip Systems, 5p
- Engineering of Complex Embedded Systems, 5p
- Professional Ethics, 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/kurser/phd/courses.

Theses

In 2003, one PhD thesis and 12 Licentiate theses were presented by MRTC staff:

- **Anders Wall** (SEL), Architectural Modeling and Analysis of Complex Real-Time Systems. Ph.D. Thesis, September.
- **Tomas Lennvall** (SDL), Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems. Licentiate Thesis, May.
- **Radu Dobrin** (SDL), Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling. Licentiate Thesis, May
- **Thomas Nolte** (SDL), Reducing Pessimism and Increasing Flexibility in the Controller Area Network. Licentiate Thesis, May.
- **Dag Nyström** (SDL), COMET: A Component-Based Real-Time Database for Vehicle Control-Systems. Licentiate Thesis, May.
- **Rikard Land** (SEL), An Architectural Approach to Software Evolution and Integration. Licentiate Thesis, September.
- **Anders Pettersson** (SDL), Reducing Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time System. Licentiate Thesis, October.

- **Thomas Larsson** (CSL), Adaptive Algorithms for Collision Detection and Ray Tracing of Deformable Meshes. Licentiate Thesis, October.
- **Joel G. Huselius** (SDL), *Preparing for Replay.* Licentiate Thesis, November.
- **Leif Enblom** (CAL), Utilizing Concurrency to Gain Performance in an Industrial Automation System. Licentiate Thesis, November
- **Christina Wallin** (SEL), A Process Approach for Senior Management Involvement in Software Product Development. Licentiate Thesis, December.
- **Frank Lüders** (SEL), Use of Component-Based Software Architectures in Industrial Control Systems. Licentiate Thesis, December.
- **Baran Çürüklü** (CSL), Layout and Function of the Intracortical Connections within the Primary Visual Cortex. 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 2003. The de facto-advisor is indicated in boldface, and 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
Joakim Adomat	Hans Hansson	**Lars Asplund**	-	MdH	Uppsala University
Mohammed El-Shobaki	Hans Hansson	**Lennart Lindh**	Henrik Thane	MdH	UU
Leif Enblom (lic)	**Lennart Lindh**	Henrik Pind	-	ABB ASY	MdH
Johan Furunäs	**Lars Asplund**	Lennart Lindh	-	MdH	UU
Raimo Haukilahti	Prof. Axel Jantsch	**Lennart Lindh**	-	MdH/KTH	KTH
Tommy Klevin	**Lennart Lindh**	-	-	RealFast	MdH
Gustaf Naeser	**Lars Asplund**	-	-	MdH	MdH
Peter Nygren	**Lennart Lindh**	Lars Asplund	-	MdH	MdH
Stefan Sjöholm	**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	Prof. **Lena Trojer** (BTH)	Björn Lisper	-	BTH/MdH	BTH
Markus Bohlin	Björn Lisper	**Per Kreuger** (SICS)	Martin Aronsson (SICS)	SICS	MdH
Jan Carlson	**Björn Lisper**	Christer Norström	Doc. Ulf Nilsson (LiU)	MdH	MdH
Baran Çürüklü (lic)	Björn Lisper	Prof. **A. Lansner** (KTH)	Peter Funk	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)	SICS	MdH
Thomas Larsson (lic)	Björn Lisper	Dr**. Tomas Akenine-Möller** (Chalmers)	-	MdH	MdH
Rikard Lindell	**Ivica Crnkovic**	Jussi Karlgren (SICS)	Peter Funk	MdH/SICS	MdH
Markus Nilsson	**Peter Funk**	Ivica Crnkovic	Björn Lisper	Stress Medicine	MdH
Christer Sandberg	**Björn Lisper**	Jan Gustafsson	-	MdH	MdH
Mikael Sandberg	**Björn Lisper**	Prof. Peter Fritzson (LiU)	-	MdH	MdH
Mikael Sollenborn	**Peter Funk**	Björn Lisper	-	MdH	MdH
Xavier Vera	**Björn Lisper**	Jan Gustafsson	-	MdH	MdH
Gordana Dodig-Crnkovic	**Björn Lisper**	Jan Gustafsson		MdH	MdH

Laboratory: SEL

Ph.D.-student	**Formal main advisor**	**Advisor**	**Advisor**	**Employed at**	**Enrolled at**
Johan Andersson	**Christer Norström**	Björn Lisper		ABB	MdH
Johan Fredriksson	Ivica Crnkovic	**Kristian Sandström**		MdH	MdH
Rikard Land (lic)	**Ivica Crnkovic**	Christer Norström	-	MdH	MdH
Magnus Larsson	**Ivica Crnkovic**	Hans Hansson	-	ABB APR	MdH
Stig Larsson	**Ivica Crnkovic**			ABB	MdH
Frank Lüders (lic)	**Ivica Crnkovic**	Björn Lisper	-	ABB APR	MdH
Goran Mustapic	Ivica Crnkovic	**Christer Norström**	-	ABB	MdH
Andreas Sjögren	**Ivica Crnkovic**	Björn Lisper	-	MdH	MdH
Christina Wallin (lic)	**Ivica Crnkovic**	Fredrik Ekdahl (ABB)	Stig Larsson (ABB)	ABB	MdH
Kurt Wallnau	**Ivica Crnkovic**	Hans Hansson	-	SEI/CMU	MdH
Joakim Fröberg	**Christer Norström**	Ivica Crnkovic	Kristian Sandström	Volvo CEC	MdH
Dag Nyström (lic)	**Christer Norström**	Jörgen Hansson (LiTH)	Hans Hansson	MdH	MdH
Jukka Mäki-Turja	Prof. P. Fritzson (LiU)	**Christer Norström**	Hans Hansson	MdH	LiU
Anders Wall (Dr)	**Christer Norström**	Hans Hansson	Ivica Crnkovic	MdH	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. Bengt Ahlgren (SICS)	-	MdH	MdH
Sigrid Eldh	**Hans Hansson**	Henrik Thane	Christer Norström	Ericsson	MdH

Damir Isovic	**Gerhard Fohler**	Ivica Crnkovic	-	MdH	MdH
Andreas Johnsson	**Mats Björkman**			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
Joel Huselius (lic)	Hans Hansson	**Henrik Thane**	-	SICS	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 all the multitude of projects and activities at MRTC, each industrial day has a special focus corresponding to a specific research direction. In 2003 the focus was on Robotics - the next step.
- 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 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 1.1.12 for details on the MRTC involvement in this programme.
- Giving commercial courses on topics of our expertise. In 2003 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 2003 was a continued commercialisation of research results from CAL within the RealFast group. Another spin-off company - Zealcore Embedded Solutions AB – got its first major order of 5000 RealTimeMachines, based on the debugging technology developed in the Tatoo project
- Intensive cooperation with ABB within Industrial Software Engineering, including
    - ❖ Periodic meetings of Team ABB, a group consisting of leading technical representatives of ABB and MRTC/MdH, which initiates and discusses common activities.

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.

During 2003 a strong effort was made to promote research and education at MRTC to the general public. Among other things we would like to mention

- "En Öppen Vret", a so called Open House, with lectures, experiments and demonstrations of our research. The Open House was carried out in cooperation with IEl/MdH.
- Many PhD-students, professors and researchers carried out visits at "gymnasier", high-schools during spring 2003, with the ambition to market the undergraduate education at MRTC.

1.8 Distinctions and Awards

MRTC staff was given the following distinctions and awards in 2003:

- Larisa Rizvanovic was awarded a personal grant from the Faculty Board (MdH), Strategic Research Funding, Meriteringsprogram för Kvinnor, which will finance her PhD studies.
- Professor Hans Hansson was appointed associate editor of Real-Time Systems, The International Journal of Time-Critical Computing Systems.

1.9 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
	34 073	3,045	37,118

Finally, we report how the approximately 7 MSEK obtained from the KK-foundation as a part of the profile grant has been spent in 2003:

Project	**Amount (KSEK)**	**Percentage**
STINA (SEL)	519	7,4%
Industrial IT (SEL)	573	8,1%
ProPlat (SEL)	361	5,1%
Open Controller (SEL)	101	1,4%
WCET (CSL)	175	2,5%
AI-group (CSL)	419	5,9%
VisiGraph (CSL)	376	5,3%
DRIVE (SDL)	443	6,3%
Debug (SDL)	529	7,5%
Probing (SDL)	328	4,7%
Vargöga (CAL)	547	7,8%
SARA (CAL)	125	1,8%
Admin	915	13,0%
VAT+MdH	1 634	23,2%

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 methods and theories for the application areas, which are scientifically well founded.

CSL has a staff of five senior researchers whereof one professor, three senior lecturers, and one researcher, 8 Ph.D. students, (4 of them industrial Ph.D. students), and eight lecturers, whereof four conduct 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:
    - ❖ Language design for specification and programming of embedded systems
    - ❖ Unit inference in modelling languages
    - ❖ Execution time analysis
- Intelligent Systems/AI, in particular:
    - ❖ Knowledge based systems and case-based reasoning
    - ❖ Learning systems - neural networks and genetic algorithms
    - ❖ Intelligent human computer collaboration and decision support
    - ❖ Computer graphics
    - ❖ Constraint programming
- Philosophy of information and computing

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 program in Computer Science, 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 2003 the laboratory was responsible for about 20 undergraduate courses. Many of them are run several times during the academic year. The courses are divided in the following groups: 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.
- **Interaction Design, Communication, and Users in IT-context, 10p**. The purpose of the course is to run innovative projects where the participants have a multidisciplinary background in computer science, innovation, design, or product development. The course gives theoretical and practical knowledge in interaction design.

2.2.2 Master of Science Year

In 2001 CSL started a "Master of Science year" in Computer Science. This is a special track for fourth year. Computer Science students who wants to carry out the final year of their M.Sc. studies close to a research group at CSL or SEL. The students specialize in one of the following research fields:

- Programming and specification (CSL)
- Industrial software engineering (SEL)
- Intelligent Systems/AI (CSL)

The Master's year gives a good basis both for graduate studies within computer science as well as for development work with within companies. Each Master's year student is assigned to one of the research groups, gets a supervisor, has got his/her own workspace, and is engaged in the work of the group in different ways.

The Master's year consists of 20 credits of courses (four 5-credit courses) and a Master's thesis work of 20 credits. The Research Methodology course is obligatory, while the rest of the courses are selected, together with the supervisor, to fit the student's focus of interest.

Master's Year in Computer Science with Programming and Specification Languages profile

This Master's year specialises in computer science. Following a course in research methods for computer science, you will take advanced courses in computer science and write a Master's thesis. Lectures are given by experts within the field. Among the selectable courses you can find Programming Language Semantics and Analysis of Algorithms.

Master's Year in Computer Science with Industrial software engineering profile

See Software Engineering Laboratory.

Master's Year in Computer Science with Artificial Intelligence (AI) Profile

This Master's year specialises in computer science. Following a course in research methods for computer science, you will take advanced courses in computer science and write a Master's thesis. Lectures are given by experts within the field. Among the selectable courses you can find Logic Programming, Case-Based Reasoning and Artificial Intelligence, cont. course.

2.2.3 Postgraduate courses

In 2003, CSL has organised the following postgraduate courses:

- **Research Methodology for Computer Science and Engineering** – The course is performed as a combined D-level undergraduate course and postgraduate course. The course gives an introduction to research and scientific methodologies. Students from several universities attended the course.
- **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** - MSc. and postgraduate students attended the course. The course gives an in depth exploration of artificial intelligence. The student chooses an area of special interest in agreement with supervisor.
- **Case-Based Reasoning** - MSc. and postgraduate students attended the course. The course gives an in depth exploration of case-based reasoning techniques.

CSL also received a grant of 50 KSEK from the KK-foundation during 2003, to plan a national graduate course in Philosophy of Informatics.

2.3 Research

During 2003, 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 2003. Two Ph.D. students at CSL have been financed by SICS during 2003, within a research projects on advanced constraint programming. SICS has also provided advising for a Ph.D. student at CSL in the area of multimodal user interfaces.

The research at the laboratory is both internally and externally funded. In 2003 CSL had external funding from VR, the KK-foundation, Vinnova (through the ASTEC competence centre), and SSF. The laboratory also received a substantial software donation from Enea OSE AB.

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 design and analysis of languages in real-time and embedded systems, but projects are also carried out in the areas of modelling languages, and functional languages. The group consists of one professor, one senior lecturer, one researcher, and eight Ph.D. students, whereof three are external. One Computer Science M.Sc. student has also been

associated with the group during the first half of 2003, and he carried out his M.Sc. thesis work within the WCET project in the group. The group cooperates with SICS within the SICS-MdH collaboration, and two employees at the Västerås branch of SICS belong to the group as external Ph.D. students. The group is also active in CUGS (national computer 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 one active research project plus one member of the board.

Publications:

- Jan Carlson, Björn Lisper. An interval-based algebra for restricted event detection. In Proc. First International Workshop on Formal Modeling and Analysis of Timed Systems (FORMATS 2003) Marseille, France, September 2003.
- Jakob Engblom, Andreas Ermedahl, Mikael Nolin, Jan Gustafsson, Hans Hansson. Worst-Case Execution-Time Analysis for Embedded Real-Time Systems. Journal of Software Tool and Transfer Technology (STTT), 4(4):437-455, August 2003. Springer Verlag.
- Andreas Ermedahl, Friedhelm Stappert, Jakob Engblom. Clustered Calculation of Worst-Case Execution Times. In Proc. Sixth International Conference on Compilers, Architecture, and Synthesis for Embedded Systems, (CASES'03), DoubleTree Hotel, San Jose, California, USA, October 2003. ACM.
- Jan Gustafsson, Nerina Bermudo, Linus Sjöberg. Flow Analysis for WCET Calculation. Technical Report, March 2003.
- Jan Gustafsson, Björn Lisper, Peter Puschner. Input-Dependency Analysis for Hard Real-Time Software. In Luiz Bacellar, Gerhard Fohler (eds.) Proc. 9-th IEEE International Workshop on Object-oriented Real-time Dependable Systems (WORDS 2003F) Capri Island, Italy, October 2003. IEEE.
- Björn Lisper. Fully Automatic, Parametric Worst-Case Execution Time Analysis. In Jan Gustafsson (ed) Proc. Third International Workshop on Worst-Case Execution Time (WCET) Analysis, pp. 77-80, Porto, July 2003.
- Christer Sandberg. Elimination of Unstructured Loops in Flow Analysis. In Jan Gustafsson (ed) Proc. Third International Workshop on Worst-Case Execution Time (WCET) Analysis, Porto, July 2003.
- Mikael Sandberg, Daniel Persson, Björn Lisper. Automatic Dimensional Consistency Checking for Simulation Specifications. In Erik Dahlqvist (ed) Proc. SIMS 2003, Västerås, September 2003.
- Xavier Vera. Coyote Project: The Simulator. MRTC Report MDH-MRTC-95/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, March 2003.
- Xavier Vera, Jaume Abella, Antonio Gonzalez, Josep Llosa. Optimizing Program Locality Through CMEs and GAs. In Proc. 12th International Conference on Parallel Architectures and Compilation Techniques (PACT) New Orleans, September 2003. IEEE.
- Xavier Vera, Björn Lisper, Jingling Xue. Data Cache Locking for Higher Program Predictability. In Proc. International Conference on Measurement and Modeling of Computer Systems (SIGMETRICS), pp. 272-282, San Diego, California, June 2003. ACM Press.
- Xavier Vera, Björn Lisper, Jingling Xue. Data Caches in Multitasking Hard Real-Time Systems. In Proc. International Real-Time Systems Symposium (RTSS), Cancun, MX, December 2003. IEEE

The group has the following projects:

Worst-case execution time analysis (WCET)

Project leader: Björn Lisper
Project members: Andreas Ermedahl

	Jan Gustafsson Christer Sandberg Xavier Vera Adam Betts (M.Sc. student, spring 2003) Daniel Sandell (M.Sc. student, fall 2003) Robert Söderström (M.Sc. student, spring 2003)
Partners:	Uppsala University (ASTEC), IAR Systems AB, Enea ET, Volcano Communication Technologies
Funding:	Swedish Research Council (VR), Vinnova (via the ASTEC competence centre at Uppsala University), 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.

We have close co-operation with the research group CODER within ASTEC in Uppsala, and we also co-operate with the compiler company IAR in Uppsala.

During the fall of 2003, Andreas Ermedahl has joined the group. Andreas graduated in WCET analysis at Uppsala University in June.

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.

Report for 2003:

During the passed year, a first prototype of our flow analysis tool has been presented by the group for a wider audience in Uppsala in June. The tool is able to analyse intermediate code generated from a C compiler, and to calculate flow facts for a number of C constructs.

Jan Gustafsson presented a paper (A Tool for Automatic Flow Analysis of C-programs for WCET Calculation) by Jan Gustafsson, Björn Lisper, Christer Sandberg, and Nerina Bermudo at the Eight IEEE International Workshop on Object-Oriented Real-Time Dependable Systems, Guadalajara, Mexico, January 2003.

Jan Gustafsson organized and was the chairperson for the international WCET workshop which was held in Porto, July 1 2003, in conjunction with the EuroMicro workshop on real-time systems.

Christer Sandberg presented a paper (Elimination of Unstructured Loops in Flow Analysis) on flow analysis on the international WCET workshop in Porto. At the same workshop, Björn Lisper presented a paper on parametric WCET analysis.

Jan Gustafsson and Björn Lisper co-authored a paper (Input-Dependency Analysis for Hard Real-Time Software) with Peter Puschner in Vienna. This paper was presented at WORDS2003F in Capri in October. The paper describes program analysis of single path programs.

Xavier Vera and Björn Lisper co-authored two papers on the use of cache locking to obtain tighter WCET estimates. These papers were presented at the SIGMETRICS and RTSS conferences, respectively. Xavier Vera also presented a paper on program optimization with respect to cache performance at the PACT conference.

Jan Gustafsson, Andreas Ermedahl and Björn Lisper have been working with the organization of a broader cooperation between European WCET groups.

Dimensional Inference in Strongly Typed Specification Languages

Project leader: Björn Lisper
Members: Mikael Sandberg (Ph.D. student)
Daniel Persson (M.Sc. student)
Partners: Linköping University
Funding: Internal

Project description:

Modelling languages such as Modelica and gPROMS specify dynamic systems for simulation. They lack the ability to detect if units and dimensions are correctly specified.

Both languages are strongly typed and use non-causality with mathematical differential algebraic equations (DAE) to solve the system. Modelica is Object-Oriented and gPROMS is more block oriented and partial to process simulation. Modelica on the other hand is multi domain. The goal of this project is to provide a tool to verify equations for consistent usage of dimensions. The dimension inference problem is defined as being able to represent the unit of variables, propagate such information along connection points and to verify equations for correct usage.

Results and achievements in 2003:

In 2002, A tool for Dimensional Analysis of gPROMS specifications was developed. During 2003 the work on the tool was completed, a M.Sc. thesis was written, and a conference paper (SIMS) was presented. Furthermore, work on a similar tool for Modelica continued.

Future plans:

The plans for the nearest future are as follows:

- Finish the Dimensional Inference tool for Modelica.
- Licentiate Thesis (Mikael Sandberg).

High Level Languages for Hard and Embedded Real-Time Systems

Project leader: Björn Lisper
Members: Björn Lisper
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 2003:

An Event algebra paper was presented (FORMATS 2003). A Licentiate proposal was presented and approved.

Future plans:

- Lic. April -04
- Ph.D. Proposal June -05
- Ph.D. June -06

2.3.2 Intelligent Systems Group

The Intelligent Systems group consists of one associated professor, one assistant professor, six Ph.D. students, one research engineer, a number of master year students with AI research profile. The main interest of the group is research and artificial intelligence and application for research results. The group is in particular interested in methods and techniques such as Case-Based Reasoning, Artificial Neural Nets, Intelligent Agents, Genetic Algorithms, Intelligent Human Computer Interaction and Knowledge Representations, Information Fusion.

Results and achievements in 2003:

- A new project ExAct was approved by SSF. Participating companies ABB, Volvo, and SKF. Project budget during 3 years is 24.5 MSEK. Peter Funk is project leader.
- Two new Ph.D. students (Sofi Elfin, IDP, Anette Hägg, Volvo) were associated with the ExAct project and the research group (main supervisor Mats Jackson IDP, Supervisor Peter Funk, IDt).
- One licentiate thesis (Baran Çürüklü).
- New AI parts in other courses including Ph.D. courses have been developed (introduction course A level), Philosophy of Computer Science, (lecture in ethical issues in artificial intelligence). Computers in Products, CT3510 (creative solutions with Artificial Intelligence).
- Participation in reviewing process for international conferences and workshops.
- Conference Chair of ECCBR 2004 (7th European Conference on Case-Based Reasoning) with Pedro A. Gonzalez Calero
- In Program Committee of AILS'04 , the 2nd joint workshop in Artificial Intelligence and Learning Systems
- In Program Committee of KES'2004 Eighth International Conference on Knowledge-Based Intelligent Information & Engineering Systems
- In Program Committee of ICCBR 2003 The 5th International Conference on Case-Based Reasoning
- Book reviewer for Pearson Education (previously Addison-Wesley and Prentice Hall) 2003
- Reviewer for Journal: International Journal of Pattern Recognition and Artificial Intelligence, 2003
- Reviewer for Journal: IEE - Software, 2003
- In Program Committee for workshop "long lived CBR systems" at ICCBR 2003
- In Program Committee of GWEM 2003, Experience Management 2003 workshop
- New collaboration with IDP (Mats Jackson, ExAct).

- New collaboration with IEl (Ylva Bäcklund, AIM).
- New MIMA masters year with IMa.

Publications:

- Baran Çürüklü. Layout and Function of the Intracortical Connections within the Primary Visual Cortex. Licentiate Thesis, Mälardalen University Press, December 2003.
- Baran Çürüklü, Anders Lansner. Quantitative Assessment of the Local and Long-Range Horizontal Connections within the Striate Cortex. In Special Session on "Biologically Inspired Computational Vision", Proc. 2nd Int. Conf. on Computational Intelligence, Robotics and Autonomous Systems, Singapore, December 2003. IEEE.
- Baran Çürüklü, Anders Lansner, Layout and Function of the Intracortical Connections within Layer 4 of Cat Area 17, Technical Report, September 2003.
- Markus Nilsson, Peter Funk, Mikael Sollenborn. In Proc. ICCBR'03 - The Fifth International Conference on Case-Based Reasoning, pp. 63-73, Trondheim, Norway, June 2003. Springer
- Markus Nilsson, Artificial intelligence diagnostics in psychophysiological medicine. Technical Report, September 2003.
- Markus Nilsson, Peter Funk. Classification of psycho-physiological measurements in medical systems. In Proc. SAIS-SSLS 2003 Joint Workshop, Örebro, Sweden, April 2003.

Future plans:

The group plans to obtain the following goals: one PhD and two licentiate theses; Increased number of publications; Increased collaboration with international universities with strong research groups in relevant areas; Continued and expanded cooperation with IEl, IDP, ISt and SICS (SSF project, English Butler project), KTH and SU.

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)
Partners:	PBM StressMedicine AB
Funding:	PBM StressMedicine AB
	KK-foundation
	Mälardalens Högskola
	teknIQ

Project description:

AI techniques have valuable benefits to offer medical systems. Techniques such as abstraction, conceptualisation (of sensor data), Semantic Nets, Case-Based reasoning (CBR), Clustering, Artificial Neural Networks and User Modeling are investigated/used in this project.

ExAct

The ExAct project is coordinated by Peter Funk (CSL), with additional partners from MdH/IDt (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.

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.

CBM (Condition Based Maintenance, reliability and availability of technical systems)

The project members are Marcus Bengtsson (PhD student), Mats Jackson (main supervisor) and Peter Funk, assistant supervisor. The project is funded by ABB, Bombardier, UTEK and by the knowledge foundation (KKS). The objective with this research project is to investigate important factors of a CBM system in order to achieve easier development and installation.

The research questions can be summarized as:

- What standards and standardization proposals can be found within the CBM system technology, and what effects do they have on future research?
- What aspects does a company need to consider when implementing a CBM system and what are the needed incentives to invest in a CBM system?
- How should a CBM system be designed, technically, and what Artificial Intelligence methods and techniques can be used as a mean to diagnose an incipient fault and predict the remaining useful life? Are there differences between machines and vehicles?

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 mostly using a Morkov 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.

Future Plans:

- Try to link different design choices when using genetic algorithms and features of the search.
- ˜Licentiate thesis (2004).

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:

One Licentiate thesis in 2003. A conference paper.

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 is planned for late 2004.

2.3.3 Other projects

The Siblings Project

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

Project description:

The aim of the Siblings project is to show that human computer interaction does not need 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. Users Say: We Do Not Like to Talk to Each Other. Proc. Second International Workshop on Interactive Graphical Communication, Institute for Contemporary Arts (ICA) in central. 2003
- Rikard Lindell. When Information Navigation Divorces File Systems – Database Surface Prototype Results. Proc. The Good, the Bad and the Irrelevant. 2003. Media Centre Lume of the University of Art and Design Helsinki.

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 (SICS/Västerås)
Partners:	SICS
Funding:	SICS

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. Technical Report, Swedish Institute of Computer Science, August 2003.

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 2003:

Licentiate thesis. Journal paper.

Publications:

- Thomas Larsson. Adaptive Algorithms for Collision Detection and Ray Tracing of Deformable Meshes. Licentiate Thesis, Mälardalen University Press, October 2003.
- Thomas Larsson, Tomas Akenine-Möller. Strategies for Bounding Volume Hierarchy Updates for Ray Tracing of Deformable Models. MRTC Report MDH-MRTC-92/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, February 2003.
- Thomas Larsson. Continuous examination using take-home problems - experiences and results in a course on data structures and algorithms. In Proc. Conference of Development of Higher Education, Gävle, Sweden, November 2003. The Council for the Renewal of Higher Education.
- Thomas Larsson, Tomas Akenine-Möller. Efficient collision detection for models deformed by morphing. The Visual Computer, 19(2-3):164-174, June 2003. Springer-Verlag.

Future plans:

In the future, 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:	Björn Lisper
Members:	Gordana Dodig-Crnkovic
	Björn Lisper
	Jan Gustafsson
	Jan Odelstad (University of Gävle)
Funding:	Internal
´	KK-foundation

Project description:

In order to get a broad understanding of the discipline it is necessary to analyze it from both scientific, philosophical and ethic perspective. That sort of analysis has not yet been done. It is instructive for many reasons. For the field of computing it is important to get intellectual context for the everyday activities we are involved with. For students within Computing it is of utmost relevance that besides learning about what to do (usually the knowledge of present day tools and methods gets out of date all too rapid) also learn about long-term rationales and intellectual context.

For every member of a Computing community it is also essential to relate to scientific, intellectual and ethic issues of the field. It gives both standards to assess the quality of work done as well as its acceptability from ethical point of view.

This project addresses the core issues in the field, systematically and comprehensively. By bringing together contemporary ideas in the various areas of this new emerging field it provides an introduction to a fundamental area of research that is constantly growing.

Results:

In 2003 we initiated the PI-network, The Network in Philosophy of Informatics. We prepared a National Course in Philosophy of Computer Science.

Publications:

- Gordana Dodig-Crnkovic. Om vikten av att undervisa datavetare och datatekniker i professionell etik. In Proc. Den femte nationella kvalitetskonferensen - Högskoleverket i samarbete med Malmö högskola, March 2003.
- Gordana Dodig-Crnkovic, Ivica Crnkovic. Computing Curricula: Teaching Theory of Science to Computer Science Students. In Proc. Hawaii International Conference on Education Honolulu, Hawaii, USA, January 2003.
- Gordana Dodig-Crnkovic. Computing Curricula: Social, Ethical, and Professional Issues. In Proc. Conf. for the Promotion of Research in IT at New Universities and at University Colleges in Sweden, May 2003.
- Gordana Dodig-Crnkovic. Shifting the Paradigm of the Philosophy of Science: the Philosophy of Information and a New Renaissance. Minds and Machines: Special Issue on the Philosophy of Information, September 2003. Kluwer.

Future:

A national course in Philosophy of Computer Science will be given in 2004.

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:

Christina Björkman: Challenging Canon: The Gender Question in Computer Science, Licentiate Thesis, Blekinge Institute 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 Embedded Technologies AB, and Volcano Communication Technologies AB on execution time analysis, through the ASTEC competence centre in Uppsala. The laboratory also collaborates with Ericsson around tools for PLEX programs.

Cooperation with PBM StressMedicine AB has been expanded with a new industrial Ph.D. student.

2.5 Theses

Two Licentiate theses were presented by CSL staff in 2003:

Thomas Larsson: ***Adaptive Algorithms for Collision Detection and Ray Tracing of Deformable Meshes.***

Many applications in computer graphics and visualization are directly dependent on accurate and fast intersection queries. To prevent bodies passing directly through each other, the simulation system must be able to track touching or intersecting geometric primitives. In real-time graphics simulations, in which hundreds of thousands of geometric primitives are involved, highly efficient collision detection algorithms are needed. The efficient handling of deformable models constitutes a particular challenge to the simulation system, since the possibilities of precomputing efficient data structures are decreased dramatically. The same type of problem arises in interactive ray tracing, where a huge number of geometric intersections must be determined in just a fraction of a second.

For these reasons, new efficient collision detection and ray tracing methods for deformable meshes are suggested in this thesis. The proposed solutions are based on bounding volume hierarchies which allow the models they represent to be deformed at every time step of the simulation. Different update methods to efficiently refit the bounding volumes in the hierarchies as the models deform are presented. The models considered are represented by polygon meshes that are either deformed by arbitrary vertex repositioning or by mesh morphing. The update methods postpone updates in the hierarchies until they are absolutely needed in order to avoid unnecessary updating work. The results from the experiments performed indicate that significant speed-ups can be achieved by using these new methods in comparison with approaches suggested previously. The thesis also shows that mesh morphing constitutes a specific example of a restricted type of deformation that allows particularly efficient hierarchical data structures, with expected sub-linear collision queries in the number of geometric primitives of the meshes.

Baran Çürüklü: ***Layout and Function of the Intracortical Connections within the Primary Visual Cortex.***

This thesis describes a top-down view of the cat primary visual cortex (area 17), which is faithful to the relevant aspects of the known physiology and anatomy. The centerpiece of this work is an abstract hypercolumn model that is mapped to cat primary visual cortex. This model shows how the recurrent (intracortical) connections can be self-organized and that their presence can explain the emergence of several response properties of the striate cells, such as contrast-invariance of orientation tuning, narrowing of the orientation tuning, response saturation followed by normalization and response facilitation mediated by long-range horizontal connections.

The abstract hypercolumn model is in line with other recurrent models by assuming broadly tuned inhibition. It is believed that large basket cells mediate this inhibition. However, the model is unique in that, when mapped to layer 4 it incorporates an additional class of interneurons, which only inhibit excitatory simple cells in their close surroundings.

The layout and function of the intracortical connections within a patch of area 17 have been addressed using developmental network models. These models are developed during exposure to visual input using a Bayesian Confidence Propagation Neural Network (BCPNN) with an incremental learning rule. The connectivity pattern demonstrated by the correlation-based network model is similar to that of area 17. Excitatory local connections are dense, whereas excitatory long-range horizontal connections are sparse and elongated along the orientation axis. Furthermore, layer 4 excitatory local connections target mainly the iso-orientation domain, whereas the excitatory long-range horizontal connections are equally distributed between all orientation domains. However, both local and long-range horizontal connections of the layer 2/3 connections are biased towards the iso-orientation domains. It is hypothesizes that this patchiness is a consequence of excitatory long-range connections made by the pyramidal cells targeting mainly other pyramidal cells located in distal iso-orientation domains. The dissimilarity between the two layers' layout might indicate functional differences.

The function of the intracortical connections has been investigated by studying response facilitation of simulated striate cells. This phenomenon is manifested by improved visibility of a Gabor patch when it is elongated along the orientation axis. This phenomenon is probably due to the elongated shape of the long-range horizontal connections. Response facilitation requires robust communication between striate cells located several millimeters from each other. It is hypothesized that spike and burst synchronization might be responsible for this. Furthermore, the anisotropy of the long-range horizontal connections seems also to help narrowing the orientation tuning of the excitatory cells.

The main conclusion to be drawn is that it is possible to explain several response properties of the striate cells by an abstract hypercolumn model, which is faithful to the known anatomy and physiology of the neocortex. When simplicity is combined with biological plausibility the models of hypercolumns can give valuable insight into the structure and function of cortical circuitry.

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 KK-foundation. His current research interests are in programming language issues, targeting parallel, embedded, and real-time systems: language design, and program transformations and analysis.

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. 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< (IdéLab, ALMI , price value 14.000 Euro to be used for further development of the idéa). His research focuses on AI methods and techniques for industrial applications, intelligent human computer interaction and internet applications, to enable intelligent systems and

functionality.

Gordana Dodig-Crnkovic is a Senior Lecturer. She is teaching:
- Formal languages, automata and theory of computation, CD5560, (Course leader and teacher)
- Vetenskapsmetodik för teknikområdet (The Methodology of Science in Technology, CT3620, (Course leader and teacher)
- Research Methodology, CT3340/CD5540,(Teaching Scientific Theory and methodology parts),
- Professional Ethics in Science and Engineering, CD5590 (Course leader and teacher)
- National Course in Philosophy of Computer Science (Responsible organizer and teacher)

2002-current Research:
Philosophy of Computation and Information
2002-2003 PI-network coordinator, http://www.idt.mdh.se/~gdc/pi-network.htm

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 at CSL. He received a Bachelor of Science at Mälardalen University 1994. He teaches mainly Programming, Algorithms and Data Structures and Compiler Theory.

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 and a master of science degree, in computer engineering, in 1999. Currently, he his working on his licentiate degree in the area of computer graphics.

Roger Jonsson is Lecturer and Ph.D. student at CSL. He received 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.

Baran Çürüklü is a PhD student and lecturer. He received his Master of Science in Applied Computer Engineering from Mälardalen University, Sweden (1998). 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 is a Ph.D. student and Lecturer at CSL. He received a BSc in Computer Science from Mälardalen University (1999). He is a former employee of ABB Atom AB, where he developed nuclear surveillance and optimisation software there for six years. His research interests include programming language design, simulation and graphics.

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). His research interests include programming language design, functional and logic programming languages, and formal methods.

Xavier Vera is a Ph.D. student at CSLab. 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.

Marcus Bohlin is a Ph.D. student employed by SICS.

Waldemar Kocjan is a Ph.D. student employed by SICS.

Marcus Nilsson is an industrial Ph.D. student in artificial intelligence employed by Stress Medicine AB. His research interests are artificial intelligence methods and techniques for medical applications.

Mikael Sollenborn is an industrial Ph.D. student employed by Eyescream AB. His research interests are personalization and adaptation techniques.

Johan Erikson is a research engineer at the department of Computer Engineering. His research interests include programming languages, graph theory and analysis of complex software systems.

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.

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 Software Engineering
- Chalmers, Dept. of Computer Engineering, on Computer Graphics,
- SICS on constraint programming, and human-machine interaction

The following international co-operation has taken place during 2003:

- Xavier Vera spent the first part of of 2003, until September, at Univ. Sydney, working with Prof. Jingling Xue,
- There are ongoing discussions to start an EU-supported collaboration on WCET analysis. The WCET group has participated in the planning of a WCET tool framework project within the proposed ARTIST2 NoE,
- Andreas Ermedahl collaborates with Friedhelm Stappert at C-lab in Paderborn on WCET analysis. A co-authored paper was presented at CASES'03,
- Jan Gustafsson and Björn Lisper co-authored a paper (presented at WORDS2003F) with 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 2003:

Björn Lisper:

- was on the program committees of the International Conference on Engineering of Reconfigurable Systems and Algorithms 2003, and the national conference Real-Time in Sweden 2003,
- was local organization chair for the International Conference on Functional Programming (ICFP'03),
- was faculty opponent for Tobias Ritzau at Linköping University, and discussion leader at Erik Berg's Licentiate seminar at Uppsala University,
- was expert evaluator for a Senior Lecturer (universitetslektor) position at Lund University, and on the grading committee of Håkan Forsberg (Chalmers),
- served on the board for the KK-foundation, and 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.
- And reviewed a number of papers for conferences and journals.

Peter Funk

- Book reviewer for Pearson Education (previously Addison-Wesley and Prentice Hall)
- Reviewer for Journal: IEE - Software, 2003
- Reviewer for Journal: International Journal of Pattern Recognition and Artificial Intelligence, 2003
- In Program Committee of ICCBR 2003 The 5th International Conference on Case-Based Reasoning

- In Program Committee for workshop "long lived CBR systems" at ICCBR 2003
- External examiner, masters thesis at UCD and approved external examiner by the National University of Ireland 2003

Jan Gustafsson

- organized and was the chairperson for the international WCET workshop which was held in Porto, July 1 2003, in conjunction with the EuroMicro conference on real-time systems.

Gordana Dodig-Crnkovic

- Book reviewer for Linz, An Introduction to Formal Languages and Automata, Jones & Bartlett (Book on automata theory)
- Popular presentation Science, Philosophy and Ethics of Computing MDH Popular Education - PhD seminar - (26 Nov 2003)
- Coordinator of PI-network , Swedish national network on Philosophy of Informatics

2.9 Interactions with society

- Björn Lisper is a member to the scientific advisory board of the journal Teknik & Vetenskap. He also gave a popular presentation on embedded systems at the seminar "Industriregionernas stora utmaning" in Örnsköldsvik in March.
- Peter Funk appeared on radio Radio Västmanland P4, interview about Artificial Intelligence research at Mälardalen University.
- Peter Funk participated in writing a number of pressreleases during 2003 that resulted in radio, TV and newspaper coverage.
- Peter Funk was interviewed about his research and research projects at Mälardalens University a number of times and articles on this appeared in NyTeknik, Västmanlands Läns landstidning (VLT), Eskilstunakurieren, Aktuell Forskning & Utveckling,
- Peter Funk held an open lecture in Artificial Intelligence at Polhems Gymnasium and Mobila Gymnasiet, Globen and gave a speech at Rotary Västmanland in 2003.
- Peter Funk is coaching and participating in a number of projects (both involving researchers and students) with the goal of comersialisation of research results (with IdéLab).

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 22 people: four senior researchers whereof two professors and two senior lecturers, 12 Ph.D. students (7 of them industrial Ph.D. students), two research engineers, and four 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
  - ❖ Software architecture
- 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 Computer Science and 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 repsonisble for the following courses:

Basic courses

- Programming tecnique
- Algorithms and datstructure
- Programming with C++
- Object oriented programming

Middle level and advanced courses

- Object Oriented programming advanced course
- Software Engineering
- Component technologies
- Component-based software engineering

- Distributed Software Development
- Engineering for embedded systems

In 2003 two new courses have been developed

- **Engineering for embedded systems** (developed by Kristian Sandström and Jukka Mäki-Turja). This course gives an introduction to development of complex embedded systems. The course includes the following: topics complexity, organisational and process, requirements engineering, architectutes of embedded systems, verification and validation, technologies and tools, etc.
- **Distributed Software Development** (developed by Ivica Crnkovic). The course gives students insight in complexity of distributed software development. The students are trained to work in distributed teams and use technology for development of distributed software applications. The course was developed and performed in cooperation with Univcersity of Zagreb, Faculty of Electrical Engineering and Computing and the students from boyt universities participated in the course.

3.2.1 The Program in Computer Science with Software Engineering Profile

The Program in Computer Science with Software Engineering Profile is a special track dedicated to students that want to specialise in Software Engineering.

Courses advanced level and master thesis work are a part of the Software Engineering Master program.

Software Engineering includes many activities throughout the product life cycle, from technical details of component technologies and software architectures to human aspects of organisation and project management. Common for these activities is that they must fit into the larger context of a complete product. That is, activities relate to each other and knowledge about many different aspects of system development is important. In the Software Engineering profile students learn how to develop high quality 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.

3.2.2 Postgraduate courses

In 2003, 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 overview of different to 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

3.3 Research

During 2003, 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 2003 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 area 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 the groups from SDL.

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

The major results of this research in 2003 group were:

- Three licenciate theses (Rikard Land, Christina Wallin, Frank Lüders)
- Organisation of Euromicro Conference, Component-based Software Engineering Track, Antalya, Turkey, September 2003.
- Coorganisation of 6th ICSE Workshop on Component-Based Software Engineering: Automated Reasoning and Prediction, In 25th International Conference of Software Engineering, ICSE Portland, Oregon, May 2003.
- Coorganisation of Swedish Third Conference on Software Engineering Research and Practise in Sweden
- Development and performing of a new graduate course (Distributed Software Development)
- Performing of three graduate courses
- Start of projects SAVE and FLEXCON, funded by SSF, in cooperation with other usinersities in Sweden
- Participation in ARTIST EU Network of Excelence, CBSENET EU Network and DOTS EU IST project
- Recruitment of three new PhD students, one of them industrial PhD student
- Publishing a book: "Implementing and Integrating Product Data Management and Software Configuration Management", Artech House Publishers 2003 ISBN: 1-58053-498-8

In 2003 the following projects have been active:

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

Project description

The project has started in 2003 q2. 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:

- Towards an Efficient and Effective Process for Integration of Component-Based Software Systems
- SERPS'03 - Proceedings of the 3rd Conference on Software Engineering Research and Practise in Sweden, Lund, Sweden. 2003, Author(s): Stig Larsson
- 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
- Are Limited Non-intrusive CMMI-based Appraisals Enough?, In Proceedings of the ESEIW 2003 Workshop on Empirical Studies in Software Engineering WSESE 2003, September 2003. Fraunhofer IRB Verlag, Author(s): Stig Larsson, F. Ekdahl

FLEXCON - flexibe controllers

Project Leader:	Karl-Erik Årzén Program director,
	Ivica Crnkovic, local project leader
	Gerhard Fohler, local project leader
Members:	Ivica Crnkovic
	Gerhard Fohler
	Johan Fredriksson
	Damir Isovic
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):

- Software Component Technologies for Real-Time Systems - An Industrial Perspective, In WiP Session of Real-Time Systems Symposium (RTSS) Cancun, Mexico, December 2003., Author(s): Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin
- Attaining Flexible Real-Time Systems by Bringing Together Component Technologies and Real-Time Systems Theory, In Proceedings of the 29th Euromicro Conference, Component

Based Software Engineering Track Belek, Turkey, September 2003. IEEE, Author(s): Johan Fredriksson, Mikael Åkerholm, Kristian Sandström, Radu Dobrin

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
	Ericsson
Funding:	The KK-foundation, ABB

Project description:

The architectural aspects (managing evolution on 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:

Licentiate Thesis: An Architectural Approach to Software Evolution and Integration, Mälardalen University Press, September 2003. Author(s): Rikard Land

Organisation of:

- Euromicro Conference, Component-based Software Engineering Track, Antalya, Turkey, September 2003. IEEE
- 6th ICSE Workshop on Component-Based Software Engineering: Automated Reasoning and Prediction, In 25th International Conference of Software Engineering, ICSE Portland, Oregon , May 2003. IEEE,

Publications:

- Implementing and Integrating Product Data Management and Software Configuration Management, Artech House Publishers 2003 ISBN: 1-58053-498-8 Author(s): Ivica Crnkovic, Ulf Asklund, Annita Persson Dahlqvist
- Integration of Software Systems – Process Challenges, In Euromicro Conference, Track on Software Process and Product Improvement Antalya, Turkey, September 2003. IEEE, Author(s): Rikard Land, Ivica Crnkovic, Christina Wallin
- Software Systems Integration and Architectural Analysis – A Case Study, In International Conference on Software Maintenance Amsterdam, Netherlands , September 2003. IEEE, Author(s): Rikard Land, Ivica Crnkovic
- On the Teaching of Distributed Software Development, In 25th International Conference Information Technology Interfaces Dubrovnik, Croatia, June 2003. IEEE, Author(s): Ivica Crnkovic, Igor Cavrak, Johan Fredriksson, Rikard Land, Mario Zagar, Mikael Åkerholm
- 6th ICSE Workshop on Component-Based Software Engineering: Automated Reasoning and Prediction, In 25th International Conference of Software Engineering, ICSE Portland, Oregon , May 2003. IEEE, Author(s): Ivica Crnkovic, Heinz Schmidt, Judith Stafford, Kurt Wallnau
- Is Software Engineering Training Enough for Software Engineers?, In 16th International Conference on Software Engineering Education and Training Madrid , March 2003. IEEE, Author(s): Ivica Crnkovic, Rikard Land, Andreas Sjögren

- Computing Curricula: Teaching Theory of Science to Computer Science Students, In Hawaii International Conference on Education Honolulu, Hawaii, USA, January 2003., Author(s): Gordana Dodig-Crnkovic, Ivica Crnkovic

ProPlat

Project leader:	Ivica Crnkovic
Members:	Christina Wallin (Ph.D. student)
Partners:	ABB
Funding:	The KK-foundation
	ABB

Project description:

The projects investigates possibilities to achieve effective senior management involvement in software product development projects by using stage-gate new product development models from traditional product development, and by suggesting a way to combine these models with contemporary software development models through pre-gate milestones.

Results:

Licentiate Thesis, A Process Approach for Senior Management Involvement in Software Product Development, Mälardalen University Press, December 2003, Author(s): Christina Wallin

Publications:

- Integration of Software Systems – Process Challenges, In Euromicro Conference, Track on Software Process and Product Improvement Antalya, Turkey , September 2003. IEEE, Author(s): Rikard Land, Ivica Crnkovic, Christina Wallin
- Three Aspects of Successful Software Development Projects, "When are projects canceled, and why?", In Euromicro Conference Balek, Turkey, September 2003. IEEE, Author(s): Christina Wallin, 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:

Licenciate thesis: Use of Component-Based Software Architectures in Industrial Control Systems, Mälardalen University Press, December 2003, Author(s): Frank Lüders

Publications:

- Adopting a Software Component Model in Real-Time Systems Development, In Proceedings of the 28th Annual NASA/IEEE Software Engineering Workshop, February 2004. IEEE Computer Society Press, Author(s): Frank Lüders

Future plans:

A PhD Thesis, 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 in embedded systems, methods and tools. We are both considering models and analysis for developing new systems and techniques for 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 2003 we have performed several case studies, including architectures for automotives (both software architectures and communication architectures), trains and robotics.

We are currently focusing on:

- 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

The group consist of one professor, one senior lecturer, one researcher and 5 PhD students, 3 of them industrial PhD students

The major results of this research group in 2003 were:

- One PhD thesis (Anders Wall)
- One licenciate theses (Dag Nyström)
- Organisation of the industrial session and the WIP session at the 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003).
- Organisation of RtiS2003 – Real-time in Sweden 2003, in Västerås.
- Initiation and start of two projects Remodel and Open controller.
- Many papers at international conferences.
- A new course in engineering of complex systems.
- Participated in the establishment of the European Network of excellence ARTIST/2

In 2003 the following projects have been active:

- SAVE/AutoComp
- A Tool Environment for the Development of Embedded systems
- DRIVE
- COMET - COMponent-based Embedded real-Time database system
- OpenController
- REMODEL

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

SAVE/AutoComp

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.

Publications:

- Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin, Software Component Technologies for Real-Time Systems - An Industrial Perspective, In WiP Session of Real-Time Systems Symposium (RTSS) Cancun, Mexico , December 2003.
- Johan Fredriksson, Mikael Åkerholm, Kristian Sandström, Radu Dobrin, Attaining Flexible Real-Time Systems by Bringing Together Component Technologies and Real-Time Systems Theory, In Proceedings of the 29th Euromicro Conference, Component Based Software Engineering Track Belek, Turkey , September 2003.
- Tobias Samuelsson, Mikael Åkerholm, Peter Nygren, Johan Stärner, Lennart Lindh, A Comparison of Multiprocessor Real-Time Operating Systems Implemented in Hardware and Software, In International Workshop on Advanced Real-Time Operating System Services (ARTOSS) Porto, Portugal , July 2003.
- Ivica Crnkovic, Igor Cavrak, Johan Fredriksson, Rikard Land, Mario Zagar, Mikael Åkerholm, On the Teaching of Distributed Software Development, In 25th International Conference INFORMATION TECHNOLOGY INTERFACES Dubrovnik, Croatia , June 2003.
- Mikael Nolin, Johan Fredriksson, Jerker Hammarberg, Joel G Huselius, John Håkansson, Annika Karlsson, Ola Larses, Markus Lindgren, Goran Mustapic, Anders Möller, Thomas Nolte, Jonas Norberg, Dag Nyström, Aleksandra Tesanovic, Mikael Åkerholm, Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003.
- Ivica Crnkovic, Goran Mustapic, Mikael Åkerholm, Modern technologies for modeling and development of process information systems, MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-100/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May 2003.

Future plans:

We will do research in component based technologies that increase productivity when developing automotive software systems and at the same time keep system analyzability and reliability intact, catering for construction of safety critical systems

A Tool Environment for the Development of Embedded systems

Project leader:	Christer Norström
Members:	Anders Wall
Partners:	ABB Robotics

Bombardier Transportation AB
Volvo Construction Equipment Components AB

Funding: ARTES and Internal

Project description:

Today the trend in computer-based products, such as cars and mobile phones, is shorter and shorter lifecycles. As a consequence, time spent on development of new products or new versions of a product must be reduced. One solution to this emerging problem is to reuse code and architectural solutions within a product family. Besides shortening development time, properly handled reuse will also improve the reliability since code is executed for longer time and in different contexts. Product line architectures have been recognized as a possible approach to this emergent development. A product line is a set of software products that share a common technology platform as well as having common functionality. A software architecture that constitutes the base on which all products in the line are built, is called a product line architecture

In this project we apply the software product line approach to the development of embedded real-time systems. More specifically, we investigate the influence on current results when introducing the temporal domain into the development of software product-line architectures. This approach will have influence on the development process. Consequently, our work will be put into the context of a process, starting with requirements analysis and ending up in verification. Even though the complete development process will be more or less covered, special emphasis will be put on construction of flexible and reusable software components for real-time systems.

Moreover, the software components that are defined and identified as a part of the product-line must be flexible enough to be used in all products of a family, yet temporal correct. Thus, we have to develop semantics for a component model that facilitates specification, construction and analysis of flexible real-time software components. The component model should also support specification of complex temporal requirements that also provide necessary flexibility.

We are also studying how to re-introduce analyzability in large and complex product lines architectures for real-time systems. Typically, existing temporal models and methods for analyzing the correctness of the temporal behavior fall short since they are too limited in their expressiveness. For instance, it is not feasible to assume worst-case behavior in terms of execution times. A probabilistic approach where execution times are modeled as statistical distributions and where analysis is based on simulations has been developed and its appropriateness has successfully been proven in a case study.

In short we see the following contributions:

- Product line architectures for real-time systems
- Flexible component model
- Component reuse in safety related systems
- A tool environment for measuring, modeling and analyzing complex product line architectures for real-time systems

Results and achievements in 2003:

Anders has defended his Ph.D dissertation: Architectural Modeling and Analysis of Complex Real-Time Systems.

Publications:

- Christer Norström, Anders Wall , Johan Andersson och Kristian Sandström Increasing maintainability in complex industrial real-time systems by employing a non-intrusive method, In proceedings of the workshop on Migration and Evolvability of Long-life Software Systems (MELLS '03) Erfurt, Germany , September 2003.

- Anders Wall, Johan Andersson, Christer Norström, Probabilistic Simulation-based Analysis of Complex Real-Times Systems, in the 6th IEEE International Symposium on Object-oriented Real-time distributed Computing Hakodate, Hokkaido, Japan, May 2003.
- Anders Wall, Johan Andersson, Jonas Neander, Christer Norström, and Martin Lembke Introducing Temporal Analyzability Late in the Lifecycle of Complex Real-Time Systems ; in the procedings RTCSA'03, February 2003.

Future plans:

The project is closed. The work conducted in this project is continued in the project Remodel.

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 increasingly 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.

Results and achievements in 2003:

Two papers have been published at international conferences. A technical report on state of the art automotive electronic architectures has been written. Two half-day workshops on electronic architectures for industry have been held at MdH with many practitioners. Two papers on vehicle network architecture have been written and submitted. There is ongoing work on another paper on analytical models for electronic architectures. Joakim has completed all courses required for a licentiate degree.

Publications:

- Anders Möller, Joakim Fröberg, Mikael Nolin, What are the needs for components in vehicular systems? - An industrial perspective, In Proceedings of the WiP Session of the 15th Euromicro Conference on Real-Time Systems,pages 45 - 48 Porto, Portugal , July 2003.
- Joakim Fröberg, Kristian Sandström, Christer Norström, Hans Hansson, Jakob Axelsson, Björn Villing, Correlating Bussines Needs and Network Architectures in Automotive Applications - a Comparative Case Study, n Proceedings of the 5th IFAC International Conference on Fieldbus Systems and their Applications (FET),pages 219-228 Aveiro, Portugal , July 2003

Future plans:

Joakim plans to present his Licentiate thesis in April 2004

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
Partners:	Volvo Construction Equipment Components AB,
	Mimer Information Technology AB
Funding:	Artes

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 2003:

Some of the results of the project include:

- A case-study performed at Volvo Construction equipement components, investigating the use of real-time database management systems in vehicular control systems.
- An implementation of COMET suited for an embedded vehicular control system.
- A concept called Database Pointers, which allow tasks to access a read-time database in an efficient and predictable way.
- A component-model which allows components to be weaved using the aspect-oriented paradigm.
- Two licentiate theses. (One at Mälardalen University and one at Linköping University.)

Publications:

- Dag Nyström, Aleksandra Tesanovic, Christer Norström, and Jörgen Hansson, “Database Pointers: a Predictable Way of Manipulating Hot Data in Hard Real-Time Systems” , RTCSA´03
- Aleksandra Tesanovic, Dag Nyström, Jörgen Hansson, and Christer Norström, “Towards Aspectual Component-Based Development of Real-Time Systems”, RTCSA´03
- Aleksandra Tesanovic, Dag Nyström, Jörgen Hansson, and Christer Norström, “Aspect-Level Worst-Case Execution Time Analysis of Real-Time Systems”, Workshop on Real-Time Programming. 2003

- Dag Nyström, Mikael Nolin, Aleksandra Tesanovic, Christer Norström, Jörgen Hansson, "Pessimistic, Concurrency-Control and Versioning to Support Database Pointers in Real-Time Databases", sumitted for publication.
- Dag Nyström, Aleksandra Tesanovic, Christer Norström, Jörgen Hansson, The COMET Database Management System, MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-98/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, April 2003
- Mikael Nolin, Johan Fredriksson, Jerker Hammarberg, Joel G Huselius, John Håkansson, Annika Karlsson, Ola Larses, Markus Lindgren, Goran Mustapic, Anders Möller, Thomas Nolte, Jonas Norberg, Dag Nyström, Aleksandra Tesanovic, Mikael Åkerholm Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003

Future plans:

Further work on how to integrate a real-time database into a vehicular control-system is planned. A special focus will be on integrating a real-time database mangement system as a part of the component framework, allowing components to be migrated among nodes in a distributed real-time system. A doctoral thesis is planned in dec 2005.

OpenController

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

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 2003:

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

Publications:

- Goran Mustapic, Johan Andersson, Christer Norström. A Dependable Real-Time Platform for Industrial Robotics. In ICSE 2003 WADS Portland, OR USA, May 2003.
- Goran Mustapić, Johan Andersson and Christer Norström. A Dependable Open Platform for Industrial Robotics. Submitted for a BOOK publication.

- Ivica Crnkovic, Goran Mustapic, Mikael Åkerholm. Modern technologies for modeling and development of process information systems. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-100/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, May 2003.
- Mikael Nolin, Johan Fredriksson, Jerker Hammarberg, Joel G Huselius, John Håkansson, Annika Karlsson, Ola Larses, Markus Lindgren, Goran Mustapic, Anders Möller, Thomas Nolte, Jonas Norberg, Dag Nyström, Aleksandra Tesanovic, Mikael Åkerholm Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003
- Goran Mustapic, Ivica Crnkovic. Propagation of quality attributes in a layered design. Third Swedish Conference on Software Engineering Research and Practise, in Lund, October 2003

Future plans:

Work on evaluation and design of technologies and tools, with respects to the system quality that needs to be achieved. A licentiate thesis is planned to be presented in October 2004.

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:

- Christer Norström, Anders Wall , Johan Andersson och Kristian Sandström Increasing maintainability in complex industrial real-time systems by employing a non-intrusive method, In proceedings of the workshop on Migration and Evolvability of Long-life Software Systems (MELLS '03) Erfurt, Germany , September 2003.

- Anders Wall, Johan Andersson, Christer Norström, Probabilistic Simulation-based Analysis of Complex Real-Times Systems, in the 6th IEEE International Symposium on Object-oriented Real-time distributed Computing Hakodate, Hokkaido, Japan , May 2003.
- Anders Wall, Johan Andersson, Jonas Neander, Christer Norström, and Martin Lembke Introducing Temporal Analyzability Late in the Lifecycle of Complex Real-Time Systems ; in the procedings RTCSA'03, February 2003.

Future plans:

During the coming two years we excpect the following results

- A method for model validity evaluation.
- An implementation of the Probabilistic Property Language.
- An approach for automatic model creation.
- An approach for measuring the changes in a system based on measurements.

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 organised together. MdH/IDt has been identified as a strategic partner of ABB research in the area of software engineering. During 2003 there are 6 industrial graduate students sponsored by ABB.

The collaboration with Volvo Construction Equipment has continued and the industrial PhD student will complete his licentiate thesis during spring 2004. The collaboration has been extended with collaboration with Volvo Truck and Volvo Car. Several joint papers have been written. Further, an Adjunct Professor from Volvo Car will join 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 Thesis

One PhD thesis and four licenciate theses were completed in 2003.

3.5.1 PhD Theses

Anders Wall: ***Architectural Modeling and Analysis of Complex Real-Time Systems.***

Most automation systems and other large industrial software systems have long lifetimes, and customers expect these systems to be supported as long as they are in operation. Furthermore, software components in these systems may be reused in different products, e.g. using a software product line approach. Hence, the lifetime of software in individual systems may be very long; several decades or even longer.

Software that is used for a long time will be exposed to frequent changes as the system evolve over time, e.g. due to adding new functionality, error corrections, or changing the hardware platform. The larger and older the system is, the harder it becomes to foresee the consequences of changes.

In this thesis we present three different techniques for managing the evolution of large and complex real-time systems. The techniques are based on analytical modeling, predicting different quality properties, e.g. temporal correctness, by analyzing a model of the software. The first technique is a component model with analytical interfaces (ReFlex) that allows us to predict different properties of a component assembly, the second is a probabilistic modeling language which is analyzed by simulations (ART-FW), and the third technique is an extension of classical timed automata with a notion of real-time tasks (TAT).

Ideally, the analytical models should evolve together with the software. However, since new features are often added and the implementation is often changed without updating the model, the model becomes obsolete and predictions based on the model are no longer valid. By applying the techniques proposed in this thesis, we can re-introduce analyzability; Using ReFlex we can update the analytical aspects while re-designing the system. Unless ReFlex has been used in the earlier design, this will require a costly redesign of the complete system, but consistency between the analytical model and the implementation will be ensured. Using ART-FW or TAT the implementation will be kept untouched by introducing a separate model. The drawback is that an extra effort is required to keep the model consistent with the implementation. We have applied ART-FW in the re-engineering activity of a large industrial system. The results indicate that the approach is indeed applicable on real systems.

3.5.2 Licentiate theses

Dag Nyström: ***COMET: A Component-Based Real-Time Database for Vehicle Control-Systems***

Vehicle control-systems have evolved from small isolated controllers to complex distributed computer-systems. These systems include nodes spanning from simple 8-bit micro-controllers with a minimum of memory to complex 32-bit processors with vast resources. The main motivation for this evolution is the need for increased functionality in motor vehicles. Examples of such functionality include momentary fuel consumption measurements, anti-spin systems, and computerized diagnostics of vehicle-status. The control of the increased functionality requires the handling and maintenance of larger volumes of data, and has created a need for a uniform and efficient way to access and maintain this data. A real-time database management system could satisfy this requirement but an extensive survey of commercial and experimental database management systems has shown that there is currently no database system suitable for vehicle control systems available.

In today's systems, data management is performed in an ad-hoc fashion at a low level of abstraction, using internal data-structures, e.g., shared variables and structures. This approach requires that the consistency of the data is maintained by the application, by, for example, resolving data access conflicts through the use of semaphores.

This thesis presents a flexible and configurable database management system designated COMET, suitable for embedded systems and in particular, vehicle control-systems. To be able to handle the varying requirements imposed by different systems, COMET emphasizes configurability and tailorability, by adopting a component-based architecture.

The result of this research is the implementation of COMET BaseLine, which is an instance of COMET suited to a particular vehicle control-system. The required behaviour of this database is based on requirements gathered from a case study performed at Volvo Construction Equipment Components AB in Eskilstuna. To fulfill these requirements, a concept called database pointers has been introduced and implemented. Database pointers provide controlled direct access to individual data elements in the database, efficiently and temporally deterministic, providing at the same time a high level of abstraction.

Christina Wallin: ***A Process Approach for Senior Management Involvement in Software Product Development***

To make business of software product development it is important that the right software products are developed the right way. Today there are a number of software development models that support project management to successfully execute software development projects, but they typically do not ensure that the resulting software products will be successful from a business perspective. To achieve this senior management involvement is needed to meet business objectives and deliver sustained and actual benefits to the customer and the organization. This thesis presents one possibility to achieve effective senior management involvement in software product development projects by using stage-gate new product development models from traditional product development, and by suggesting a way to combine these models with contemporary software development models through pre-gate milestones. For verification, experiences from a corporate wide software platform deployment initiative are collected and discussed. The initiative used a stage-gate new product development model for project selection and steering, and an incremental software development model for project management and execution.

Rikard Land: ***An Architectural Approach to Software Evolution and Integration***

As time passes, software systems need to be maintained, modified, and integrated with other systems so as not to age and become obsolete. In the present thesis, we investigate how the concepts of software components and software architecture can be used to facilitate software evolution and integration. Based on three case studies, we argue that considering a software system at a high abstraction level, as a set of connected components, makes possible a cost efficient and structured evolution and integration process. The systems in two of our case studies are information systems developed in-house used for managing and manipulating business-critical data. The third case study concerns an integration framework in which systems can be integrated without modification. In the thesis, we describe how several architectural alternatives can be developed based on architectural descriptions of existing systems, and how these can be evaluated regarding a number of concerns in a relatively rapid way, while achieving an acceptable confidence/effort ratio. We describe how some of these concerns can be addressed in more detail, namely maintainability, cost of implementation, and time of implementation; we also discuss the risk involved in the decision. We show how although the existing architecture may reflect insufficient design decisions and an outdated state of practice, it can and should be seen as a prototype revealing strengths that should be preserved and weaknesses that should be addressed during redesign. We also describe four different integration approaches and the feasibility of each under various circumstances: Enterprise Application Integration (EAI), interoperability through import and export facilities, integration at data level, and integration at source code level. The two last of these are compared in more detail, revealing that code level integration is more risky but not necessarily more costly than data level integration, but is advantageous from a technical perspective.

Frank Lüders: ***Use of Component-Based Software Architectures in Industrial Control Systems***

Component-based software engineering (CBSE) denotes the disciplined practice of building software from pre-existing smaller products, generally called software components, in particular when this is done using standard or de-facto standard component models. The popularity of such models has increased greatly in the last decade, particularly in the development of desktop and server-side software. The main expected benefits of CBSE are increased productivity and timeliness of software development projects. The last decade has also seen an unprecedented interest in the topic of software architecture in the research community as well as among software practitioners. CBSE has notable

implications on systems architecture, and an architecture that supports CBSE, e.g. by mandating the use of a component model, is called component-based software architecture.

This thesis investigates the benefits and problems related to the use of such architectures in industrial control systems, which are computer-based systems that control physical processes and equipment. The investigation is mainly performed through an industrial cases study of a global company developing a new generation of control systems, intended to replace several existing systems. To leverage its global development resources and the competency of different development centers, the company decided to adopt a component-based software architecture that allows certain functionality to be realized by independently developed components. The architecture incorporates a limited version of a standard component model.

The process of redesigning the software architecture is presented in this thesis, along with the experiences made during and after the project. An analysis of these experiences shows that the component-based architecture effectively supports distributed development and that the effort required for implementing certain functionality has been substantially reduced. The use of the selected component model in real-time systems is furthermore analyzed from a more general perspective. It is shown that adopting the model means that real-time requirements can still be satisfied in most cases, but that this may require certain precautions to be taken.

3.6 Staff

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. He is currently working as Dean at Mälardalen University. 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 and he has manifested that through several successful transfers to the automotive industry. 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.

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 6 years.

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 Joakim Fröberg is an Industrial Ph.D. student employed Volvo Construction Equipment Components AB where he is working with architecture development and technology strategy 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. His research interests include architectures of vehicle computer-based systems, but also systems and requirements engineering related to engineering of vehicle electronics.

Dag Nyström is, since Nov 2000, a Ph.D. student at the Software Engineering lab at IDt. His area of research is Embedded Real-Time Databases. Prior to this position he has been an undergraduate student at IDt since 1997.

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 is an industrial Ph.D. student employed by ABB Automation Products AB since 1993. 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.

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.

Andreas Sjögren is a Ph.D. Student. He received a MSc at Mälardalen University 2001. His research interests include Component-based Development, with focus on specifications of components

Christina Wallin is an industrial Ph.D. student employed by ABB Corporate Research. Her main research interest is Software Engineering Processes.

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 a research engineer at MdH and working part time 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 and working as a Software Engineer, he enrolled the PhD program at MdH in 2002. 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.

Mladen Kap is a research engineer working on a co-operation project with the CompFab Company. He obtained his licentiate degree from Imperial College London. He has worked at ABB on design and development of automation 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.

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 1.4):

- 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 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 2003:

Ivca Crnkovic

- has been active (responsible for a workpackage) in EU IST project DOTS and EU CBSENet network group.
- has organised cooperation with University of Zagreb, Croatia which resulted in performance of a common course.
- has established cooperation with Technical University Eidhoven, The Nehterlands- mutual guest lectures have been organised

Rikard Land

- was a guest resercher at University of Zagreb under period of 6 months.

Christer Norström

- has together with Anders Wall initiated cooperation with Nimal Nissanke Faculty of Business, Computing and Information Management London South Bank University.
- 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
- Software Engineering Institute at CMU

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 2003 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 and MRTC organized a CBSE workshop at the ICSE conference in Toronto (CBSE6). The workshop had a wide response which led to a decision to organize a symposium on CBSE in 2004
- SEI was actively involved in Euromicro CBSE conference track organized by SEL
- SEI, MdH and ABB Robotics have started new research project related to component-based development.
- Ivica Crnkovic visited SEI and gave a seminar about research work at MRTC.

Monash University, Australia

The Software Engineering group has established 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. A PhD student (Rikard Land) from MdH stayed at University

in Zagreb during six months, and during that stay a common course (distributed development) will we developed. The course was held in autumn 2003 as a common course (examinetors prof. Mario Zagar, Zagreb , and Prof. Ivica Crnkovc, MdH).

Eindhoven University of Technology (TUe)

SEL has started cooperation with Eindhoven University of Technology, The Netherlands. Ivica Crnkovic visited TUe, Dr. Michel R. V. Chaudron, and discussed cooperation. A plan for cooperation has been done, and possible some PhD students will be exchanged between the research centers.

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 2003:

Ivca Crnkovic

- Organiser of CBSE track on IEEE Euromicro Conference in Antalya, Turky, September 2003
- Coorganiser of 6th workshop on CBSE at IEEE international conference on software engineering in Portland, US
- The opponent on the PhD thesis of Asmus Padnikow at Linköping University, March 2003
- The opponent on the PhD thesis of Mikael Svahnberg at Blekinge Institute of Technology, November 2003
- Invited speaker at Mipro Conference, Industrial Systems, May 2003, Opatija, Croatia
- Invited speaker at 26th International Conference Information Technology Interfaces 2004, Dubrovnik, Croatia, June 2003
- Organiser of a working session science and higher education at 26th International Conference Information Technology Interfaces 2004, Dubrobnik, Criatia, June 2003
- Guest lecturer at Technical University, Eidhoven, The Nederlands, Spetember 2003
- PC member for International Software Engineering Conference, Industrial track, Portland, May 2003
- PC Member of ESEC/FSE international conference
- PC member of SCM-11 symphosium at at IEEE international conference on software engineering in Portland, US
- PC member at Third Swedish Conference on Software Engineering Research and Practise, in Lund, October 2003
- 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.
- Superviser of Rikard Land in completion of their licenciate degree Spetembet 2003.
- Superviser of Christina Wallin in completion of their licenciate degree December 2003.
- Superviser of Frank Luders in completion of their licenciate degree Spetembet 2003.

Christer Norström

- Guest editor for a special issue on factory commiunication 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 is expected to be published in June 2004.
- Member of the programme committee for FeT'2003 - The 6th FeT Conference. Fieldbus Systems and their Applications.
- Member of the International Advisory Committee and programme committee for the 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003).

- Organiser of the industrial session and the WIP session at the 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003).
- General chair for RtiS2003 – Real-time in Sweden 2003,
- Reviewing applications for the Norwegian Research Council.
- Member of the board of SNART (Swedish association for real-time research).
- Member of the PhD examination committee for Alexander David, Uppsala University.
- Member of the PhD examination committee for Tomas Berling, Lund Institute of Technology.
- Has been supervising Anders Wall to completion of a PH.D. Septermber 2003.
- Has been supervising Dag Nyström to completion of a licentiate degree May 2003.

Kristian Sandström

- Program Co-chair Real-Time in Sweden 2003 (RTiS03)

3.9 Interactions with society

Ivica Crnkovic

- Held seminar on Software Configuration Management and Product Data Management seminar organised by Institute for International Research, Sweden
- Hel a seminar on Component-based software engineering at Croatian Electrical Distribution (HEP) company

Christer Norström

- has been giving several courses on design of real-time systems for industry.
- has been giving several public lectures about the current development in embedded systems.
- has been invited to participate in the discussion about growth in Sweden by the Social democrats.
- has been interviewed in several magazines about Robotdalen.
- has provided an one hour lecture on how to build up and manage research environments for the the KKS-foundations.
- has built up a collaboration portfolio with ABB Robotics including, research projects, industrial graduate students, bachelor and master thesis, trainee positions, and job rotations.

Kristian Sandström

- Industry course in engineering of complex embedded systems.
- Has initiated and been leading cooperation with secondary school providing student and teacher exchange.

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 7 senior researchers and 16 postgraduate students, all of whom are 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.

The figure below shows the basic philosophy and organisation of courses. The courses in solid ovals were given 2002 and those in dashed are under development.

The basic courses in computer systems are followed by the SDL core profile course real-time systems basics, which 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 covering more advanced material, some with engineering perspectives, some with a more traditional scientific perspective. As a complement to these courses, seminars and tutorials on specific topics are given on a more sporadic basis (indicated with dashed circles in the figure above). In addition to these courses SDL contributes substantially to the scientific methodology course given by CSL.

During 2003, the development of a web-based version of the basic Real-Time systems course was completed. The course is given for the first time during spring 2004.

New courses and programmes (Int'l MSc-year etc.)

The pedagogical philosophy of the 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 2003 given to Henrik Thane.

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 2003 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
Mitsubishi Research Labs, Boston, USA
Liesbeth Steffens, Philips Research, The Netherlands
Alan Burns, University of York, UK
Michael Gonzalez-Harbour, University of Cantabria, Spain
TTTech, Vienna, Austria
CSEM Switzerland
Thomson Multimedia, France
TU Eindhoven, The Netherlands

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.

The following are the concrete projects in this area:

Flexible Reliable Timing Constraints

Funding: ARTES and Internal

Project description:

The goal of this project is to develop methods for the derivation, specification, and run-time execution of activities with constraints, which exploit inherent flexibility in temporal demands, e.g., on application level, instead of over-constraining specifications. We propose to use flexible timing constraints, which express feasibility information of activities rather than numbers demanded by common system models and scheduling algorithms. In this year, we have studied the novel temporal constraints demanded by media processing.

FIRST - Flexible Integrating Scheduling Technology - EU IST Project

Results and achievements in 2003:

- Radu Dobrin has completed his Licentiate thesis, “Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling”
- Tomas Lennvall has completed his Licentiate thesis, “Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems”

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.

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.

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.

Publications

Theses

- Radu Dobrin: Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling, Licentiate thesis
- Thomas Lennvall: Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems, Licentiate thesis

Book contributions

- Gerhard Fohler, Tomas Lennvall, and Radu Dobrin. Architectures for Dependable Systems, volume 2677 of Lecture Notes in Computer Science, chapter A Component Based Real-time Scheduling Architecture. Springer Verlag
- Pau Marti, Josep M. Fuertes ,and Gerhard Fohler. The Handbook on Information Technology in Industrial Automation, chapter Networked Control Systems – An Overview. CRCPress/IEEEPres

Journal papers

- Damir Isovic, Gerhard Fohler, and Liesbeth F. M. Steffens. Real-time issues of MPEG-2 playout in resourse constrained systems. Accepted for International Journal on Embedded Systems

Reviewed conference articles

- Johan Fredriksson, Mikael Åkerholm, Kristian Sandström, Radu Dobrin. Attaining Flexible Real-Time Systems by Bringing Together Component Technologies and Real-Time Systems Theory. Proceedings of the 29th Euromicro Conference, Component Based Software Engineering Track, Belek, Turkey, September Damir Isovic, Gerhard Fohler, and Liesbeth F. M. Steffens. Timing constraints of MPEG-2 decoding for high quality video: misconceptions and

realistic assumptions. In 15th Euromicro Conference on Real-time Systems (ECRTS03), Porto, Portugal, July2003

- Tomas Lennvall, Jan Carlson, and Gerhard Fohler. Enhancing time triggered scheduling with value based overload handling and task migration. In Proceeedings of 6th IEEEInternational Symposium on Object- oriented Real-time distributed Computing, 2003.
- Giuseppe Lipari and Gerhard Fohler. A framework for composing real-time schedulers. In Proceedings of the International Workshop on Test and Analyis of Component Based Systems, Warsaw, Poland, April 2003.
- Liesbeth Steffens, Gerhard Fohler, Giuseppe Lipari, Giorgio Buttazzo. Resource Reservation and Service Contract. International Workshop on Advanced Real-Time Operating Systems Services (ARTOSS 2003), Porto, Portugal, July 2003
- Weirong Wang, Al Mok, and Gerhard Fohler. A hybrid proactive approach for integrating off-line and on- ine real-time schedulers. In Third International Conference on Embedded Software, Philadelphia, PA, USA, October 2003 (EMSOFT03), Philadelphia, PA, USA, Oct2003.

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. Another issue of recent interest 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.

Achievements:

During 2003, routing for sensor networks has been studied, as well as the semantics of back-end proxies in comparison to non-proxy solutions.

Future plans:

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

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 todays 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.

Future plans:

During 2004, the issues of aggregated traffic and flow stability will be further studied, together with the applicability of traffic characterization in traffic analysis.

EvaluNet – Network Performance Evaluation

Project leader:	Mats Björkman
Members:	Andreas Johnsson
	Bob Melander
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:

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

Future plans:

During 2004, 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.

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
	kövde University
	erorgia Institute of Technology

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).

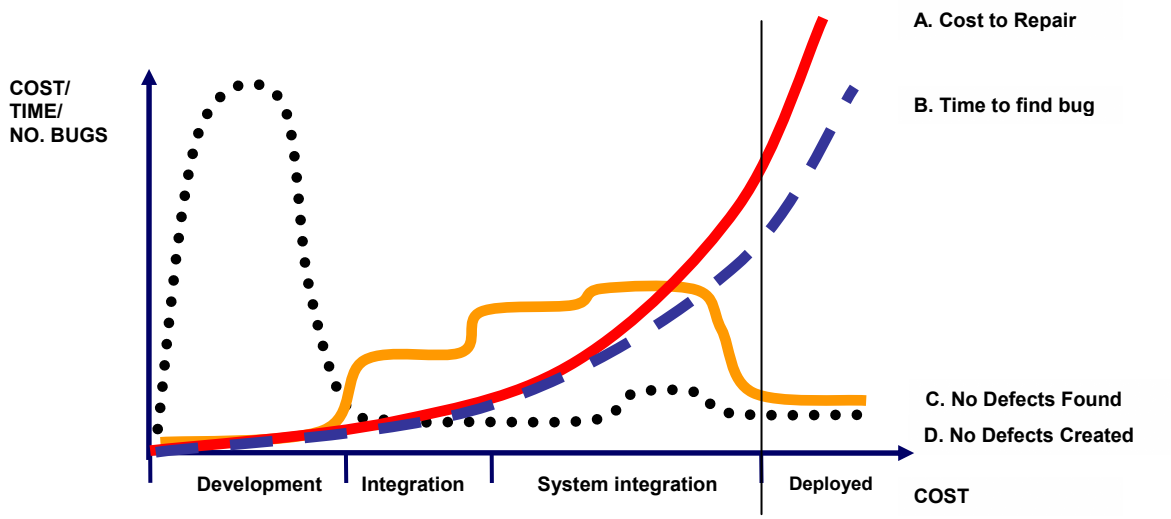


Figure 1. Graph *D*, shows the number of bugs introduced per lifecycle phase. Graph *C*, shows the number of bugs found per phase. That is, bugs are often introduced early but found late. Graph *B*, shows the relative time it takes to find one bug. More complex bugs are only found during later stages 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 C) 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.

TATOO - Test and Testability of Distributed Real-Time Systems

Project leader:	Henrik Thane
Members:	Anders Pettersson
Partners:	ABB Robotics
	ealcore Embedded Solutions AB
	olvo Construction Equipment Components AB
	Uiversity of Skövde
Funding:	ARTES
	nternal

Project description:

This project has been around since 1998 and ended with the completion of Anders Pettersson's Licenciate thesis. During the years methods and tools have been developed for monitoring and testing of single processor real-time systems as well as distributed real-time systems (DRTS). Specifically methods and tools for achieving deterministic monitoring and testing of DRTS, testability metrics, testability increasing design rules were developed. After Henrik Thane's completion of his Ph.D thesis (2000), the project continued on with Anders Pettersson.

Results and achievements in 2003:

During 2003 a number of publications were published and presented, with the icing on the cake of Anders Pettersson's Licenciate Thesis in October 2003.

Theses

- Anders Pettersson: Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time System. Licenciate thesis, Mälardalen University, October 2003.

Reviewed conference articles

- Daniel Sundmark, Henrik Thane, Joel G Huselius, Anders Pettersson: Replay Debugging of Complex Real-Time Systems: Experiences from Two Industrial Case Studies, In Proceedings of the 5th International Workshop on Algorithmic and Automated Debugging (AADEBUG03),pages 211-222 Gent, Belgium , September 2003.
- Henrik Thane, Daniel Sundmark, Joel G Huselius, Anders Pettersson: Replay Debugging of Real-Time Systems Using Time Machines. In Proceedings of the International Parallel and Distributed Processing Symposium (IPDPS'03), presented at the First International Workshop on Parallel and Distributed Systems: Testing and Debugging (PADTAD),pp.288-295 Nice, France , April 2003. ACM
- Anders Pettersson, Henrik Thane: Testing of Multi-Tasking Real-Time Systems with Critical Sections. In In proceedings of the 9th International Conference on Real-Time and Embedded Tainan City, Taiwan, R.O.C , February 2003.

Technical Reports

- Anders Pettersson: Testing of Computer Software with Temporal Constraints: A State-Of-The-Art Report. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-115/2004-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, October 2003.
- Anders Pettersson: Experimental Evaluation of a Test Procedure for DeterministicTesting of Real-Time Systems. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-114/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, October 2003
- Daniel Sundmark, Henrik Thane, Joel G Huselius, Anders Pettersson: Replay Debugging of Complex Real-Time Systems: Experiences from Two Industrial Case Studies. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-114/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, October 2003
- Anders Pettersson: The Revised EOG-algorithm. Technical Report, October 2003.

Future plans:

Anders Pettersson and Daniel Sundmark will continue their research, and pursue their Ph.Ds., in the new project LESS Bugs which is funded by KK Foundation .

DEBUG

Project leader:	Henrik Thane
Members:	Daniel Sundmark,
	oel Husselius
	athias Ekman
Partners:	ABB Robotics

	ombardier Transportation
	NEA Real-Time AB
	Zealcore Embedded Solutions AB
	SAAB Avionics
	IAR Systems
Funding:	SSF
	Internal
	Bombardier Transportation

Project description:

This project deals with investigation, design and development of methods and techniques for embedded multitasking real-time software debugging. Our vision is to provide an environment where debugging of multitasking real-time systems is no different than traditional debugging of sequential single-tasking non-real time software. Traditionally, debugging is performed by the use of specialized debugger tools. Once a failure in a program is detected, the execution is repeated in a debugger tool, where you can single-step, breakpoint and watch selected variables during the re-execution. This is done repeatedly until the the bug that led to the failure is found. This method of debugging (called cyclic debugging) calls for a deterministic execution of the program, i.e. given the same input, the program will always follow the same path through the code and produce the same output. However, in the domain of multi-tasking real-time systems, very few executions are deterministically reproducable. Firstly, this is due to the fact that real-time systems traditionally interact with an external context via sensors and actuators. Real-time systems also depend heavily on the correctness of a real-time clock. These kinds of interactions are virtually impossible to reproduce deterministically. Secondly, multi-tasking systems include fundamentally non-deterministic aspects such as asynchronous preemptions and interrupts. In order to handle these problems, information of the non-deterministic aspects of the system needs to be monitored and extracted. This leads to yet another problem. Embedded systems, by definition, have very few interactive resources available and even though if extensive monitoring is possible within the system (which not always is the case), the monitored information might not be presented to the user in a proper way.

Results and achievements in 2003:

During 2003 a number of publications were published and presented, with the icing on the cake of Joel Huselius's Licenciate Thesis in October 2003.

Journal articles

- Henrik Thane: Time Machines and Black Box Recorders for Embedded Systems Software
- ERCIM News, (52):32-33, January 2003. Journal of European Research Consortium for Informatics and Mathematics

Theses

- Joel Huselius: Preparing for Replay, Licentiate thesis 16, Mälardalen University, November 2003. Author: Joel Huselius

Reviewed conference articles

- Daniel Sundmark, Henrik Thane, Joel G Huselius, Anders Pettersson: Replay Debugging of Complex Real-Time Systems: Experiences from Two Industrial Case Studies, In Proceedings of the 5th International Workshop on Algorithmic and Automated Debugging (AADEBUG03), pages 211-222 Gent, Belgium, September 2003.
- Joel G Huselius, Henrik Thane, Daniel Sundmark: Availability Guarantee for Deterministic Replay Starting Points in Real-Time Systems, In Proceedings of the 5th International Workshop on Algorithmic and Automated Debugging (AADEBUG03), pages 261-264 Ghent, Belgium, September 2003.

- Joel G Huselius, Daniel Sundmark, Henrik Thane: Starting Conditions for Post-Mortem Debugging using Deterministic Replay of Real-Time Systems, In Proceedings of the 15th Euromicro Conference on Real-Time Systems (ECRTS03), pages 177-184 Porto, Portugal, July 2003
- Henrik Thane, Daniel Sundmark, Joel G Huselius, Anders Pettersson: Replay Debugging of Real-Time Systems Using Time Machines. In Proceedings of the International Parallel and Distributed Processing Symposium (IPDPS'03), presented at the First International Workshop on Parallel and Distributed Systems: Testing and Debugging (PADTAD), pp.288-295 Nice, France, April 2003. ACM

Technical Reports

- Joel G Huselius: Source-Code to the ECETES Logging Strategy, Technical Report, August 2003.
- Daniel Sundmark, Henrik Thane, Joel G Huselius, Anders Pettersson: Replay Debugging of Complex Real-Time Systems: Experiences from Two Industrial Case Studies. MRTC Report ISSN 1404-3041 ISRN MDH-MRTC-114/2003-1-SE, Mälardalen Real-Time Research Centre, Mälardalen University, October 2003

Future plans:

Daniel Sundmark will present his licenciate thesis in March 2004, and then continue his research in collaboration with Joel huselius, Anders Petterson and Mathias Ekman in the new project LESS Bugs which is funded by KK Foundation.

ASTERIX

Project leader:	Henrik Thane
Members:	Henrik Thane
	Anders Pettersson
	Daniel Sundmark
Partners:	Zealcore Embedded Solutions AB
	Georgia Institute of Technology
Funding:	Internal

Project description:

To enable validation of our more theoretical results and to show their applicability we have developed an entire design framework, ASTERIX. This framework includes, a real-time kernel the ASTERIX RTOS, that in a practical manner makes use of many of the recent advances made in the real-time systems research community. The basic ambition behind the development of the Asterix real-time kernel was to pack state-of the art research results into package such that it can be easily used and understood by people in the embedded systems industry. From an academic point of view the Asterix real-time kernel fulfils all the basic requirements necessary for facilitating different types of timing analyses. For a software designer this signifies that the Asterix real-time kernel has the means to satisfy engineering of real-time software in the same fashion as civil engineers make use of structural calculus when designing bridges or houses. The Asterix real-time kernel is in combination with its support environment in a unique position to provide the embedded systems industry with a development kit that can increase the reliability, safety, and testability of their applications with several magnitudes compared to existing development systems. From the outset of the development project we decided that the kernel would be distributed as an open source program. For a customer this has several benefits: nothing can be cheaper than free, and risks taken by relying on a small company for providing a real-time kernel can be minimized by having access to the source code. In summary, the kernel packs state-of-the art features into a package that is all free and open. Although the Asterix real-time kernel defines the state-of-the-art with respect to other real-time kernels its greatest strengths lays in its open platform and its support by extremely powerful development and

verification tools. For example tools, for design, scheduling, monitoring, debugging and testing of distributed real-time systems.

Results and achievements in 2003:

- B. Akgul, V. Mooney, H. Thane and P. Kuacharoen, "Hardware Support for Priority Inheritance," Proceedings of the IEEE Real-Time Systems Symposium (RTSS'03), pp.246-254, December 2003

4.3.4 Real-time Systems Design research group

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 TD (Henrik Lönn)
	LiU/RTSLAB (Jörgen Hansson/Simin Nadj-Tehrani)
	KTH/DAMRK (Martin Törngren)
	UU/UppAal (Paul Pettersson/Wang Yi)

The core to a successful system is the basic architecture. We are studying the many aspects of architectures especially related to real-time systems and reliability, which includes specification of architectures, architecture analysis, component models, essential components in embedded systems, methods and tools. We are both considering models and analysis for developing new systems and techniques for 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 2002 we have performed several case studies, including architectures for automotives (both software architectures and communication architectures), trains and robotics.

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

Details of our projects are given below:

SAVE

Project leader:	Hans Hansson, MdH
Members:	Mikel Nolin
	Thomas Nolte
	Henrik Thane
	Joel Huselius
Partners:	LiU/RTSLAB (Jörgen Hansson/Simin Nadj-Tehrani)
	KTH/DAMRK (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. SVAE 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 2003 (see also the corresponding report for SEL)

Main Activities

- Contribution with chapters on Real-Time Systems (Hans Hansson, Mikael Nolin, Thomas Nolte) and Testing and Monitoring (Joel Huselius, Henrik Thane) to the extensive survey (the SAVE-book) on component-based techniques for safety-critical vehicular systems.
- Graduate course on "Component Based Software Engineering for Embedded Systems", given by Mikael Nolin.
- Research on modelling and analysis of the CAN-bus (Thomas Nolte, Hans Hansson, Mikael Nolin); resulting in several publications, including the licentiate thesis "Reducing Pessimism and increasing Flexibility in the Controller Area Network" by Thomas Nolte (presented in May 2003)
- Research on replay debugging (Joel Huselius, Henrik Thane); resulting in several publications, including the licentiate thesis "Preparing for Replay" by Joel Huselius (presented nov 10, 2003)

Academic co-operation

- No concrete SAVE-relevant academic co-operation outside SAVE during the period, apart from the following more general co-operations:
- Participation in the EU Network ARTIST – Action line on Component Based Design
- Co-operation established with Universitat de les Illes Balears (Guillermo Rodriguez-Navas, Julian Proenza Arenas), regarding relaxed modelling of RT-communication

Industrial co-operations

There are close links with the project HEAVE (see presentation of HEAVE). HEAVE is a co-operation between SDL, Volvo Construction Equipment (Eskilstuna) and CC-Systems (Uppsala/Västerås).

Publications

Theses

- Joel Huselius: Preparing for Replay, Licentiate thesis 16, Mälardalen University, November 2003. Author: Joel Huselius
- Thomas Nolte: Reducing Pessimism and Increasing Flexibility in the Controller Area Network, Licentiate thesis 10, Mälardalen University, May 2003.

Journal articles

- Henrik Thane: Time Machines and Black Box Recorders for Embedded Systems Software
- ERCIM News, (52):32-33, January 2003. European Research Consortium for Informatics and Mathematics

Reviewed conference articles

- Daniel Sundmark, Henrik Thane, Joel G Huselius, Anders Pettersson: Replay Debugging of Complex Real-Time Systems: Experiences from Two Industrial Case Studies, In Proceedings of the 5th International Workshop on Algorithmic and Automated Debugging (AADEBUG03),pages 211-222 Gent, Belgium , September 2003.
- Joel G Huselius, Henrik Thane, Daniel Sundmark: Availability Guarantee for Deterministic Replay Starting Points in Real-Time Systems, In Proceedings of the 5th International Workshop on Algorithmic and Automated Debugging (AADEBUG03),pages 261-264 Ghent, Belgium , September 2003.
- Joel G Huselius, Daniel Sundmark, Henrik Thane: Starting Conditions for Post-Mortem Debugging using Deterministic Replay of Real-Time Systems, In Proceedings of the 15th Euromicro Conference on Real-Time Systems (ECRTS03),pages 177-184 Porto, Portugal , July 2003.
- Thomas Nolte, Mikael Nolin, Hans Hansson: Server-Based Scheduling of the CAN Bus, In 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003) Calouste Gulbenkian Foundation, Lisbon, Portugal , September 2003.
- Joakim Fröberg, Kristian Sandström, Christer Norström, Hans Hansson, Jakob Axelsson, Björn Villing: Correlating Bussines Needs and Network Architectures in Automotive Applications - a Comparative Case Study, In Proceedings of the 5th IFAC International Conference on Fieldbus Systems and their Applications (FET),pages 219-228 Aveiro, Portugal , July 2003. IFAC
- Thomas Nolte, Mikael Nolin, Hans Hansson: Using Servers to Provide Bandwidth Isolation on the Controller Area Network, In 2nd International Workshop on Real-Time Lans in the Internet Age (RTLIA 2003) in conjunction with the 15th Euromicro International Conference on Real-Time Systems (ECRTS 2003) Polytechnic Institute of Porto, Portugal , June 2003.
- Thomas Nolte, Hans Hansson, Christer Norström: Probabilistic Worst-Case Response-Time Analysis for the Controller Area Network, In Ninth IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS 2003) Toronto, Canada , May 2003. IEEE Computer Society Press

Other conference publications

- Anders Möller, Joakim Fröberg, Mikael Nolin: What are the needs for components in vehicular systems? - An industrial perspective -, In Proceedings of the WiP Session of the 15th Euromicro Conference on Real-Time Systems, pages 45 - 48 Porto, Portugal , July 2003.
- Thomas Nolte, Anders Möller, Mikael Nolin: Using Components to Facilitate Stochastic Schedulability Analysis, In IEEE RTSS 2003, WiP Session, Cancun, Mexico, December 2003.

- Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin: Software Component Technologies for Real-Time Systems - An Industrial Perspective, In IEEE RTSS 2003, WiP Session, Cancun, Mexico, December 2003.

Technical Reports

- Joel G Huselius: Source-Code to the ECETES Logging Strategy,Technical Report , August 2003.
- Jukka Mäki-Turja, Mikael Nolin: Improved Analysis for Real-Time Tasks With Offsets - Advanced Model, MRTC Report, Mälardalen Real-Time Research Centre, Mälardalen University, May 2003
- Mikael Nolin: Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003
- Number: ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE
- Thomas Nolte, Mikael Nolin, Hans Hansson: Server-Based Scheduling of the CAN Bus
- MRTC Report, Mälardalen Real-Time Research Centre, Mälardalen University, April 2003
- Number: ISSN 1404-3041 ISRN MDH-MRTC-99/2003-1-SE
- Thomas Nolte, Mikael Nolin, Hans Hansson: Providing Bandwidth Isolation on the Controller Area Network by Using Servers, Technical Report , April 2003.

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 2003:

This project was launched in Q4 2003 and started with a test implementation of, so called, single shot execution (SSX) tasks in Arcticus' real-time operating system Rubus. The result was a proof of concept that Rubus allows easy implementation of new execution paradigms, in that SSX tasks was implemented using a resource effective shared stack. Further the long term goals of the project was specified in a project plan encompassing 3 years of activities, which is supposed to generate one licentiate and one PhD degree.

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 is 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, is 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 is 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 is 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.

Results and achievements in 2003:

MRTC's and SAVE's involvement in EAST/EEA started in 2002. During 2003 we have participated in numerous working meeting with the other EAST/EEA partners. We have also worked actively with EAST/EEA partners to produce format project deliverables. In cooperation with the SAVE project, a literature study over component technologies and techniques that can be used for component technologies in vehicular systems was conducted.

Publications:

- EAST/EEA Work Task 3.4 (eds. Alice Halter and Vincent de Bryun, PSA Peugeot Citroën), EAST-EEA Embedded Electronic Architecture, Verification and Validation Methods used with EAST ADL. December 2003.
- EAST/EEA Work Task 3.4 (ed. Mikael Nolin), EAST-EEA Embedded Electronic Architecture, Timing Analysis Techniques. June 2003.
- Ed. Mikael Nolin. Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report 102, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003. Number: ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE
- Mikael Nolin, Summary of Timing Analysis Techniques, June 2003.
- Jukka Mäki-Turja, Mikael Nolin. Faster Response Time Analysis of Tasks with Offsets, In WiP Session of Real-Time Systems Symposium (RTSS), Cancun, Mexico, December 2003.

Future plans:

During 2004 the work within EAST/EEA will for 6 months. Focus within the working groups where SAVE is active will be to finalise the formal project deliveries. Here MRTC and SAVE will contribute with their deep knowledge about analysis and verification techniques.

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 2003:

The project started in January 2003 with the recruitment of Anders Möller as an industrial PhD-student, employed both by MdH and CC-Systems. During 2003 a study of industrial requirements was conducted and an evaluation of existing component technologies (with respect to the requirements) is well on the way (see publications below). Also, HEAVE-members participated and organised a course about existing component technologies and techniques that can be use in component technologies. The result was a comprehensive literature survey.

Publications:

- What are the needs for components in vehicular systems? - An industrial perspective. In Proceedings of the WiP Session of the 15th Euromicro Conference on Real-Time Systems, pages 45 - 48 Porto, Portugal, July 2003. Anders Möller, Joakim Fröberg, Mikael Nolin
- Ed. Mikael Nolin. Component Based Software Engineering for Embedded Systems - A literature survey, MRTC Report 102, Mälardalen Real-Time Research Centre, Mälardalen University, June 2003. Number: ISSN 1404-3041 ISRN MDH-MRTC-102/2003-1-SE
- What are the needs for components in vehicular systems? - An industrial perspective. In Real-Time in Sweden (RTiS) Västerås, Sweden, August 2003. MRTC. Anders Möller, Joakim Fröberg, Mikael Nolin
- Software Component Technologies for Real-Time Systems - An Industrial Perspective. In WiP Session of Real-Time Systems Symposium (RTSS) Cancun, Mexico, December 2003. Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin
- MRTC-rapporten

Future plans:

During 2004 the evaluation of existing component technologies will be finalized. From the evaluation a suitable base for a component technology for heavy vehicles will be selected, and any modifications and/or extensions will be specified. The result should be a component technology that matches the requirements we have found.

RATAD Reliability And Timing Analysis of Distributed systems

Project leader: Hans Hansson
Members: Thomas Nolte
Christer Norström
Ralf Elvsén
Sasikumar Punnekkat

Partners: ABB Automation
Funding: ARTES, Internal

Project description:

Modeling and analysis are important tools in the development of safety critical real-time systems. The introduction of state-of-the-art analysis techniques in industry is however rather slow. One reason for this is the pessimism in models and analysis, e.g., schedulability analysis for realistic systems are typically based on simplifying assumptions which leads to pessimism that forces designers to make costly over-designs, dimensioning the system for worst-case situations that may never occur. At the same time, the over all system requirement is to satisfy a reliability measure of, say, at most 10-9 faults per hour.

This project proposes a reliability analysis method that considers the effects of faults and timing parameter distributions (including execution time distributions, jitter distributions, and sporadic task inter-arrival time distributions) on schedulability analysis. The goal is to provide designers with well-founded support that allow them to make trade-offs between timing guarantees and reliability.

Results and achievements in 2003:

In 2003 the main effort was in producing the Licentiate Thesis of Thomas Nolte. The 12th of May 2003 Thomas defended his thesis [1]. This thesis included both work on reducing the level of pessimism when calculating worst-case latencies of Controller Area Network (CAN) frames, and some work on server based scheduling for the CAN. The latter originated from mid 2002 when Thomas Nolte was visiting professor Kwei-Jay Lin at the University of California in Irvine.

For CAN, an improved stochastic analysis was presented in May [2]. Regarding server-based scheduling, some initial work was presented in mid summer [3] together with a full presentation in September [4]. Finally, the latest work-in-progress was presented in the beginning of December [5]. Here we are trying to provide a stochastic analysis for component-based real-time systems, as part of the SAVE project.

Publications:

- [1] Reducing Pessimism and Increasing Flexibility in the Controller Area Network, Thomas Nolte, Licentiate Thesis, Mälardalen University, May, 2003.
- [2] Probabilistic Worst-Case Response-Time Analysis for the Controller Area Network, Thomas Nolte, Hans Hansson, Christer Norström, In Ninth IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS 2003), IEEE Computer Society Press, Toronto, Canada, May, 2003.
- [3] Using Servers to Provide Bandwidth Isolation on the Controller Area Network, Thomas Nolte, Mikael Nolin, Hans Hansson, In 2nd International Workshop on Real-Time Lans in the Internet Age (RTLIA 2003) in conjunction with the 15th Euromicro International Conference on Real-Time Systems (ECRTS 2003), Polytechnic Institute of Porto, Portugal, June, 2003.
- [4] Server-Based Scheduling of the CAN Bus, Thomas Nolte, Mikael Nolin, Hans Hansson, In 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003), Calouste Gulbenkian Foundation, Lisbon, Portugal, September, 2003.
- [5] Using Components to Facilitate Stochastic Schedulability Analysis, Thomas Nolte, Anders Möller, Mikael Nolin, In Work-In-Progress Session of the 24th IEEE Real-Time Systems Symposium (RTSS'03), p 7-10, IEEE Computer Society, Cancun, Mexico, Editor(s):Tarek Abdelzaher, December, 2003.
- [6] Hans Hansson, Thomas Nolte, Christer Norström, and Sasikumar Punnekkat, Integrating Reliability and Timing Analysis of CAN-based Systems, IEEE Transaction on Industrial Electronics, 49(6), December 2002.

- [7] Thomas Nolte, Hans Hansson, Christer Norström, and Sasikumar Punnekkat. Using Bit-stuffing Distributions in CAN Analysis, IEEE/IEE Real- Time Embedded Systems Workshop (Satellite of the IEEE Real-Time Systems Symposium) London, December 2001
- [8] Thomas Nolte, Hans Hansson, and Christer Norström, Minimizing CAN Response Time Jitter by Message Manipulation, In Proc. 8th IEEE Real-Time and Embedded Technology and Applications Symposium, San Jose, CA, USA, September 2002.
- [9] Thomas Nolte, Hans Hansson, and Christer Norström, Probabilistic Worst- Case Response-Time Analysis for the Controller Area Network, Submitted, January 2003.
- [10] Thomas Nolte, Hans Hansson, and Mikael Sjödin, Efficient and Fair Scheduling of Periodic and Aperiodic Messages on CAN using EDF and Constant Bandwidth Servers, Technical Report , May 2002.
- [11] Thomas Nolte, Mikael Sjödin, and Hans Hansson, Server Based Scheduling of the CAN Bus, Ongoing, January 2003.
- [12] Thomas Nolte, and Kwei-Jay Lin, Distributed Real-Time System Design using CBS-based End-to-end Scheduling, In proceedings of the 9th IEEE International Conference on Parallel and Distributed Systems, Taipei, Taiwan, ROC, December 2002.

Future plans:

Thomas will continue his research within the SAVE programme with the work presented in [5].

EAST/EEA

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

Project description:

EAST/EEA is 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 Sjödin, is 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 is 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 is 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.

Results and achievements in 2002:

MRTC's and SAVE's involvement in EAST/EEA started in 2002. During the year we have participated in numerous working meeting with the other EAST/EEA partners. We have also delivered a set of document to EAST/EEA (see below).

Publications:

- Mikael Sjödin. Response-Time Analysis for Dynamically and Statically Scheduled Systems, MRTC Report 55, April 2002.

- Jukka Mäki-Turja, Mikael Sjödin. Combining Dynamic and Static Scheduling in Hard Real-Time Systems, MRTC Report 71, October 2002. (Submitted for publication)
- Jad El-khoury, Martin Törngren, De Jiu Chen. MetaH: summary based on published research papers, EAST/EEA internal report, October 2002.
- Jad El-khoury, De Jiu Chen, Martin Törngren. State of the art survey of modelling approaches for design of embedded control systems. Draft-report distributed to EAST in November 2002.
- Jad El-Khoury, Martin Törngren, De Jiu Chen. Linking "Simulink behaviour" the EAST ADL (Functional Design Architecture), EAST/EEA internal report, August 2002.

Future plans:

During 2003 the work within EAST/EEA will continue. Focus within the working groups where SAVE is active will shift towards the implementation issues and verification and validation aspects. Here MRTC and SAVE will contribute with their deep knowledge about analysis and verification techniques.

4.4 Theses

In 2003 SDL staff presented the following five Licentiate Theses:

- Thomas Nolte: Reducing Pessimism and Increasing Flexibility in the Controller Area Network
- Radu Dobrin: Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling
- Tomas Lennvall: Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems
- Anders Pettersson: Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time Systems
- Joel Huselius: Preparing for Replay

Below, these theses are presented in more detail.

Thomas Nolte, ***Reducing Pessimism and Increasing Flexibility in the Controller Area Network***

In May 2003 Thomas Nolte presented his Licentiate thesis

Reducing Pessimism and Increasing Flexibility in the Controller Area Network, Licentiate Thesis 10, Mälardalen University (MdH), May 2003.

Faculty opponent: Prof. Luís Almeida, University of Aveiro, 3810-193 Aveiro, Portugal.
Examiner: Prof. Mats Björkman, Mälardalen University.
Supervisor: Prof. Hans Hansson

Abstract:

The Controller Area Network (CAN) is a widely used real-time communication network for automotive and other embedded applications. As new applications continue to evolve, the complexity of distributed CAN based systems increase. However, CAN's maximum speed of 1 Mbps remains fixed, leading to performance bottlenecks. In order to make full use of this scarce bandwidth, methods for increasing the achievable utilisation are needed.

Traditionally, real-time scheduling theory has targeted hard real-time systems, which most of the time are safety critical. Since these systems (by definition) are not allowed to have any timing flaws, analysis techniques need to take all possible scenarios of execution combinations and execution times of the system into consideration. This will result in a system that is configured for the worst possible scenario. Whether this scenario is likely, or even possible, in the real system is not considered. Hence, the result may be an unnecessarily expensive system, with potentially overly provisioned resources.

In this thesis we address two issues. In the first part, we investigate how to loosen up pessimistic real-time analysis in a controlled way, thereby allowing the designer to make well-founded trade-offs between the level of real-time guarantee and the system cost. Specifically, we investigate and model the bit-stuffing mechanism in CAN in order to retrieve representative distributions of stuff-bits, which we then use in the response time analysis instead of the worst-case values normally used. We evaluate the validity of these stuff-bit distributions in two case studies, and we integrate this representation of message frame length with the classical CAN worst-case response-time analysis.

In the second part of the thesis, we propose a novel way of scheduling the CAN. By providing server-based scheduling, bandwidth isolation between users is guaranteed. This increases the flexibility of CAN, by providing efficient handling of sporadic and aperiodic message streams. Server-based scheduling also has the potential to allow higher network utilisation compared to CAN's native scheduling. The performance and properties of server-based scheduling of CAN is evaluated using simulation. Also, the server-based scheduling is applied in an end-to-end analysis.

Radu Dobrin, *Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling*

In May 2003 Radu Dobrin presented his licentiate thesis

Transformation Methods for Off-line Schedules to Attributes for Fixed Priority Scheduling, Technology Licentiate Thesis, Mälardalen University, May 2003.

Faculty opponent:	Prof. Petru Eles, Department of Computer and Information Science, Linköping University
Examiner:	Prof. Ivica Crnkovic
Supervisor:	Prof. Gerhard Fohler

Abstract:

Off-line scheduling and fixed priority scheduling (FPS) are often considered as complementing and incompatible paradigms. A number of industrial applications demand temporal properties (predictability, jitter constraints, end-to-end deadlines, etc.) that are typically achieved by using off-line scheduling. The rigid off-line scheduling schemes used, however, do not provide for flexibility.

FPS has been widely studied and used in a number of industrial applications, e.g., CAN bus, mostly due to its simple run-time scheduling and small overhead. It can provide more flexibility, but is limited with respect to predictability, as actual start and completion times of execution depend on run-time events.

In this work we show how off-line scheduling and FPS run-time scheduling can be combined to get the advantages of both -- the capability to cope with complex timing constraints while providing run-time flexibility.

The proposed approaches assume that a schedule for a set of tasks with complex constraints has been constructed off-line.

We present methods to analyze the off-line schedule and derive FPS attributes, e.g., priorities, offsets, and periods, such that the runtime FPS execution matches the off-line schedule. The basic idea is to analyze the schedule and to derive task attributes for fixed priority scheduling. In some cases, i.e., when the off-line schedule can not be expressed directly by FPS, we split tasks into instances to obtain a new task set with consistent task attributes. Furthermore, we provide a method to keep the number of newly generated artifact tasks minimal.

Finally, we apply the proposed method to schedule messages with complex constraints on the Controller Are Network (CAN).

Tomas Lennvall, ***Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems***

In May 2003 Tomas Lennvall presented a licentiate thesis

Tomas Lennvall: Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems, Licentiate Thesis, No 12, Mälardalen University, May 2003.
Faculty opponent: Dr. Giuseppe Lipari, Scuola Superiore S. Anna, Italy
Examiner: Prof. Ivica Crnkovic.
Supervisor: Prof. Gerhard Fohler

Abstract:

System designers face many choices when designing a real-time system. They have to decide how to deal with the original requirements imposed on the system, which operating system (OS), OS functionality, and scheduling algorithm. Ideally designers have a lot of freedom when choosing the most suitable configuration for the system. Unfortunately this is not the case in most present day situations.

Real-time applications impose complex constraints, such as precedence, end-to-end deadlines, jitter, and distribution, in addition to non-complex constraints, such as periods and deadlines. There might also be a need to handle on-line activities, such as aperiodic or sporadic tasks, or even to anticipate overload during run-time.

On-line scheduling provides flexibility and supports overload handling, but handling complex constraints can be costly or even intractable. On the other hand, off-line scheduling resolves complex constraints and provides determinism at the cost of flexibility. This disparity between scheduling paradigms forces designers to choose either flexibility or determinism.

OS kernels are usually monolithic, meaning that kernel functionality, dispatcher, and scheduling algorithms are usually intertwined to achieve higher performance, at the cost of limiting the designer's choice.

In this thesis we provide designers with some methods to alleviate these problems. We increase the flexibility in off-line scheduled systems by using the total bandwidth server (TBS) for aperiodic task handling. Furthermore we provide overload handling in off-line scheduled systems, which are handled in such a way that the original constraints are still met. Tasks can also be migrated from overloaded nodes to provide load balancing. We also propose a plug-in scheduling architecture where we disentangle the scheduling algorithm from the kernel routines providing for easy replacement of algorithm, as opposed to the monolithic kernels. This gives designers more flexibility in choosing the appropriate scheduling algorithm independently from the OS.

Anders Pettersson, ***Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time Systems***

In October 2003 Anders Pettersson presented his licentiate thesis

Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time Systems, Licentiate Thesis no 15, Mälardalen University, ISSN 1651-9256, ISBN 91-88834-13-1. October 2003.
Faculty opponent: Ph. D. Paul Pettersson, Uppsala University, Sweden
Examiner: Prof. Christer Norström.
Supervisors: Dr. Henrik Thane (actual) and Prof. Hans Hansson (formal)

Abstract:

An important issue in software testing is the ability to observe the execution of the software; this is especially true for real-time systems (RTS). RTS are difficult to observe, and the ability to test RTS is

inherently low. Embedded RTS have few interfaces for observation and the execution of multi-tasking RTS is usually non-deterministic. As a consequence, testing of RTS cannot be exercised with existing tools for sequential programs. New tools and methods are necessary that enable observation of the system despite few interfaces while at the same time address the non-determinism issue.

The contribution in this thesis is three-folded: (1) we present a tool suite that allows deterministic testing of multi-tasking RTS, in which synchronization of tasks is resolved off-line or on-line. (2) We show by building a test bed how to use the tool suite. (3) We present the design and functionality of Asterix the Real-Time Kernel.

In (1) we propose an analysis tool that derives all possible system level control-flow paths of multi-tasking RTS in which synchronization between communicating tasks are resolved on-line by using the Priority Ceiling Emulation Protocol (PCEP; also know as the Immediate Inheritance Protocol). The analysis tool is an extension of an existing tool in which synchronization were resolved off-line by using release time offsets or priorities to separate the tasks in time.

Based on the number of derived control-flow paths test coverage criteria are defined, and estimations of test effort can be done early in the development of a system. In (2) we show how the defined test coverage criteria relate to the number of traversed control-flow paths during test execution. We also show how the estimation of tasks' execution times affects the analysis. The analysis tool is applied on multi-tasking RTS in which the tasks are synchronized off-line. The real-time applications are then exercised on the test bed using Asterix as the operating system.

In (3) we present a small-sized real-time kernel named Asterix that has support for software based instrumentation of kernel events as well as application usage of system calls. The major problem of software instrumentation is the change in execution behavior that occurs when a RTS is executed without or without the probes. In Asterix we avoid this probe-effect by leaving the probes in the kernel during normal operation.

Also, a literature survey covering the state-of-the-art in the field real-time systems testing is presented.

Joel Huselius, ***Preparing for Replay***

In November 2003 Joel Huselius presented his licentiate thesis

Preparing for Replay, Licentiate Thesis no 16, Mälardalen University, ISSN 1651-9256, and ISBN 91-88834-15-8. November 2003.

Faculty opponent:	Prof. Peter Fritzson, University of Linköping, Sweden
Examiner:	Prof. Mats Björkman.
Supervisors:	Dr. Henrik Thane (actual) and Prof. Hans Hansson (formal)

Abstract:

Cyclic debugging is the process normally used for examining and removing bugs in computer systems. For this process, the possibility to deterministically repeat an execution is a requirement - without repeatable experiments, it is not certain that existing bugs can be located. Thus, in order to debug real-time systems, which normally do not allow repeatable experiments, additional methods are needed to provide repeatability. Several solutions based on a resource demanding record/replay approach have been proposed: By recording data describing the occurrences of non-deterministic events during a reference execution, and then using this data to force a consecutive replay execution to perform in the same way as the reference, repeatability in experiments is achieved.

We adhere to the previous work on deterministic replay by Thane et al. The method assumes that memory resources have limited capacity compared to the amount of data recorded. This assumption leads to that data available after the completion of the reference execution does not cover the reference execution in its entirety, wherefore replay must be started from a state which is not the initial state of the system. To facilitate this, at predefined locations in the code, checkpoints are taken of the

individual task-states. In order to reduce the overhead imposed on the system, checkpoints are not required to be exhaustive, only to cover the parts of the data-space with non-deterministic properties.

The combination of these factors leads to an environment that requires new methods for initiating replay - one of the contributions of this thesis is such a method. By treating each task in the system independently, we show (by means of an industrial case-study) that a restarted version of the system can be made to look like the reference execution.

In order to guarantee that a replay execution can always be performed, the addition of this new method triggers the requirement of new dynamic methods for managing data during recording. The second contribution of this thesis is a dynamic memory manager that fills this gap and is also shown to improve memory utilization in sporadic real-time systems.

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
- Siemens Business Systems, Germany
- 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, Sweden 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, is programme director for the national real-time systems research initiative ARTES, co-ordinates the national research initiative SAVE, and is visiting professor at Uppsala University. 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 previously 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 to the industry. Among the products provided are the unique TimeMACHINE debugger and Black-Box recorders for embedded systems, but also design and analysis tools for distributed automotive applications. ZealCore provides professional services in terms of consulting and education in the safety-critical real-time area.

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 a researcher and project leader. 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.

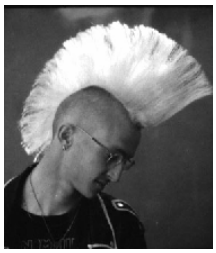
Adam Dunkels is a researcher at the Swedish Institute of Computer Science (SICS) since 2000 and a PhD student at SDL since 2002. He published his MSc thesis in 2000 after three years of undergraduate studies at Luleå University of Technology. His current research interests include lightweight communication 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.

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 Jonsson is a Ph.D. student at SDL. His research deals with measurement and analysis of available bandwidth in best effort networks. He received a M.Sc. from Uppsala University, 2002.

Tomas Lennvall is a postgraduate student at SDL. He received his Master of Science in Computer Engineering from Mälardalen University in 2000. His research interests are heterogeneous systems, evolution of real-time systems, and multimedia.

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.

Jonas Neander is a CUGS Ph.D. student at SDL. His current research interests are communication support for small embedded devices.

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. His current research interests are reliability and timing analysis of distributed systems, especially issues regarding stochastic solutions for real-time systems and communications. He 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 University of California, Irvine (UCI). At Mälardalen University (MdH), he is the PhD representative (doktorandombud) of the University since September 2003. Moreover, he is the MSc/BSc Thesis Coordinator at the Department of Computer Science and Engineering (IDt). Prior to becoming Ph.D. student, he has been an undergraduate student at IDt since 1997. He is a Student Member of IEEE.

Anders Pettersson is a Ph.D. Student at Department of Computer Science and Engineering (IDt) 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 of multi-tasking real-time system. Anders main contribution in the thesis is an extension of a method for analysis of real-time 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 monitoring and debugging. He also has about a year of industrial experience of software engineering in this field. He gives courses in Operating Systems at Mälardalen University.

Larisa Rizvanovic is working as a research engineer at the SDL. She received an MSc in Computer Engineering from Mälardalen University in 2001.

Ylva Boivie is research co-ordinator at MRTC. She received her MSc in Mechanical Engineering at the Royal Institute of Technology in Stockholm in

1990, 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 2001:

- Gerhard Fohler and Hans Hansson participated (together with Ivica Crnkovic, CSL) 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 planning for a continuation of ARTIST as a Network of Excellence in the 6th Framework Programme was initiatiated.

Mats Björkman is

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

Gerhard Fohler

- coordinated the planning of the European IST project FIRST – Flexible real-time systems technology; partners University of York, UK, University of Cantabria, Spain, Scuola S. Anna, Italy. FIRST was positively evaluated
- partner in EU IST project FABRIC - Federated Applications Based on Real-time Interacting Components Architecture for a ubiquitous computing platform, EU IST Project, partners including Philips Research, TNO, Thomson Multimedia
- partner in ARTIST: European Union, IST Accompanying Measure on Real-Time Computer Systems, action line adaptive real-time systems
- was involved in 4 proposals to EU 6th framework programmes (1 Network of Excellence, 3 STREPS)

Hans Hansson

- is leading a national effort for continued funding of Real-Time research in Sweden. All senior researchers at SDL and researchers from all groups with real-time research in Sweden are participating in this effort. This effort, resulted in a 7 MSEK grant to support newly recruited graduate students with courses, mobility, etc.
- 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 an effort to obtain support from KKS for an industrial graduate school in association with the SAVE-programme. The school – SAVE-IT – received a 20.8 MSEK grant drom KKS, and includes co-operation with LiU, KTH, and UU.
- is participating in a European consortium, REWIND, that applied for funding from EU for a project aiminf at developing an integrated system and components for the communication and co-ordination of rescuing teams responding in the field to disaster situations. Partners in REWIND include Siemens Business Services, University of Catania, Universiy of Messina, Paderborn University, Institute of Computer Technology, TU Wien, Eptron SA, Fundación Robotiker, Temix s.r.l., Polytechnic Institute of Porto, Ente Parco dell'Etna EP, FREQUENTIS Nachrichtentechnik Ges.m.b.H., Austria FRQ, and Direccion de Proteccion Civil y Bomberos del Ayuntamiento de Bilbao, Spain.
- has established co-operation with Universitat de les Illes Balears (Guillermo Rodriguez-Navas, Julian Proenza Arenas)

Henrik Thane

- collaborated in a research Project together with Professor Vincent Mooney from Georgia Institute of Technology, USA. Resulted in one Conference publication at The Real-Time Systems Symposium in Cancun December 2003.
- Initiated research collaboration with ABB Corporate research, Bombardier Transportation, and Level 21. Resulted in a research grant from KK foundation as well as funding from the industry in total exceeding 9 million SKr.
- Initiated research collaboration with the University of Skövde in the field of testing real-time systems, Robert Nilsson.
- Performed a research case study together with SAAB Avionics, military radar systems.

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

- Peter Altenbernd, C-Lab, Paderborn Germany
- Giorgio Buttazzo: Scuola Superiore S.Anna, Pisa, 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
- Alexandre David, 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.

A number of international scientists have visited SDL, including,

- Dr Peter Altenbernd, C-Lab in Paderborn, Germany
- Krithi Ramamritham, IIT Mumbay, India

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 2002:

Mats Björkman

- is scientific evaluator for the KK foundation.
- was on the grading committee at two PhD dissertations.
- was opponent at one PhD dissertation.
- was "opponent" at two litentiate presentations.
- was PC member, WFCS 2003.
- is scientific advisor for a media technology educational program, Blekinge tekniska högskola.
- was reviewer for ACM/IEEE Transactions on Networking, and 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 co-program chair of the 1st Workshop on Embedded Systems for Real-Time Multimedia (ESTIMEDIA)
- was on the programme committees for the IEEE Real-Time Systems Symposium (RTSS), Euromicro Conference on Real-time Systems (ECRTS), IEEE Real-time Technology and Applications Symposim (RTAS), Workshop on Parallel and Distributed Real-Time Systems (WPDRTS), IEEE International Symposium on Object-oriented Real-time Distributed Computing (ISORC), International Workshop on Synchronous Languages, Applications, and Programming (SLAP), International Workshop on Test and Analysis of Component Based Systems (TACOS), Latin American Symposium on Dependable Computing (LADC), Design, Automation and Test in Europe (DATE), 2004, Topic: Design methods for emerging technologies and applications
- was opponent to the Licentiate thesis of Sorin Manolache, LiTH

Hans Hansson

- was appointed associate editor of Kluwer's Journal of Real-Time Systems
- is Programme Director for the national research programme ARTES and visiting professor at Uppsala University.
- has been supervising the following graduate students completing theses during 2002:
- Andreas Ermedahl (PhD), UU
- Thomas Nolte (Lic), MdH
- Anders Pettersson (Lic; jointly with Henrik Thane), MdH
- Joel Huselius (Lic; jointly with Henrik Thane), MdH
- 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 three PhD dissertations (Ola Redell KTH, Kristina Forsberg CTH, and Paul Pop LiTH)
- was/is scientific evaluator of the EU Fifth Framework Project NEXT-TTA
- was external evaluator of project proposals for a European national research programme
- was together with Sang Lyul Min (Korea) organising The European Summer School on embedded systems (ESSES), a three months graduate summer school on Low-Power, Embedded and Real-Time systems organised in Västerås July-October 2003.
- was/is on the programme committees for EMSOFT 2003 - Third International Conference on Embedded Software, Euromicro Conference on Real-Time Systems; FeT 2003 - 5th IFAC International Conference on Fieldbus Systems and their Applications; WPDRTS'2003 - The 11th International Workshop on Parallel and Distributed Real-Time Systems; Real-Time in Sweden - RTiS 2003; Euromicro Conference on Real-Time systems 2003; 7th International Conference on Principles of Distributed Systems OPODIS-2003; 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
- was external evaluator for the appointment of one Professor at Halmstad University.

4.9 Interactions with Society

The members of SDL are interacting with society in several ways, in 2002 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.
- was member of the board at MdH 1998-2003.

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.
- Took part in Tekniska Mässan as an exhibitor.
- An extensive Case Study at ABB Robotics was performed (encompassing almost one man year) in order to validate the results in the TATOO project.

Zealcore Embedded Solutions AB, a spin-off company established in 2001, got its first major order of 5000 RealTimeMachines, based on the debugging technology developed in the Tatoo project.

5 The Computer Architecture Laboratory (CAL)

Lab leader: Lars Asplund

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 a new initiative where the laboratory in cooperation with other departments, industry and society – to establish an internationally recognised activity in robotics. This activity cover undergraduate, graduate education and research. The research in this initiative is for this group based on current research in the laboratory, 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 one 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 / laboratory assistants.

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:

- **Assembly language programming, 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.
- **System 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.
- **Advanced computer architecture, 5p**: The course focuses on advanced issues in modern microprocessors, such as caches, pipelines, branch prediction, superscalars, multithreading, etc.

- **System architecture II, 5 p**: This course builds on the knowledge from previous courses. The course is on a higher level of abstraction and includes aspects as interconnects, device drivers, and the hardware / software interface.
- **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). The length of the course I doubled, giving enough time to finish quite big 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
- **Computers in Products 5p**. The course is given for students that do not have computer science 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 new ways for using computers in the future. The students will also be shown how companies' way of working and organisation is influenced by new technology.
- **Multiprocessor systems, 5p**. The focus of the course in on parallel computer architectures and how to program these machines efficiently.
- **ASIC Design, 5p**. The course gives the knowledge necessary to design Integrated Circuits. The students learn how to use design tools and how to take a Hardware Design Language design all the way down to verified layout. Great emphasis is put on testability issues.

The group has planned an International Master program in Robotics, that will take its first start in 2004.

The group has initiated a new engineering program ('civilingenjörsprogram') in Robotics, which also start fall 2004.

Also, CAL is 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.

5.3 Research

The research at CAL is organised in two main areas with a bais on System-on-Chip solutions for image analysis and graphics rendering

- 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 Astor 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 (http://www.mrtc.mdh.se/cal/sara/)
Partners: ABB
ERICSSON
Georgia Institute of Technology, USA

	MENTOR GRAFICS
	XILINX
	Altera
	KTH
	RealFast
Project members	Lennart Lindh
	Peter Nygren
	Mohammed El Shobaki
	Leif Enblom
	Raimo Haukilahti
	Stefan Sjöholm
	Andreas Löfgren
	Stefan Stjernen

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.

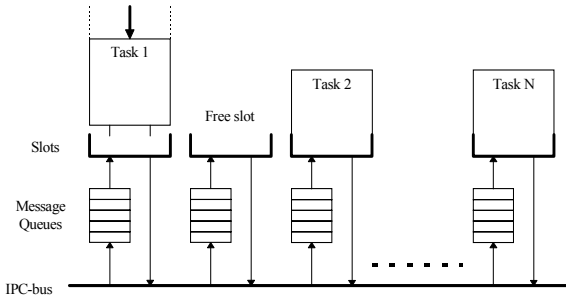
RTU - a class in the base system

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:

1. One slot is allocated to one processor
2. One slot is allocated to two or more processors, which means it is scheduled between the processors.

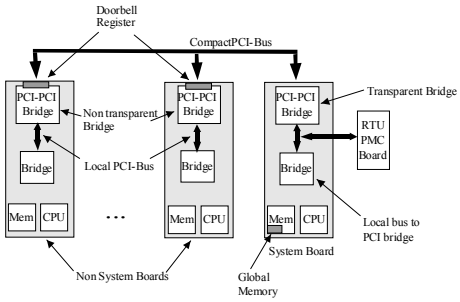


The IPC bus model.

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.

Hardware Architecture

The hardware platform in the SARA- system is a Compact PCI (cPCI) system with eight slots that can hold CPU-boards. The RTU is implemented on a PMC Board.



Block diagram of SARA-System and Picture of a RTU-PMC board

Some key features of the SARA system:

- One HW-RTOS can serve 1-8 heterogeneous CPU/DSP-boards
- A thin layer interface for the HW-RTOS (less than 50 lines of C-code per system-call)
- The system is transparent to the application
- Inter-Process Communication managed by a Virtual Communication Bus (VCB)
- GNU development tools; gcc, gdb with the ddd graphical interface, etc.
- Integration with Linux

Results and achievements

The main result spring 2003 was a prototype of the SARA system in different ways. The next step is to build a base system of SARA on SOC (implemented on a FPGA).

Courses:

- **Distributed Real Time System Project** - This is a project course where 25 students complete a project with a complete system and that is divided in to subprojects. Each sub project has its own group with a project leader. The course ends with an integration part and a presentation where people from the industry are invited. This year's project was a tic-tac-toe ("tramp chess") playing robot. The multiprocessor system SARA was used as a control system.
- **Development of an ASIC Design, 5p**. The course gives the knowledge necessary to design Integrated Circuits. The students learn how to use design tools and how to take a Hardware Design Language design all the way down to verified layout. Great emphasis is put on testability issues.
- **Component Based Design of One-Chip Systems, 5,0 P**. New tools to design a base platforms for one-chip solutions. The course is a state of art.

Examinations 2003:

Licentiate theses by Leif Enblom

Publications 2003:

- Analysis of replacing software-based systems with FPGA and a case study on a digital output IO-board, Stefan Sjöholm, Euromicro Symposium on Digital System Design '03, 1-6 September 2003, Belek, Turkey.
- VHDL För Konstruktion", Stefan Sjöholm, Lennart Lindh, Studentlitteratur, 2003, 503 sidor, ISBN 91-44-02471-1
- VHDL- En Introduktion", Stefan Sjöholm, Lennart Lindh , Studentlitteratur, 2003, 138 sidor, ISBN 91-44-02932-2
- Leif Enblom, "Parallel Execution of I/O System and Application Functionality", International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA2003), CSREA Press, Las Vegas, USA, June 2003.
- Leif Enblom, "Utilizing Concurrency To Gain Performance in an Industrial Automation System", ISBN 91-88834-21-2, Licentiate Thesis, Mälardalen University Press, Presented November 2003.
- Zhonghai Lu, Raimo Haukilahti: NoC Application Programming Interfaces. Networks on Chip, eds. Axel Jantsch and Hannu Tenhunen, pp. 239-260, 2003. Kluwer Academic Publishers
- Jaehwan Lee, Vincent John Mooney III, Karl Ingström, Anders Daleby, Tommy Klevin and Lennart Lindh, A Comparison of the RTU Hardware RTOS with a Hardware/Software RTOS, ASP-DAC 2003 (Asia and South Pacific Design Automation Conference 2003), pp. 6, 2003, Kitakyushu International Conference Center, Japan
- T. Samuelsson, M. Åkerholm, P. Nygren, J. Stärner, L. Lindh, "A Comparison of Multiprocessor Real-Time Operating Systems Implemented in Hardware and Software", International Workshop on Advanced Real-Time Operating System Services (ARTOSS), 2003, Porto, Portugal
- P. Nygren, L. Lindh, "Uniform Interprocess Communication interface for Hardware and", International Workshop on Advanced Real-Time Operating System Services (ARTOSS), 2003, Porto, Portugal
- Andreas Löfgren, Filip Traugott, Kim Andersson, Lennart Lindh, "Successful Prototyping of a Real-Time Hardware Based Terrain Navigation Correlator Algorithm", Euromicro symposium on Digital System Design, Belek, Turkey, September 2003.

Workshop

Organized two "Intellectual Property Based FPGA SOC Design" workshop in Västerås. The workshop provides a link between the research group and in 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. For more information see www.idt.mdh.se/ipis.

Subprojects

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

Hardware Software Co-design

Project members Peter Nygren
Lennart Lindh (supervisor)

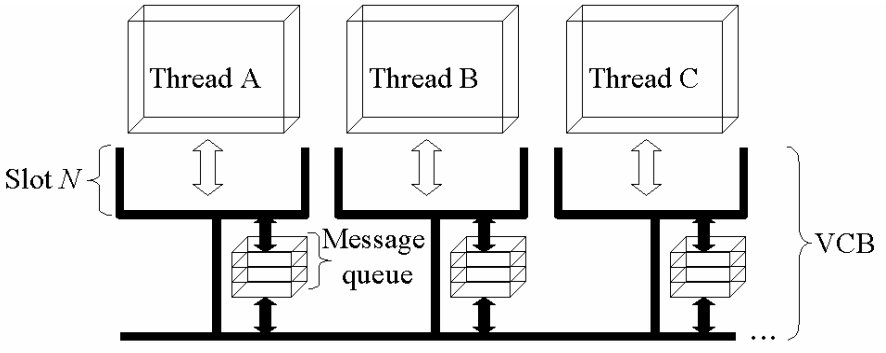
Project description

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.

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).



The VCB-API contains the system calls

- Init
- Connect
- Disconnect
- Send
- Receive
- Broadcast
- Send wait

System architecture

The today's system architecture includes a software processor kernel CPU from Xilinx, which runs the different software threads. One real time unit, an 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.

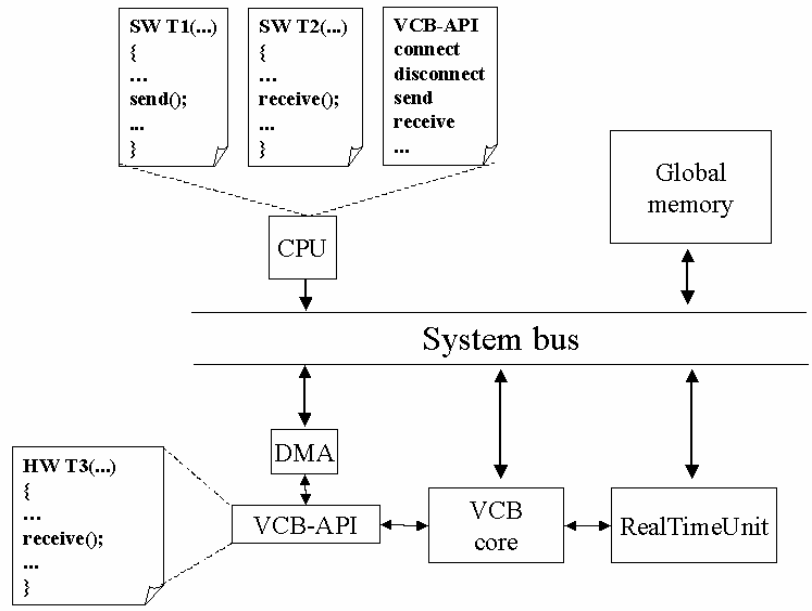


Figure 2 Hardware and Software architecture

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

- P. Nygren, L. Lindh, "Uniform Interprocess Communication interface for Hardware and", International Workshop on Advanced Real-Time Operating System Services (ARTOSS), 2003, Porto, Portugal

Future plans

As a result of the project, one Licentiate thesis is planned during 2004.

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 timestamped 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.

Contributions

The main contributions of this work are the ideas on system-level monitoring of hardware RTKs, on-chip rather than by probing external processor busses. We believe that on-chip monitoring support will be required in future development of real-time systems, especially those based on SoCs.

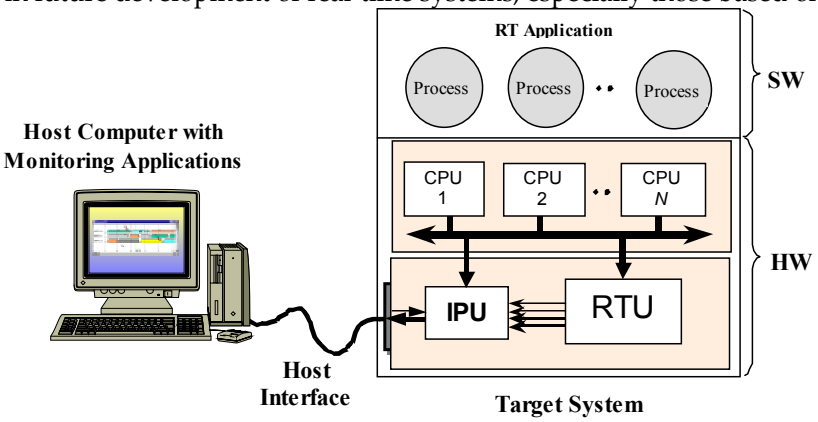


Figure: Overview of MAMon

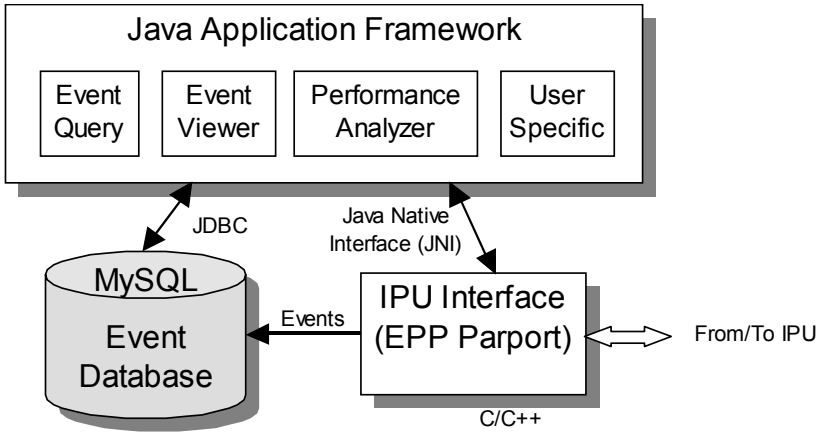


Figure: Monitoring Application Environment on the Host

Industrial co-operation

We have a strong co-operation with two industrial partners; RFO RealFast Operating 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.

Future plans

As a result of the MAMon-project, one Licentiate thesis is planned during 2004, and at least two Master theses. Other planned developments are the following:

- Integrate the knowledge and Mamon in the cource Component Based Design of One-Chip Systems, 5,0 Points.
- Assist our industrial partner (RFO AB) in the development and commercialisation of MAMon.

Multiprocessor Data-Driven Real-Time Systems

Project members Leif Enblom
Lennart Lindh (supervisor)

Project description

Demands on industrial systems are growing from year to year. The systems are required to respond and act to a growing number of events, and/or are required to perform an increasing volume of calculations. This project has been focused on achieving more performance for an industrial real-time control system. The real-time control system is used to protect electrical power stations from being destroyed by strokes of lightning. Sensors in the system continuously collect information on currents and voltages from the electrical power station which the control system protects. The sensors deliver the collected data to a computer system that bases its decisions on the arriving data. When a dangerous situation is detected circuit breakers decouple the hazardous power line.

Today, the computer system is based on a single processor architecture. The problem is that this architecture does not provide enough performance to support demanding system configurations such as more advanced application algorithms and increased amount of data collected from the sensors. In order to obtain correct, timely execution of the protection applications, designers may need to optimize application code aggressively. Unwanted simplifications of algorithms or low sampling frequencies of sensor data may be the result.

The motivation for this project is to study how the real-time control system is affected by being adapted to a multiprocessor or distributed architecture in order to increase the available computing resources. The objective is to improve the performance of system components in general and application components in particular.

By identifying components in the existing control system that exhibit a large amount of concurrency and a relatively small amount of data exchange the study found a performance improving solution. The I/O system that is responsible for collecting sensor data and the application functionality both exhibit a large amount of mutual concurrency and may therefore scale on a system with multiple processors. In experimental configurations the I/O system components and an application model were arranged to execute in parallel on two processors. This approach exploits the concurrency available at the interface between the I/O system and application components.

While parallel architectures are used in some industrial systems, not much has been written about the possibilities and threats when legacy systems are adapted to such architectures. By describing a model of an industrial real-time control system and extending that model with a mechanism that enables multiprocessor execution, we have contributed to the understanding of both the functional composition and performance issues concerning parallel execution in such industrial systems.

Results and achievements in 2003

The results of a case-study where a data-driven I/O system has been investigated for use in a multiprocessor environment, was presented at the PDPTA´03 conference in Las Vegas. The figures below show how the I/O system and the application have been divided onto two separate processor boards. Results from measurements show that processing resources (up to 66% when compared with a single processor system configuration) can be freed for application components by utilizing this concurrency in a two processor configuration.

A picture of the experimental setup.

System structure of the experimental setup.

During the year of 2003 Leif has completed all necessary requirements for a licentiate degree.

Publications

- Leif Enblom, Lennart Lindh, "Adding Flexibility and Real-Time Performance by Adapting a Single Processor Industrial Application to a Multiprocessor Platform", Proceedings of the ninth Euromicro Workshop on Parallel and Distributed Processing, February 2001.
- Leif Enblom, "Parallel Execution of I/O System and Application Functionality", International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA2003), CSREA Press, Las Vegas, USA, June 2003.
- Leif Enblom, "Utilizing Concurrency To Gain Performance in an Industrial Automation System", ISBN 91-88834-21-2, Licentiate Thesis, Mälardalen University Press, Presented November 2003.

Future plans

This research subproject within SARA has ended and resulted in two papers presented at international conferences, two technical reports, and one licentiate thesis. No immediate plans for a continuation of the project exist. Ideas for future work do however exist in the field of middleware architectures for multiprocessor real-time systems. Focus would then be on utilizing middleware functionality (such as for example correlation activities) in order to increase performance and predictability for real-time systems.

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. The project is expected to result in a licentiate thesis during 2004.

Results and achievements in 2003

- Zhonghai Lu, Raimo Haukilahti: NoC Application Programming Interfaces. Networks on Chip, eds. Axel Jantsch and Hannu Tenhunen, pp. 239-260, 2003. Kluwer Academic Publishers

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.

Future plans

As a result of the project, one Licentiate thesis is planned during 2004.

Replaced by 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).

First a SOTA of replacing software running on processors with an FPGA will be made. Thereafter several case studies will be presented within the subject. The goal of the case studies is to show how an uP can be replaced by an FPGA in differnt IO-boards 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 behavioral controller. The behavioral controller is a design technique to be used when replacing uP with FPGA. The behavioral 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 2003

"Analysis of replacing software-based systems with FPGA and acase study on a digital output IO-board", Stefan Sjöholm, Euromicro Symposium on Digital System Design '03, 1-6 September 2003, Belek, Turkey.

"VHDL För Konstruktion", Stefan Sjöholm, Lennart Lindh, Studentlitteratur, 503 sidor, ISBN 91-44-02471-1

"VHDL- En Introduktion", Stefan Sjöholm, Lennart Lindh , Studentlitteratur, 138 sidor, ISBN 91-44-02932-2

System-on-Programmable-Chip

Project members - Andreas Löfgren
Lennart Lindh (supervisor)

Research Summary

Has recently initiated his research in the area of System-on-Programmable-Chip and how to design and reuse Intellectual Property components in programmable logic. Focus will be 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 2003

- Andreas Löfgren, Filip Traugott, Kim Andersson, Lennart Lindh, "Successful Prototyping of a Real-Time Hardware Based Terrain Navigation Correlator Algorithm", Euromicro symposium on Digital System Design, Belek, Turkey, September 2003.

5.3.2 Safety-Critical Systems group

Project leader: Lars Asplund
Project members: Joakim Adomat
Johan Furunäs
Gustaf Naeser

The SafetyChip project is a co-operation between Mälardalen University and MIT in Boston for developing safety critical systems at the highest degree of safety level. The suit of tools that are going to be developed starts with a tool that can generate a formal model from written code. The formal model that is to be specified is not intended to be used for direct verification. It is, however, very important that the model is highly readable by all programmers. The generation of the formal model is automatic, but to ensure the correctness of the transformation, human interaction is required. The model generated is later used to generate input to several model checkers such as UPPAAL and Kronos. This transformation from our own model to the various model checkers is all-automatic and does not require any human interaction. The correctness of this transformation is by means of diversity in the transformation to several different model checkers. The same is also true for the guarantee that the model checkers are dependable. All verification should pass at least three different model checkers.

The model of the application described in our own model is also the basis for the generation of the SafetyChip. The SafetyChip is a device that monitors the execution of an instrumented program. The instrumentation will most probably be performed in a Run-Time Kernel, implemented in hardware.

The project has been defined as 10 work packages, presented below:

1. **Tool for VHDL translation into Automata** (this part of the project is placed at MIT)
   A project with the goal to make automatic transformations from VHDL into a common model has been carried out at MIT. The intermediate format is from the VHDL translation tool is at the moment directly translated into UPPAAL automata.
2. **Tool for Ada-95 translation into Automata** (this part of the project is placed at MRTC)
   Transformation of Ada is by means of ASIS (Ada Semantics Interface Specification) has been carried out at MdH. 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. However, intermediate code, which shows the control structure of the source code can also be generated.
3. **Semantics** (MRTC)
   Identify typical behaviour of a Real-Time System. A formalism such as UPPAAL cannot directly handle preemption, utilizing the fact that for a each CPU there is only one process at a time. In the new model there will be a special notion of priority and process identification. The handling of BCET and WCET is also important in the verification of a complete Ada system, and the gurkh-model will handle this.
4. **Readability/GUI** (MIT)
   Based on previous studies of the user perception and readability of different syntax for expressing automata (or circuits), i.e. graphs, logic gates, and/or tables, text, this work-package will investigate the user perception of the gurkh-language.
5. **Translation into UPPAAL-syntax, read/understand results** (MRTC)
   The gurkh-language is intermediate code (or notation) that is later used as a basis both for generating VHDL-code for the SafetyChip (see below) and for generating input to one or several model checkers (preferable timed automata).

A tool/interface should be designed such that the gurkh-language can be translated into model-checker syntax and the output from the model checker should be read back to the tool. If several model checkers are used the tools should compare the various outputs, and note if any of the model checkers give a different answer.

In case of a negative result (i.e. from all model checkers) the user can either follow the trace in the gurkh-formalism or go into one of the model checkers (one of the users favourite).

In case there is a discrepancy between the outputs of the model checkers a warning flag should be raised, and this can come from either an error in one of the model checkers or an error in one of the translators.

A general tool is to be created, but this project should give all necessary information about the necessary steps and related problems in a translation.

6. **Translator from our model into any Model Checker-syntax based on a description of the Model Checker** (MIT)

   The tool for translation to various UPPAAL will be used for generalizing to a translator-generator for various model checkers. For each model checker that is to be connected there has to be a translator. This project aims at a tool for creating these translators, in the same way as gcc can be created from a description of a target machine and its operating system.

   The project requires a formalism for expressing the functionality of a model checker, both in terms of semantics and in term of syntax. The formalism can very well be based on properties in the gurkh-language.

7. **A new dedicated model checker** (MIT)

   In the approach we rely on existing or from other research groups defined model checker. It is, however, possible to define a new model checker that is directly based on the gurkh-formalism.

   This project is, in some sense, outside the scope of both research groups, and cooperation with a student from the Computer Science department at MIT.

8. **Generation of code for the SafetyChip (**MRTC)

   The gurkh-formalism 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. **Run-Time Kernel in VHDL** (MRTC)

   An important aspect is the actual implementation. 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 natural step is the Socrates-project mentioned above.

   A first prototype of a kernel has been run on the FPGA.

10. **SafetyChip in VHDL** (MRTC)

    The SafetyChip is a hardware unit with built in timers that monitor all clocks given in the formalism used to describe the application. From the RTK, hardware signals are sent out to the SafetyChip at each transition. An identity is used to differ from the possible signals that can occur in each situation. 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.

Hardware platform

The project has developed a hardware platform based on one of the latest chips from Xilinx(it has an integrated PowerPC and a large area of FPGA). The platform contains this new chip (as a donation from Xilinx we have received 16 circuits) 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 in the future. Not only will this platform be used in the gurkh-project, but it will also be the main processor for the new robots – the Aros Robot – that are being developed at MRTC.

Publications

- K Lundqvist and L Asplund, "A Ravenscar-Compliant Run-time Kernel for Safety-Critical Systems", Journal of Real-Time Systems, 24, 29-54, 2003
- L Asplund and K Lundqvist," The Gurkh Project: A Framework for Verification and Execution of Mission Critical Applications",22nd Digital Avionics Systems Conference 12-16 October 2003, Indianapolis.
- Johan Andrén-Dinerf, Lars Asplund, et al."ChipVision A Vision System for Robots Based on Reconfigurable Hardware", RoboCup International Symposium 2003, Padua Italy

5.4 Theses

One licentiate theses was presented in 2003 by CAL researchers:

Leif Enblom, *Utilizing Concurrency to Gain Performance in an Industrial Automation System*

This work presents and discusses the results from a study, focused on achieving more performance for an industrial real-time control system. The real-time control system is used to protect electrical power stations from being destroyed by strokes of lightning. Sensors in the system continuously collect information on currents and voltages from the electrical power station which the control system protects. The sensors deliver the collected data to a computer system that bases its decisions on the arriving data. When a dangerous situation is detected circuit breakers decouple the hazardous power line.

Today, the computer system is based on a single processor architecture. The problem is that this architecture does not provide enough performance to support demanding system configurations such as more advanced application algorithms and increased amount of data collected from the sensors. In order to obtain correct, timely execution of the protection applications, designers may need to optimize application code aggressively. Unwanted simplifications of algorithms or low sampling frequencies of sensor data may be the result.

The motivation of this work is to study how the real-time control system is affected by being adapted to a multiprocessor or distributed architecture in order to increase the available computing resources. The objective is to improve the performance of system components in general and application components in particular. By identifying components in the existing control system that exhibit a large amount of concurrency and a relatively small amount of data exchange the study found a performance improving solution. The I/O system that is responsible for collecting sensor data and the application functionality both exhibit a large amount of mutual concurrency and may therefore scale on a system with multiple processors. In experimental configurations the I/O system components and an application model were arranged to execute in parallel on two processors. This approach exploits the concurrency available at the interface between the I/O system and application components. Results from measurements show that processing resources (up to 66% when compared with a single processor system configuration) can be freed for application components by utilizing this concurrency in a two processor configuration. The advantage gained is an increase in flexibility for application designers to select a multiprocessor system configuration for demanding applications.

While parallel architectures are used in some industrial systems, not much has been written about the possibilities and threats when legacy systems are adapted to such architectures. By describing a model of an industrial real-time control system and extending that model with a mechanism that enables multiprocessor execution, we contribute to the understanding of both the functional composition and performance issues concerning parallel execution in such industrial systems.

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:

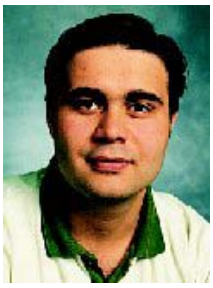
- ABB Automation Products (1996-, 1999-) – supports two industrial Ph.D. student
- Ericsson Radio Systems AB (1999-) – supports one industrial Ph.D. student
- Protang AB (1999-) – supports one industrial Ph.D. student
- XILINX (1998-) – supports hardware circuits
- ABB Robotics (1997-) – provides industrial 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.

Stefan Boegård is a lecturer at CAL, whose latest course was assembly language programming given last fall. He received his MSc in Electrical Engineering at LTH in 1970. He has been working at MdH since May 2000, and before that in industry, starting 1970 with ABB/ASEA for some years, then mostly with RemaControl AB interrupted for some years with CelsiusTech in Järfälla.



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.

Leif Enblom is an industrial Ph.D. student and received his Bachelor of Science in Computer Engineering from Mälardalen University, Sweden (2000). His research is targeted at industrial real-time applications and systems, and their suitability for multiprocessor platforms. The research is conducted in corporation with ABB Automation Systems, Västerås, where the case studies are performed.

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 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 in computer architecture and a postgraduate student. He received his bachelor of science in applied computer engineering (1995). His research interest is in cache memories in real time systems and is currently working on a licentiate thesis on cache related pre-emption delay.

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.

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 project 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)
- 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
- Reviewer of 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 2004 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 the initiative of creating the innovation system, Robotdalen.

6 Nat'l Grad Schools, Lic School and MSc pgms

In this section, four special educational programmes with strong relations to the MRTC research are presented.

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 Växsjö 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)

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 2004:

- Johan Andersson
- Johan Fredriksson
- Kaj Hänninen
- Andreas Johnsson
- Anders Möller
- Larisa Rizvonovic
- Mikael Åkerholm

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++.

The Industrial Licentiate School

The purpose of the industrial licentiate school is education of industry-researchers, i.e., technical specialists with excellent abilities to formulate, develop and critically evaluate technical solutions to industrial problems. Academically, the goal is to complete a licentiate exam. The licentiate programme comprises 30 credit points (weeks) of coursework and a 50 points thesis project. The projects are typically performed in close co-operation with associated industries; which in many cases coincide with the student's employer. Students lacking industrial experience will spend some time in industry and all students will be offered visits to international industrial or academic research groups. The obligatory courses of the school are Research Project, Planning and Research Methodology for Computer Science and Engineering. The students can select other courses according to their research area.

- Students admitted to the industrial licentiate school in 2003:
    - Stig Larsson, ABB Research
    - Mikael Åkerholm, MdH
    - Johan Fredriksson, MdH
    - Mathias Ekhman, Bombardier
- Students admitted to the industrial licentiate school in 2002:
    - Goran Mustapic, ABB Robotics
    - Daniel Sundmark , MdH
    - Jonas Neander , MdH
    - Johan Andersson, ABB Robotics
- Students admitted to the school in 2001 and continued in 2002:
    - Joel Huselius, MdH
    - Rikard Land, MdH
    - Rikard Lindell, MdH
    - Markus Nilsson, SMID AB
    - Andreas Sjögren, MdH
    - Mikael Sollenborn, MdH
    - Christina Wallin, ABB CRC
- The following students have completed their Licenceate degree:
    - Joel Huselius, MdH
    - Rikard Land, MdH
    - Christina Wallin, ABB CRC

The MSc programme in Real-Time systems

The *magister* year in real-time systems is a one-year program for special education of students towards research in real-time systems. Closely connected to the department real-time research, the students receive special guidance to be well prepared for research in scientific and industrial environments.

The MSc students in RTS 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. They range from software

solutions to hardware implementations, mathematical and safety critical analysis of complete real-time systems.

- CT3090 - Scientific Methodology (B-level), 5p
- CT1570 - Advanced Real-Time Systems (D-level), 5p
- CT3160 - Analysis of Multiprocessor Systems (D-level), 5p
- CT3190 - Safety Critical Real-Time Systems (D-level), 5p
- Master's Thesis, 20 p

Students in 2003/2004:

- Kristiansson, Erik
- Strandberg, Mathias
- Larsson, Mats
- Short, Michael
- Irobi, Sandra

Students in 2002/2003:

- Ni, Peng Peng
  (project: Bandwidth Estimation for Adaptive Multimedia over Wireless Networks)
- Myklebust, Rasmus
  (project: VHDL-implementation av ett indexeringssystem för en inbyggd databas)

The MSc programme in Computer Science

This *magister* year in computer science is a one-year education that specializes in one of the following research fields of the Computer Science lab:

- Programming and specification languages (program analysis, language design, implementation …)
- Industrial software engineering (component-based software engineering, embedded system engineering, dietributed development.)
- Artificial intelligence (experience reuse, decision support, intelligent agents, learning systems, ...)

The Master's year gives a good basis both for graduate studies within computer science as well as for development work with within companies.

The Master's year students will be assigned to one of the research groups, get a supervisor, is provided their own workspace, and be engaged in the work of the group in different ways.

Courses

Depending on the previous knowledge and the interests of the student, 20 credits of courses and the final master's thesis are selected in consultation with the supervisor of the student. The courses are mainly on D-level. The student can choose, for example, among the courses below in computer science, or some course(s) within a close subject, for example mathematics or computer engineering.

General courses:

- Research Methodology for Computer Science, 5 credits
- Computer Graphics, continuation course, 5 credits

Programming languages and specification languages:

- Programming Language Semantics, 5 credits
- Object Oriented Programming, continuation course, 5 credits
- Algorithm Analysis, 5 credits

Industrial Software Engineering

- Component Based Software Engineering, 5 credits
- Component-based technologies, 5 credits
- Distributed Software Development, 5 credits
- Engineering of Complex Embedded Systems, 5 credits

Artificial Intelligence

- Artificial Intelligence, continuation course, 5 credits
- Logic programming, 5 credits
- Case-based reasoning, 5 credits

Master's Thesis, 20 credits

There are a number of possibilities how to perform the final master's thesis. It can for example be performed within one of the research areas of the department, in close cooperation with researchers and graduate students. Another possibility is to perform the master's thesis at some of the companies with which the department has active cooperation, for example ABB or Ericsson. The thesis subject is chosen within the research fields selected for the year.

Students 2003/2004:

- Industrial Software Engineering
    - David Pösö
    - Daniel Kling
    - Stefan Karlsson
- Artificial Intelligence
    - Johan Andrén (AI in medicine)
    - Daniel Andersson (AI in medicine)
    - Andreas Jonsson (AI in medicine)
    - Mikael Hedelind (in industry)
    - Karin Karlsson (AI in medicine)
    - Jessica Malm (AI in medicine)
    - Andreas Johansson (in industry)

Students 2002/2003:

- Industrial Software Engineering
    - Jari Ala-Kurikka
    - Baharak G. Fard
    - Magnus Haeppling

Students 2001/2002 (the first year of the MSc programme in Computer Science):

- Programming languages and specification languages:
    - Johan Malmström
    - Daniel Persson
    - Linus Sjöberg
- Industrial Software Engineering
    - Jonas Berglin
    - Stefan Gustafsson
    - Caroline Nyholm
- Artificial Intelligence
    - Conny Gyllendahl
    - Johan Karlsson
    - Denis Kulenovic
    - Ezra Sheppard

New international MSc-programmes in 2004

In 2004 we are offering the following international MSc-programmes within the newly established Mälardalen International Master Academy (MIMA):

- **Artificial Intelligence** - In this program you can chose the length of your studies depending on how much you want to penetrate the subject. During the last semester you will carry out and write a Master degree project. The project may even last for one and a half semester if you are really into research. 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 you prefer 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 semester mainly due to a filosophy to start with theory and later in the programme specialize in one area, with an experimantal 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, see http://www.robocup.org. There are two different profiles, Electronic Control and Computer Architecture and System on Chip

7 Seminars, Lectures and the Industrial day

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 workshop 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, and SDL).

7.1.1 Internal Speakers

1. Licenciate thesis Proposal by Dag Nyström
2. Licenciate thesis proposal by Thomas Nolte
3. Thesis Presentation: Operating Systems for Symmetric Multiprocessors by Christian Andersson and Johan Fredriksson
4. Licenciate thesis proposal byTomas Lennvall
5. Licenciate thesis proposal by Radu Dobrin
6. Parallel Execution of I/O System and Application Functionality by Leif Enblom
7. Virtuoso RTOS byRaimo Haukilahti
8. Thesis Presentation: Industrial Ethernet EtherNet/IP by Johnny Nordin & Marie Persson
9. Thesis Presentation by Johan Erikson & Bo Lindell
10. Licentiate thesis defense by Thomas Nolte
11. Licentiate thesis defense by Dag Nyström
12. Research Seminar IDt IEl - Wireless Communication chaired by Mats Björkman
13. Research Seminar IDt IEl – Robotics chaired by Lars Asplund
14. Thesis Presentation by Toni Riutta, Kaj Hänninen, Gisèle Mwepu, Susanne Eriksson, Ingela Hedman, and John Melin
15. Presentations from IP
16. Licentiate thesis defense by Radu Dobrin
17. Thesis Presentation by Baharak G. Fard, Jari Ala-Kurikka, Daniel Lundberg, Enrico Viero, Ola Ottermalm, Pier Blomkvist, Magnus Haeppling and Jonas Seborn
18. Testbänkens täckningsgrad, Analys av kodtäckningsverktyg arranged by CAL
19. Thesis Presentation by Anna Martinussen och Åza Sjöquist
20. Workshop on Embedded Systems
21. Licenciate thesis Proposal by Christina Wallin
22. Licentiate thesis defense by Rikard Land; An Architectural approach to Software Evolution and Integration
23. Serie of Seminars arranged by Anders Martinsen; teknIQ
24. Thesis Presentation chaired by Anders Martinsen
25. USB interface for Embedded Systems
26. Workshop on Robotdalen charied by Lars Asplund
27. Licentiate thesis defense by Thomas Larsson: Adaptive Algorithms for Collision Detection and Ray Tracing of Deformable Meshes
28. Licentiate proposal seminar: Artificial intelligence diagnostics in psychophysiological medicine by Markus Nilsson
29. Thesis Presentation by Jonas Ehlin: Jump Address Memory (JAM) in Multi-X
30. Licentiate thesis defense by Christina Wallin
31. Licentiate thesis defense by Frank Lüders
32. Thesis Presentation by Henrik Bodin, Daniel Halvarsson, Per-Arne Lennartsson, Denis Kulenovic, Per-Erik Hinderson, and Thomas Holm
33. MRTC Seminar :Paper Presentation by Stig Larsson
34. Öppen Vret arranged by IDT and IEl

35. Licentiate thesis defense by Baran Çürüklü: Layout and function of the intracortical connections within the primary visual cortex
36. PhD Proposal by Baran Çürüklü: A Canonical Model of the Primary Visual Cortex
37. Licenciate thesis Proposal by Jan Carlson: A resource-efficient event detection algebra
38. Licenciate thesis Proposal by Waldemar Kocjan: Dynamic Global Constraints
39. PhD proposal by Xavier Vera: Cache and Compiler Interaction

7.1.2 External Speakers

1. Macromedia Flash i industriell tillämpning by Anders Älvegran, Future Breeze Technology AB
2. Elektronik i framtida produkter by Bo Wikström
3. Invited Talk - Space Quality by Claes Berlin
4. Towards timing analysis and prediction for IEC6-1131 component systems by Prof. Heinz Schmidt, Monash University
5. Designing Compact Fuzzy-Rule Based Systems Using GAby Dr. Ning Xiong

7.2 Real-Time in Sweden (RTiS´03)

MRTC arranged and hosted the Swedish National Real-Time Associations (SNART) seventh biannual Real-Time in Sweden (RTiS) conference in August 18th-19th in Västerås. The conference covered four topics: Verification and Validation; Control and Real-Time; Engineering of Complex Embedded Systems and Component-Based Engineering of Embedded Systems. Each topic had invited speakers from both academy and industry.

This year we had four distinguished academic speakers, Prof James Whittaker, Prof Heonshik Shin, Prof Soo-Ik Chae and Prof Kang G. Shin. From industry we had the following distinguished speakers, Mikael Adenmark, Scania, Sigrid Eldh, Ericsson, Torkel Finnström, SAAB Bofors Dynamics AB, Peter Cigéhn, TietoEnator Telecom & Media, John Lundbäck, Arcticus Systemsand of course many other prominent speakers from both academia and industry.

The conference was very well-attended, and there were many opportunities for researchers, engineers, students and other interested participants to make new contacts.

7.3 IPIS Workshop – User Gruop for IP in Sweden (Intressegruppen för IP i Sverige)

IPIS – User Group for IP in Sweden main focus is to organize workshops, transfer knowledge between the participants and build cooporation between comapnyes and Universities. During 2003 MRTC was responsible for arranging two IPIS meetings.

7.4 MRTC Industrial Day

The MRTC Industrial Day is an annual event organised in March-April 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.

7.4.1 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 (Lasr Aspund)
- Panel: Robotics in Society (Panellists: Tom Duckett, Erik Sandevall, Torgny Brogårdh, Lars Asplund; Moderator: Christer Norström)

7.4.2 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)

7.4.3 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)

7.4.4 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

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2. Stefan Sjöholm, Lennart Lindh: VHDL För Konstruktion, Studentlitteratur 2003 ISBN: 91-44-02471-1,
3. Stefan Sjöholm, Lennart Lindh: VHDL- En Introduktion, Studentlitteratur 2003 ISBN: 91-44-02932-2,

8.1.2 Journals

4. Gordana Dodig-Crnkovic: Shifting the Paradigm of the Philosophy of Science: the Philosophy of Information and a New Renaissance, Minds and Machines: Special Issue on the Philosophy of Information, , Kluwer, September 2003.
5. Jakob Engblom, Andreas Ermedahl, Mikael Nolin, Jan Gustafsson, Hans Hansson: Worst-Case Execution-Time Analysis for Embedded Real-Time Systems, Journal of Software Tool and Transfer Technology (STTT), 4(4):437-455, Springer Verlag, August 2003.
6. Thomas Larsson, Tomas Akenine-Möller: Efficient collision detection for models deformed by morphing, The Visual Computer, 19(2-3):164-174, Springer, June 2003.
7. Henrik Thane: Time Machines and Black Box Recorders for Embedded Systems Software, ERCIM News, (52):32-33, European Research Consortium for Informatics and Mathematics, January 2003.

8.1.3 Thesis

8. Baran Çürüklü: Layout and Function of the Intracortical Connections within the Primary Visual Cortex, Licentiate Thesis, Mälardalen University Press, December 2003.
9. Frank Lüders: Use of Component-Based Software Architectures in Industrial Control Systems, Licentiate Thesis, Mälardalen University Press, December 2003.
10. Christina Wallin: A Process Approach for Senior Management Involvement in Software Product Development, Licentiate Thesis, Mälardalen University Press, December 2003.

11. Joel G Huselius: Preparing for Replay, Licentiate Thesis, Mälardalen University Press, November 2003.
12. Leif Enblom: Utilizing Concurrency to Gain Performance in an Industrial Automation System, Licentiate Thesis, Mälardalen University Press, November 2003.
13. Thomas Larsson: Adaptive Algorithms for Collision Detection and Ray Tracing of Deformable Meshes, Licentiate Thesis, Mälardalen University Press, October 2003.
14. Anders Pettersson: Analysis of Execution Behavior for Testing of Multi-Tasking Real-Time System, Licentiate Thesis, Mälardalen University Press, October 2003.
15. Rikard Land: An Architectural Approach to Software Evolution and Integration, Licentiate Thesis, Mälardalen University Press, September 2003.
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18. Dag Nyström: COMET: A Component-Based Real-Time Database for Vehicle Control-Systems, Licentiate Thesis, Mälardalen University Press, May 2003.
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21. Tomas Lennvall: Handling Aperiodic Tasks and Overload in Distributed Off-line Scheduled Real-Time Systems, Licentiate Thesis, Mälardalen University, May 2003.

8.1.4 Articles in collection

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8.1.5 Conferences and workshops

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26. Xavier Vera, Björn Lisper, Jingling Xue: Data Caches in Multitasking Hard Real-Time Systems, International Real-Time Systems Symposium (RTSS), Cancun, MX, IEEE, December 2003.
27. Jukka Mäki-Turja, Mikael Nolin: Faster Response Time Analysis of Tasks With Offsets, WiP Session of Real-Time Systems Symposium (RTSS), Cancun, Mexico, December 2003.
28. Anders Möller, Mikael Åkerholm, Johan Fredriksson, Mikael Nolin: Software Component Technologies for Real-Time Systems - An Industrial Perspective, WiP Session of Real-Time Systems Symposium (RTSS), Cancun, Mexico, December 2003.
29. Thomas Nolte, Anders Möller, Mikael Nolin: Using Components to Facilitate Stochastic Schedulability Analysis, Work-In-Progress Session of the 24th IEEE Real-Time Systems Symposium (RTSS'03), (editor(s):Tarek Abdelzaher), pages 7-10, Cancun, Mexico, IEEE Computer Society, December 2003.

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33. Weirong Wang, Al Mok, Gerhard Fohler: A Hybrid Proactive Approach for Integrating Off-line and On-line Real-Time Schedulers, Third International Conference on Embedded Software, Philadelphia, PA, USA, October 2003.
34. Jan Gustafsson, Björn Lisper, Peter Puschner: Input-Dependency Analysis for Hard Real-Time Software, 9-th IEEE International Workshop on Object-oriented Real-time Dependable Systems (WORDS 2003F), (editor(s):Luiz Bacellar, Gerhard Fohler), Capri Island, Italy, IEEE, October 2003.
35. Andreas Ermedahl, Friedhelm Stappert, Jakob Engblom: Clustered Calculation of Worst-Case Execution Times, Sixth International Conference on Compilers, Architecture, and Synthesis for Embedded Systems, (CASES'03), pages 12, DoubleTree Hotel, San Jose, California, USA, ACM, October 2003.
36. Stig Larsson: Towards an Efficient and Effective Process for Integration of Component-Based Software Systems, SERPS'03 - Proceedings of the 3rd Conference on Software Engineering Research and Practise in Sweden, Lund, Sweden, October 2003.
37. Johan Fredriksson, Mikael Åkerholm, Kristian Sandström, Radu Dobrin: Attaining Flexible Real-Time Systems by Bringing Together Component Technologies and Real-Time Systems Theory, Proceedings of the 29th Euromicro Conference, Component Based Software Engineering Track, Belek, Turkey, IEEE, September 2003.
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39. Thomas Nolte, Mikael Nolin, Hans Hansson: Server-Based Scheduling of the CAN Bus, 9th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2003), Calouste Gulbenkian Foundation, Lisbon, Portugal, September 2003.
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53. Damir Isovic, Gerhard Fohler, Liesbeth Steffens: Timing constraints of MPEG-2 decoding for high quality video: misconceptions and realistic assumptions, Proceedings of the 15th Euromicro Conference on Real-Time Systems (ECRTS 03), Porto, Portugal, IEEE, July 2003.
54. Christer Sandberg: Elimination of Unstructured Loops in Flow Analysis, WCET 2003 Workshop, Porto, July 2003.
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57. Thomas Nolte: Session Summary: QoS over IP, 2nd International Workshop on Real-Time Lans in the Internet Age (RTLIA 2003) in conjunction with the 15th Euromicro International Conference on Real-Time Systems (ECRTS 2003), Polytechnic Institute of Porto, Portugal, July 2003.
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95. Markus Nilsson: Artificial intelligence diagnostics in psychophysiological medicine, Technical Report , September 2003.
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97. Waldemar Kocjan, Per Kreuger: Filtering Methods for Symmetric Cardinality Constraint, Technical Report , Swedish Institute Of Computer Science, August 2003.
98. Thomas Nolte, Mikael Nolin, Hans Hansson: Providing Bandwidth Isolation on the Controller Area Network by Using Servers, Technical Report , April 2003.
99. Jan Gustafsson, Nerina Bermudo, Linus Sjöberg: Flow Analysis for WCET calculation, Technical Report , Jan Gustafsson, March 2003.
100. Damir Isovic, Gerhard Fohler: Resource Aware MPEG-2 Playout Using Real-time Scheduling, Technical Report , Malardalen Real-Time Research Centre, March 2003.

8.2 MSc Theses

The following MSc-theses have been presented at the CSE department in 2003:

- Ala-Kurikka, Jari ; Golpayegani Fard Baharak: Enabling Distributed Simulation Usign an Extensible Middleware Web Service Component
- Blomkvist, Pier; Haeppling, Magnus: Using Voice to Control and Supervise Processes in a Wireless Environment
- Bodin, Henrik: Positionering av Mobila Enheter
- Byström, Christine; Johansson, Robert: Synchronizing Real-Time Data Streams over Wireless Networks
- Chryssovitsdanos, Panagiotis; Jonsson, Casper: Real-time Dynamics in Games
- Ehlin, Jonas: JAM in Multi-X
- Eriksson, Johan: A Structural Operational Semantics for PLEX
- Eriksson, Susanne; Hedman, Ingela; Mwepu, Gisele: Implementation of a Database for a Hard Real-Time Control System
- Fredriksson, Johan; Andersson, Christian: Design and Implementation of a Symmetric Mulitprocessor Operating system
- Halvarsson, Daniel; Lennartsson, Per-Arne: Porting a robot control system from VxWorks to Windows CE .NET
- Hindersson, Per-Erik; Kulenovic, Denis: Visual adaptive web-shopping using personalization techniques

- Lindell, Bo: Analysis of reentrancy and problems of data interference in the parallel execution of a multiprocessor AXE-APZ system
- Malmquist, Andreas; Käll, Erik: USB Interface for Embedded systems
- Mandery, Jakob: Creating a Switch Order Solution using the .NET Platform and Data Replication
- Melin, John: 3 D - skanner optimerad för fötter
- Ni, Peng Peng: Bandwidth estimation for adaptive multimedia over wireless networks
- Nilsson, Peter: IP Interconnecion
- Nordin, Johnny; Persson, Marie: Industrial Ethernet - EtherNet/IP
- Orre, Tobias: Occlusion Culling
- Ottemalm, Ola: Intelligent Agents and the SIMA Prototype
- Persson, Daniel: Dimensional Analysis and inference for gPROMS
- Riutta, Toni; Hänninen, Kaj: Optimal Design
- Savic, Natasa: SoftPLC Integration with Robot Controller
- Seborn, Jonas: Evaluation of Java Message Service
- Sivert, Michael: Managing Communication Resources