

Research Profile

Embedded Systems

SEES

June 24, 2005

1. Introduction

In the summer of 2004 the departments of Electrical Engineering, Mechanical Engineering, Mathematics and Computer Science and Industrial Design of TU/e joined forces to strengthen the interdepartmental cooperation in the field of Embedded Systems.

In this concise survey we postulate our objectives, we look ahead on our research themes, we describe our application areas, we present the participating groups, we explore some related activities, and we sketch our plans for the near future.

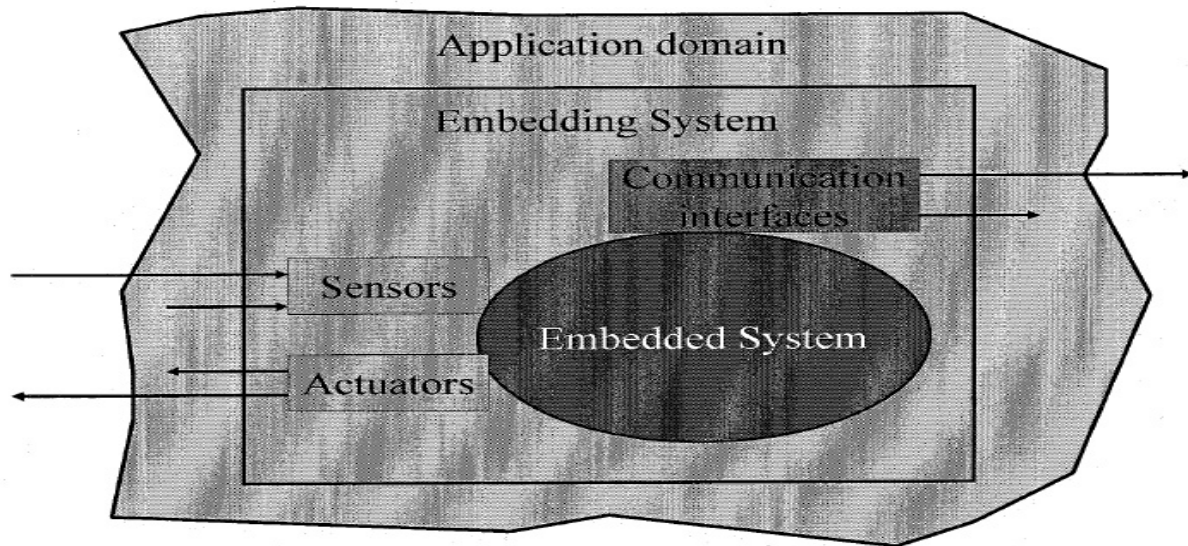
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2. Scope of SEES

An **embedded system** is a flexible, reactive electronic data processing system, including advanced algorithms, to control its **embedding system**.

Embedded Systems



PROGRESS Embedded Systems Roadmap, HvG, 19-02-2003

Embedded and embedding system

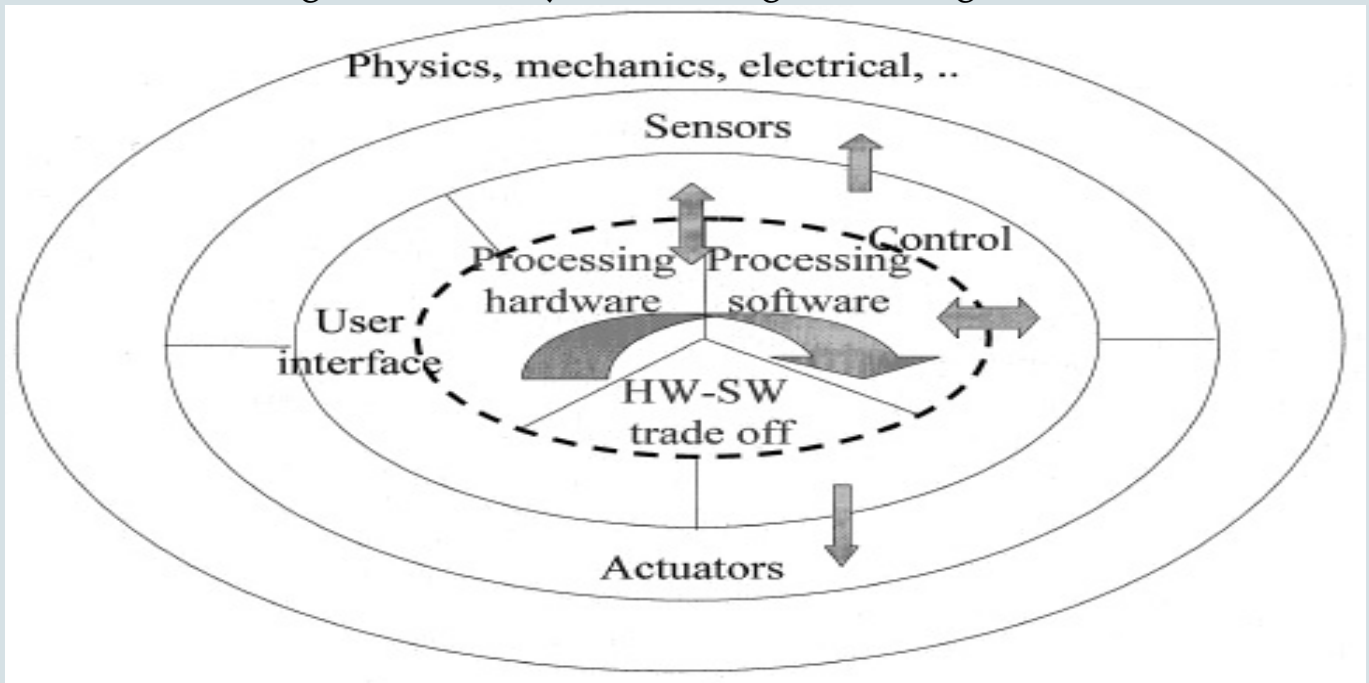
- The focus of SEES is on design methodologies, architecture and algorithms (control and signal processing), and on the interaction between the embedded and the embedding system for improving their combined performance.
- The participating groups have knowledge of the embedded and embedding system and their interaction.
- SEES aims at generating scientific and engineering knowledge on the design of embedded systems jointly with these interacting parts, based on system wide modeling.

Present situation

- Excellent local modeling and design activities
 - architecting
 - concurrency
 - control
 - networking
 - signal processing
 - applications: automotive, mechatronics, multi-media, settop boxes, traffic, ...
- No system wide modeling and design activities
- A real border in between models, environments, design criteria
- Few border crossings exist

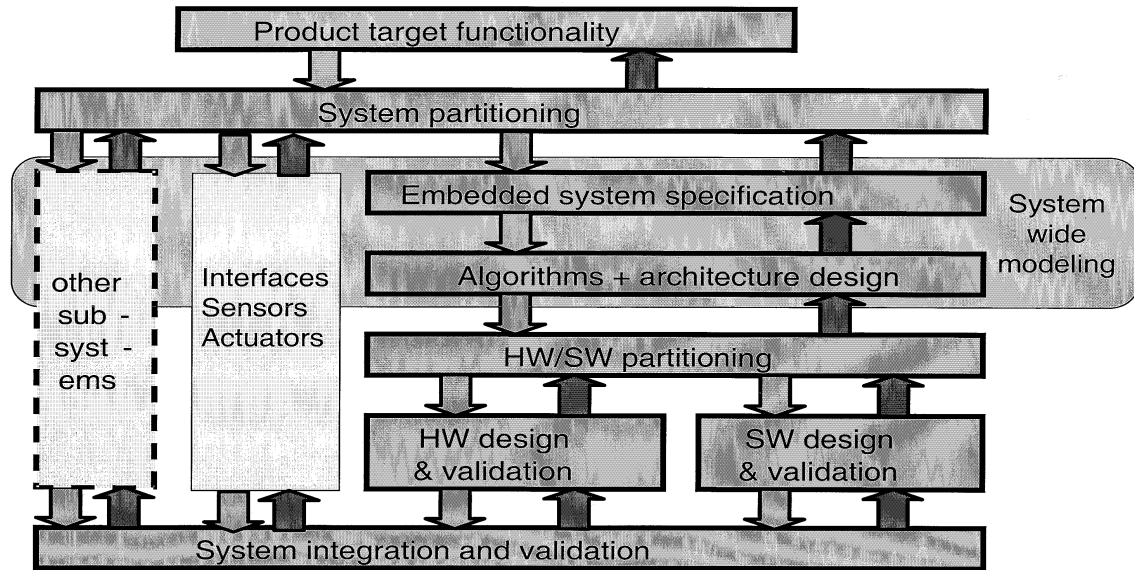
Desired situation, control point of view

- Emphasis on system wide modeling and integration of design
- Border crossing is a necessity for an integrated design



Desired situation, architecture point of view

Desired situation



10/5/2005

SEES

4

Benefits of integration

- Computer science can deal with complex processing systems and functional physical models and guarantee dependability
- Computer science and electrical engineering can deal with complexity
- Software supports flexibility, maintainability and late changes
- Standardized electronics and Moore's law permit cost reduction
- Control and signal processing can deal with complex physical processes and simple models of software behavior
- Controlled processes behave predictably, reduce uncertainty
- Control yields reliability, robustness and performance

Embedded systems have the promise to combine the advantages yielding attractive designs with compelling characteristics.

3. Application areas

- Control intensive applications
- Performance intensive applications
- Dependability intensive applications
- Network intensive applications

3.1. Control intensive applications (CIA)

Design of software-rich, advanced technological devices and machines characterized by hard real time constraints. Integration yields the required flexibility, functionality, robustness and performance for acceptable costs.

Examples: wafer steppers, copiers, MRI scanners and vehicles.

3.2. Performance intensive applications (PIA)

Integrated and optimal design of complex processors and their software to realize cost-effective solutions for demanding performance intensive applications. PIA have soft real time constraints.

Examples: multi-media devices, vision, set-top boxes and optical storage.

3.3. Dependability intensive applications (DIA)

Safety critical applications.

Examples: traffic, medical equipment, protocols.

3.4. Network intensive applications (NIA)

Wired and wireless connected systems.

Examples: world wide web, distributed multimedia, distributed data processing.

Note that distinctions between application areas are decreasing.

A possible other application area is in the direction of ambient intelligence (smart environment, domotica).

Industrial partners

For all four application areas there are industrial partners in the Eindhoven region, a.o.

- for CIA ASML, Imtech, Océ, Assembléon, Philips Medical Systems, Philips Research Laboratories, Philips Advanced Technology
- for PIA Philips Research Laboratories, Philips Semiconductors, Philips TASS, Philips Medical Systems
- for DIA Bosch Security, Philips Medical Systems, Vanderlande, Assembléon, ASML, Nyquist
- for NIA Bosch Security, Philips Research Laboratories, Philips TASS, Océ

4. Research objective

SEES aims to develop theory and techniques, and to build (computational) tools, inspired by computer science, electrical engineering science, mechanical engineering science, industrial design and mathematics, for a fast, correct and predictable **system wide design** of complex embedded systems satisfying functional and non-functional requirements.

This requires:

- developments within separate areas
- improving interfaces among areas
- system wide modelling and system wide predictable design

5. Research themes

Research in the area of embedded systems in the participating groups can be clustered in the following themes. In each of the themes, different application areas are relevant. We want to stimulate developments that allow and stimulate integration (border crossing), especially research in the following themes:

1. system wide modeling
2. system wide predictable design
3. hardware–software architecting

Research themes, more detailed

Oneliners of our new research

1. Crossing modelling paradigms: hybrid, discrete event
2. Behavioural and performance modelling, model checking, analysis techniques
3. (a) Component-based systems: predictable component assemblies
(b) Service-oriented architectures: sharing content, processing, resources in networked environment
(c) Architectural patterns, system evolvability, product architectures, components

6. Participating groups

Dept	Group	Acron	Leader	Par
E	Control Systems	CS	VdBosch	9.1
	Electronic Systems	ES	Otten	9.2
	Signal Processing Systems	SPS	Bergmans	9.3
W	Control Systems Technology	CST	Steinbuch	9.4
	Dynamics and Control	DC	Nijmeijer	9.5
	Systems Engineering	SE	Rooda	9.6
W&I	Design and Analysis of Systems	OAS	Groote	9.7
	Formal Methods	FM	Baeten	9.8
	System Architecture and Networking	SAN	Lukkien	9.9

E = Electrical Eng.; W = Mechanical Eng.; W&I = Mathematics and Computer Science

Future participation is to be expected from Industrial Design and Mathematics

Participating groups arranged by application areas

<i>Application areas</i>	<i>Participating groups</i>		
	E	W	W&I
Control intensive applications (CIA)	VdBosch (CS)	Nijmeijer (DC) Rooda (SE) Steinbuch (CST)	Baeten (FM)
Performance intensive applications (PIA)	Bergmans (SPS) Otten (ES)		Groote (OAS) Lukkien (SAN)
Dependability intensive applications (DIA)			Groote (OAS)
Network intensive applications (NIA)	Otten (ES)		Lukkien (SAN)

See 3 for a description of the application areas

Participating groups arranged by expertise

<i>Expertise</i>	<i>Participating groups</i>		
	E	W	W&I
Concurrency		Rooda (SE)	Baeten (FM) Groote (OAS) Lukkien (SAN)
Control/physics	VdBosch (CS)	Nijmeijer (DC) Rooda (SE) Steinbuch (CST)	
Signals/ multimedia	Bergmans (SPS) Otten (ES)		Lukkien (SAN)
HW/SW design	Otten (ES)		Lukkien (SAN)

Participating groups arranged by research themes

<i>Research themes</i>	<i>Participating groups</i>		
	E	W	W&I
System wide modeling	all	all	all
System wide predictable design	all	all	all
Hardware/ software architecting	Bergmans (SPS) Otten (ES)		Lukkien (SAN)

See 5 for a description of the research themes

Existing cooperations among participating groups

<i>Research topic</i>	<i>Participating groups</i>		
	E	W	W&I
Boderc	VdBosch (CS) Otten (ES)	Nijmeijer (DC) Steinbuch (DCT)	
Tipsy Tangram Hybrid χ		Rooda (SE)	Baeten (FM)
Progress	VdBosch (CS)		Groote (OAS)
Candela Trust4All I-share	Bergmans (SPS) (De With)		Lukkien (SAN)
..			

Summarizing SEES

departments	3
groups	9
tenured staff	50
non-tenured staff	25
Ph.D. students	
115 in total, of which SEES related	55

7. Context

- Research schools
- Dedicated M.Sc. programs
- Post Doctoral Engineering programs
- Embedded Systems Institute
- Other connected research profiles TU/e

7.1. Research Schools

- **COBRA** : COmmunication technologies, Basic Research and Applications
- **DISC** : Dutch Institute of Systems and Control
- **EM** : Engineering Mechanics
- **IPA** : Institute for Programming research and Algorithmics

	E	W	W&I
COBRA	ES, SPS		
DISC	CS	CST, DC	
EM		CST, DC, SE	
IPA		SE	FM, OAS, SAN

7.2. Dedicated M.Sc. programs

- **Embedded Systems**

There is a *special M.Sc. program* Embedded Systems, organized as a variant within the M.Sc. programs Computer Science and Engineering, and Electrical Engineering and Information Technology. The department of Mathematics and Computer Science is the commissioner. This M.Sc. program is mainly associated with PIA.

- **Systems and Control**

There is a *special M.Sc. program* Systems and Control, organized as a variant within the M.Sc. programs Electrical Engineering and Information Technology, and Mechanical Engineering. The department of Mechanical Engineering is the commissioner. This M.Sc. program is mainly associated with CIA.

- Master of Technological Design on Embedded Systems
The Design Technology Institute (DTI), a joint venture of TU/e and the National University of Singapore, offers an international Master of Technological Design program on Embedded Systems. This program is currently hosted in Singapore, and is mainly associated with PIA and NIA.

7.3. Post Doctoral Engineering programs

- ICT : Information and Communication Technology
- ST : Software Technology

7.4. Embedded Systems Institute (ESI)

The national Embedded Systems Institute has Eindhoven roots (in EESI), has an Eindhoven location and has strong TU/e participation in the projects. Four major projects in ESI at the moment are

- **BODERC** : Beyond the Ordinary: Design of Embedded Real-time Control
- **TANGRAM** : Test Approach based on integrated product generation and product realization applied to ASML Machines
- **IDEALS** : Idiom Design for Embedded Applications on Large Scale
- **TRADER** : ...

Members of SEES participate in these ESI projects.

It is a challenge for SEES to cooperate with ESI and to contribute to its scientific agenda with mutual beneficial effects.

7.5. Connected research profiles

Ambient Intelligence	W&I/SAN
Biomedical Engineering Sciences	E/CS
Broadband Telecommunication Technologies	E/ES, E/SPS W&I/FM/InfSec
Catalysis and Process Engineering	E/CS
Dynamics of Fluids and Solids	W/DC, W/SE
...	

8. Plans for the near future

- SEES Day 2005

On June 24th all senior and junior researchers engaged in the Research Profile Embedded Systems will meet in the Auditorium. Between lectures and drinks there will be plenty of time to discuss the posters prepared by all Ph.D.-students.

- Additional funding

- Interdepartmental/interdisciplinary Ph.D.-projects
- Postdoc positions
- Visitors programme
- International network

9. Participating groups in detail

9.1. Control Systems (E/CS) : Van den Bosch

9.1.1. Objectives

Research in modeling, analysis and synthesis of uncertain, nonlinear and multi-mode (hybrid)dynamic systems.

Based on our expertise and the benefits expected in application, we focus on the following specific areas:

- Multi-mode (hybrid) systems
- Model reduction
- System identification

We have selected applications in electrical, embedded, automotive and biomedical systems and chemical production processes.

9.1.2. Staff (1/1/2005)

- Tenured staff (5.9): van den Bosch; Backx (0.4), Van den Boom, Damen, van Riel, Veltman (0.3), Weiland, Zhu (0.2)
- Non-tenured staff (2.0): Juloski, Astrid
- PhD students (10.0): Kessels, Schouten, Sandee, Lazar, Huisman, Nauta, Jokic, van Lierop, Musters, Cloudt
- Funding: STW (4 PhD), Senter (1 PhD), IOP (3 PhD), Industry (2 PhD)

9.1.3. Projects

- Designing embedded controllers for copiers
- Model predictive control of hybrid systems
- Identification of hybrid systems
- Electrically guided vehicles
- Energy management systems for vehicles
- Advanced 6 DOF planar actuators
- Intelligent power nets
- Advanced strategies catalytic converters
- Modelling qualitative knowledge

9.2. Electronic Systems (E/ES) : Otten

9.2.1. Objectives

Mission: To provide a scientific basis for design trajectories of electronic circuits and systems.

Themes: Predictable and efficient methodologies for the implementation of complex electronic systems. We develop, implement and maintain consistent and complete flows, and use them for realizing innovative multimedia embedded systems with emphasis on video processing and embedded architectures. *Algorithms* play a key role here.

9.2.2. Staff (1/1/2005)

- Tenured staff (6.8): Otten; Corporaal, De Haan, Groeneveld, Van Meerbergen; Basten, Jozwiak; Geilen, Van der Putten, Voeten
- Non-tenured staff (3.0): Mesman, Theelen, Zhao
- PhD students (SEES related): Fatemi, Gheorghita, Poplavko, Stuijk, ...
- Funding: ...

9.2.3. Projects

- AE-NoC, PREMADONA, DEMONS, LOLSFDSM
(Network-on chip, Philips)
- OZONE, BETSY
(Nomadic multiprocessing)
- MOVE-ASP, PROMES, SMARTCAM, VIDEO-
(Architectures for multimedia systems)
- BODERC, TEL-perf-an
(Modeling and performance analysis)

9.3. Signal Processing Systems (E/SPS) : Bergmans

9.3.1. Objectives

Signals are carriers of information. Signal processing concerns the conversion of information into signals, and the extraction of information from signals. Foundations of this field are:

- signal theory,
- information and communication theory, and
- theory of adaptive signal processing.

The research programme strives to advance signal-processing technology through a balanced mixture of analytic and systems-oriented work, aimed at combining academic excellence with industrial and clinical relevance. The analytic work concerns aspects of the above 3 theories. The systems-oriented work falls fully within the scope of SEES, and is focused on 3 key types of information:

- sensory information (e.g. audio and video);
- digital information (e.g. digital communications and storage), and
- physiological information (e.g. electrocardiogram, electroencephalogram).

To ensure industrial and clinical relevance of this systems work, it is done in close collaboration with strategic partners, partly through bidirectional staff exchanges.

9.3.2. Staff (1/1/2005)

- Tenured staff (8.0): Bergmans; Bastiaans, Cluitmans, Sommen, Tjalkens, Willems; Blom, Ritzerfeld, Vogten
- Non-tenured staff (4.4): Hasman, Korsten, Oei, de With (1.0); de Clercq, de Vries, Mischi, Farin, Han (3.4)
- PhD students (SEES related): Albers, Bakker, Bondarev, Cvetkovic, Han, Jaspers, Lao, Li, Morvan, Pastrnak, Petrovic, Riani, Wijnhoven, Zafarifar, Zuo, ...
- Funding: Philips (7 Ph.D.), DTI (5), Senter (4), STW (3), ITEA (2), EU (2), Kempenhaeghe (2), Bosch (1), BSIK (1), IOP (1), SOBU (1)

The SPS group also participates in the research profile Broadband Telecommunication Technologies.

9.3.3. Projects (SEES related)

- PICKUP: techniques and architectures for embedded video compression and image quality improvement (Morvan, Zafarifar; Philips).
- CANDELA: techniques and architectures for video content analysis, combined with networked delivery and storage technologies and architectures (Han, Lao, Petrovic, Wijnhoven; W/SAN (Lukkien), Philips, ...).
- PREMADONA: network-on-chip based platforms for multimedia architectures (Pastrnak; E/ES (Corporaal), W/SAN (Lukkien), Philips Research, ...).
- and parts of MEDICAST, TWODOS, FETAL MONITORING, mode-group diversity multiplexing, detection of epileptic seizures

9.4. Control Systems Technology (W/CST) : Steinbuch

9.4.1. Objectives

Mission: Systems and control for motion and automotive research

Themes:

- Multivariable motion control
- Advanced feedforward and Learning control
- Data-based control
- Slip control and optimization of automotive powertrains

9.4.2. Staff (1/1/2005)

- Tenured staff (7.2): Steinbuch; de Jager; van de Molengraft, Rosielle, Veenhuizen, Post, Nuij, Kok
- Non-tenured staff (4.0): Bosgra, van Druten, Vroemen, Serrarens
- PhD students (SEES related): Bukkems, Hofman, ...
- Funding: 20 PhD students (4 1st, 1 2nd, 15 3rd)

The group CST also participates in the research profile Dynamics of Fluids and Solids.

9.4.3. Projects (SEES related)

- Boderc - In cooperation with ESI and partners (1 PhD)
- Nonlinear Control of Linear Systems using hybrid control (1 PhD)
- Autotuning of embedded automotive control structures (1 PhD, DAF/Paccar)

9.5. Dynamics and Control (W/DC) : Nijmeijer

9.5.1. Objectives

Mission: Dynamics and control of mechanical systems

Analytical, numerical and experimental

Research themes:

- Nonlinear dynamics (non-smooth, hybrid, bifurcations, numerical tools)
- Nonlinear control (incl. non-smooth, friction)
- Vehicle Dynamics and Control
- Engineering Optimization
- Acoustics and Noise Control

9.5.2. Staff (1/1/2005)

- Tenured staff (6.0): Nijmeijer, Fey, Lopez, van de Wouw, Rosielle, Rijpkema, Kodde
- Non-tenured staff (4.0): Besselink, Schmeitz, Camlibel, Goorden (coordinator Robocup)
- PhD students (SEES related): Cloosterman, Doris, Roset
- Funding: 12 PhD students (2 1st, 3 2nd, 7 3rd)

The group DC also participates in the research profile Dynamics of Fluids and Solids.

9.5.3. Projects

- Boderc – In cooperation with ESI and partners.
- Control of Manufacturing Systems, in cooperation with Rooda (W/SE)
- SICONOS (EU) Control of Non-smooth Systems
- HYCON NoE, joint with vdBosch (E/CS), Rooda (W/SE)

9.6. Systems Engineering (W/SE) : Rooda

9.6.1. Objectives

The (Manufacturing) Systems Engineering group aims to use quantitative methods for the analysis, design and implementation of manufacturing systems exhibiting concurrent behavior.

The objectives are to develop theory and techniques, and to build computational tools, inspired by mechanical engineering science, computer science and mathematics, and to apply these in selected cases from industry.

SEES related application domain: Manufacturing machines

- front-end semiconductor processing (wafer steppers)
- back-end semiconductor processing (SMDs)

9.6.2. Staff (SEES related) (1/1/2005)

- Tenured staff (4.0): Rooda; van Beek, van de Mortel-Fronczak, Progromsky
- PhD students (8.0): van de Berg, Bortnik, Boumen, Braspenning, de Jong, Schiffelers, Stoets, Weber
- Funding: 1st: 2 (TU/e), 2nd: 1 (NWO), 3rd: 5 (Industry, Senter)

The group SE also participates in the research profile Dynamics of Fluids and Solids.

9.6.3. Projects (SEES related)

- Topsy: Tools and techniques for integrating performance analysis and system verification (IPA, Van de Mortel; with Baeten, Van de Pol / Fokkink-CWI/VU)
- Kinematic calibration sequencing (IPA, Van de Mortel)
- Model-based design of SMC (IPA, Van de Mortel)
- Tangram: Model-based testing of machines (3 PhD) (IPA, Van de Mortel, Rooda; with o.a. Baeten)
- Modeling, simulation and verification of hybrid systems (IPA, Van Beek; with Baeten)
- Performance based design of hybrid systems (EM, Pogromsky)

9.7. Design and Analysis of Systems (W&I/OAS) : Groote

9.7.1. Objectives

The OAS group aims at the design of interacting systems with predictable behaviour. Therefore, modelling techniques for discrete system behaviour are developed, with excursions to timed and hybrid extensions. For these models it is determined whether they perform within certain behavioural constraints for instance denoted using modal logics. The main vehicle for this is the language μ CRL and the μ CRL verification toolset.

Applications are the driving force underlying the research, which is the reason for active involvement in standardisation bodies for the FIREWIRE II and HL7 communication standards.

9.7.2. Staff (1/1/2005)

- Tenured staff (5.4): Groote; Zantema; Hoogerwoord, Reniers, Romijn, Wesselink; van de Pol
- Non-tenured staff (3.0): Cuijpers, Goga, vacancy
- PhD students (6.0): Koprowski, Mathijssen, Mooij, Mousavi, Tveretina, Van Weerdenburg
- Funding: NWO (4 PhD, 1 postdoc, 1 staff), STW (2 postdoc)

9.7.3. Projects

- **AIMES-II** – Architectural modeling of embedded systems (Cuijpers, *vacancy*; Chaudron, Groote)
- **IQPS** – Improving the quality of protocol standards (Romijn; Goga, Mooij, Wesselink)
- **ITVDS** – Integrating techniques for the verification of distributed systems (Tveretina; Zantema); cooperation: CWI
- **SACC** – Software Architecture = Components + Coordination (Mousavi; Groote); cooperation: W&I/SAN
- **VOLTS** – Verification of large transition systems (*vacancy*; Groote)
- **V&R** – Verification and rewriting (Koprowski; Zantema)

9.8. Formal Methods (W&I/FM) : Baeten

9.8.1. Objectives

Research in Formal Methods is a systematic and scientific study of issues in computer science, based on solid mathematical principles. The area of Formal Methods concerns fundamental research and considers systems and constructions used in computer science. These constructions are described exactly in a formal syntax and are supplied with a formal semantics whenever appropriate.

Based on our expertise and the benefits expected in application, we focus on the following specific areas:

- Process algebra
- Theorem proving and type theory
- Security
- Formal methods in software development

9.8.2. Staff (1/1/2005)

- Tenured staff (4.8): Baeten; Middelburg; Mauw, Nederpelt; Kuiper, Lutik, de Vink
- Non-tenured staff (2.0): Jojgov, Orzan
- PhD students (8.0): Khadim, Man, Markovski, Middelkoop, Sokolova, Trcka, Van Beek, Van Osch
- Funding: NWO (2 PhD), STW (2 PhD), Senter (1 PhD), BSIK (2 PhD)

The group FM also participates in the research profile Broadband.

9.8.3. Projects

- **TIPSY** – Tools and techniques for integrating performance analysis and system verification (Trcka; Luttk); cooperation: W/SE, CWI
- **TANGRAM** – Model-based testing of machines (Van Osch; Luttk); cooperation: ESI, ASML
- **AMPATS** – Modelling and performance analysis of telecommunication systems (Sokolova; De Vink); cooperation: E/ES
- **BRICKS** – Project AFM₃₋₂: Transmission control protocols for the internet (Markovski; De Vink); cooperation: CWI
- **SPECTEC** – Specification tooling for embedded components (Van Gool; Kuiper) cooperation: Philips
- Modular proof system for OO (Middelkoop; Kuiper, Huizing)

9.9. System Architecture and Networking (W&I/SAN) : Lukkien

9.9.1. Objectives

Goal of the research is to advance the development and integration of networked resource-constrained embedded systems. Typical examples concern consumer electronics terminals. To that end we perform research on:

- real-time systems,
- real-time networking,
- (distributed) software architecture and
- high-performance embedded processing architectures.

Two highlights:

- Software architecture is studied in order to develop a new component model, suitable for high volume terminals. Issues are the software integrity and repair as well as performance prediction to guide the software-adaptation process.
- We study the problem of seamless multimedia streaming in a home network both by analysing typical application behavior and by developing suitable control architectures. The analysis leads to models that steer the decisions procedures.

9.9.2. Staff (1/1/2005)

- Tenured staff (5.5): Hilbers, Van Berkel; Lukkien, Van der Stok; Bril, Chaudron, Mak, Radovanovic
- Non-tenured staff (3.5): van Gool, Mei, Muskens, Verhoeven
- PhD students (8.0): Albu, van der Horst, Jarnikov, Korostelev, Kozlov, Lange, Mazuryk, Russello
- Funding: NWO (1 PhD), STW/Progress (4 PhD), Senter (1 PhD); several postdocs (BSIK, ITEA/ Senter)

9.9.3. Projects

- Internet-based monitoring and control of embedded systems (Mazuryk)
- SACC – Software Architecture = Components + Coordination (Russello)
- QoS IHDN – Quality of service for in-home digital networks (Albu, Jarnikov, Kozlov)
- IDEALS – Idiom design for embedded applications on large scale (van Gool)
- SPACE4U – Software platform and component environment for you (Mei, Muskens)
- CANDELA – Content analysis and network delivery architectures (Korostelev)
- EMPANADA – Empirical analysis of architecture and design qualities (Lange)
- FREEBAND I-SHARE
- TRUST4ALL
- FINESSE

Colofon

Issued on the occasion of the First SEES Day, Friday 24 June 2005, by the *kerncommissie*: prof.dr. J.C.M. Baeten (chair), prof.dr.ir. P.P.J. van den Bosch (E), prof.dr.ir. J.F. Groote (W&I), and prof.dr.ir. J.E. Rooda (W)

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