Research Evaluation Computer Science 2009

Documentation for the evaluation of research in computer science in the period 2002–2008
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Preface

Half a century ago, E.W. Dijkstra published his shortest-path algorithm. Less than a decade later, N.G. de Bruijn started with the developments towards Automath, a system for verifying formally written proofs of mathematical theorems. Although the Computer Science Division of the Technische Universiteit Eindhoven was founded only in 1981, a year before the end of the active Automath research, these two people were of immense significance for Eindhoven’s fame. Dijkstra more for computer science, De Bruijn more for mathematics. Did such remarkable achievements recur in the Computer Science Division over the last few years? Let me try and answer this question with a rather biased selection of three observations.

First of all, it is hard to judge what is remarkable at the time of creation. In the sixties, Dijkstra’s shortest-path algorithm did not stand out, and in the seventies, De Bruijn’s Automath project was not granted NWO funds. A more recent example is our claim to have given birth to adaptivity of electronic documents; here too the first NWO proposals were rejected while currently we are leading a big European project on this topic. Had we not started this research at the time, somewhat later another university might have made the claim to fame.

So how would we be able to tell about future fame of our current research staff? High production of papers correlates well with high quality. Already on this basis alone, we have reason to believe that, for instance, the work flow technology of our division will gain world recognition.

Another way to forecast future fame is to measure current impact. In this light, an example of achievements likely to be remembered is the insight that many geometric algorithms work better for fat objects (looking like balls) than for thin objects (looking like sticks), and the theory behind this, which is already widely spread. There is more work within the department we are proud of than the examples just mentioned, but it is up to the visiting committee rather than to me to pass a judgment.

Despite what was said about NWO’s failure to recognize De Bruijn’s greatness, we could measure success by grants obtained in scientific competition. In this respect the division is clearly appreciated. Next to a high score in NWO funding, we can boast one VICI and two VIDIs in the period 2002-2008, as well as involvement in several international networks.

Second of all, computer science has become so wide and deep that it becomes hard for results to stand out. By the nature of our research, very few results are isolated gems anymore. The visualization group of our division already receives high acclaim today. It is conceivable though that such applied research will be less visible for future generations, so that the TU/e origin of some remarkable tools for obtaining graphical insights into large data sets might easily be forgotten. Also, to the best of our knowledge, we have gained quite some recognition for further development and early applications of process algebra for industrial checks and verifications of correctness. But surely many other research centers are engaged in similar efforts.

Third and last of all, one may question whether, in a time of great collaborative efforts, often imposed by giant funding schemes, the individual achievement should be our measure of success. One of the hidden strengths of our computer science research is the good collaborative spirit among staff members of different research groups within the division (and the department). Let me mention just two cases here. For one, the union of the computer science and mathematics...
staff in the EIPSI institute enables us to make ourselves visible as a major technological player in societal security issues. The other case concerns the work on networked embedded systems which has acquired a lot of industrial attention because of direct applicability and generation of Intellectual Property. The work has led to collaborations with industrial partners on topics ranging from highly parallel embedded computing to new methods for resource management.

Still, individual achievement is a decisive factor when it comes to our long-term strategy, which consists of hiring the best permanent staff we can on the basis of their skills and expertise, rather than their potential for particular societal applications. Over the last eight years we have been successful in this regard, positioning highly qualified leaders at each of the nine research groups. As a result, our Computer Science Division offers a broad coverage of the important research areas that are needed to fulfill its mission. Although the leaders are in place, one of the nine research groups is still in a transition phase and another is still in its start-up phase.

Whereas the long-term strategy is concerned with the creation and maintenance of a solid scientific knowledge base, the short-term strategy focuses on collaborations based on society driven research agendas. The existence of the LaQuSO laboratory within the division, the Joint Research Unit with the Embedded Systems Institute located on the TU/e campus, and the short lines to the surrounding industry fit within this strategy.

Beside the research groups and LaQuSo, one more group is active within the Computer Science Division. These are the staff members of OOTI, the post-graduate school Software Technology, which is part of the Stan Ackermans Institute and leads to a Professional Doctorate in Engineering. With its strong bonds with industry, this school also contributes to our short-term research agenda.

In conclusion, Eindhoven's strict methodology of the early years has been broadened into a rich spectrum of both fundamental and applied computer science. The Computer Science Division has matured into a steady scientific player with strong societal connections in today's informatics turmoil.

Arjeh M. Cohen,
Dean of the Department of Mathematics and Computer Science
Eindhoven, June 2009
Part A

Division of Computer Science
Part A

Full title
Division of Computer Science
Department of Mathematics and Computer Science
Technische Universiteit Eindhoven

Date of establishment
1981

Affiliations

research schools: IPA (Instituut voor Programmatuurkunde en Algoritmiek)
   chair: TU/e, Department of Mathematics and Computer Science
ASCI (Advanced School for Computing and Imaging)
   chair: Technische Universiteit Delft
SIKS (School voor Informatie- en Kennissystemen)
   chair: Vrije Universiteit Amsterdam
BETA (Institute for Business Engineering and Technology Applications)
   (until September 2008)
   chair: TU/e, Department of Industrial Engineering Innovation Sciences

3TU.Federation: NIRICT (Netherlands Institute for Research in ICT)
   CeDICT (Centre for Dependable ICT Systems)
   Joint Research Unit for Embedded Systems Engineering
   LaQuSo (Laboratory for Quality Software)

Formal cooperations
CWI: Centrum voor Wiskunde en Informatica
ESI: Embedded Systems Institute
EEF: European Educational Forum
1. Mission statement

The TU/e is a research-driven, design-oriented technical university. The mission of the Division of Computer Science is to be internationally leading in the science and engineering of software systems. This mission regards both research and education. The research focuses on two related and complementary themes:

- Design methods and algorithmics for large-scale, reliable software systems.
- Analysis of software systems.

Within these themes, we aim at developing universally applicable methods and techniques. To achieve this we complement our theoretical research with empirical research, where we develop software tools, and test and apply our techniques on concrete software systems.

2. Leadership and management

Background. The Department of Mathematics and Computing Science (W&I) is one of the nine departments of the Eindhoven University of Technology, hereafter referred to as TU/e. The Department of Mathematics and Computer Science is subdivided into two divisions, one for computer science and one for mathematics. The department was established in 1956, the Division of Computer Science started in 1981. The department’s budget in 2008 was approximately 24 M€. Of the departmental budget, 45% is dedicated to the division of Computer Science. Currently (June 2009) the staff of the CS division comprises 136 fte, and includes 10 full professors, 9 part-time full professors, 5 associate professors, 26 assistant professors, 19 post-doctoral fellows, 53 PhD students, 6 scientific programmers and 7 administrative support staff as well as the staff of LaQuSo, the Laboratory for Quality Software. The Division of Computer Science is responsible for the bachelor programme Technische Informatica, as well as for the master programmes Computer Science & Engineering (CSE), Embedded Systems (ES), and Business Information Systems (BIS). In addition the division offers a programme (OOTI, Ontwerpersopleiding Technische Informatica) leading to a professional doctorate in engineering (PDEng) on Software Technology.

There are approximately 327 BSc students, 223 MSc students, and 27 PDEng students.

Formal leadership. The Department of Mathematics and Computing Science is organized according to the MUB, a system of university administration that was introduced nationally in 1998. In this system integral management and control are in the hands of the Department Board. Since 2009 the board consists of the dean, the managing director (the head of the Department Administration), and two vice-deans—one vice-dean being the chair of the Division of Mathematics, the other being the chair of the Division of Computer Science—with the dean having the decisive vote. The board is advised by the educational directors of Mathematics and Computer Science. The board organizes the department for its education and research tasks. The members of the board are appointed by the Executive Board of the university. The Department Board decides on the research strategy of the divisions and is involved in all staff appointments: professors and associate professors are appointed by the Executive Board of the university on recommendation of the board; assistant professors and other staff are appointed by the board itself. In taking its decisions, the Department Board consults the Department Council (which consists of elected representatives of staff and students) and the Division Boards of Computer Science and Mathematics.

Each division of the Department of Mathematics and Computer Science has its own board that is in charge of the day-to-day running of the division. The Board of the Division of Computer Science has three members, who are appointed by the Department Board. Since June 2008 these are...
prof.dr. J.C.M. Baeten (chair), dr. N. Sidorova, and dr. A. Wolff. The Division Board is in charge of dividing the research and education tasks of the division over the individual staff members. This assignment is made in concert with the relevant Curriculum Directors. Research groups are organized around chairs. The research groups depicted in the organization chart of the Division of Computer Science—see Fig. 1—directly correspond to the research programmes presented in this documentation. Hence, from now on we use the terms “programmes” and “research groups” interchangeably. Every group has about 0.4 fte secretarial support staff and most groups also have technical support staff in the form of a scientific programmer. Currently, the division consists of the following research groups:

<table>
<thead>
<tr>
<th>Research groups</th>
<th>Programme leaders</th>
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<tbody>
<tr>
<td>AIS</td>
<td>Architecture of Information Systems</td>
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<tr>
<td>DH</td>
<td>Databases and Hypermedia</td>
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<tr>
<td>FM</td>
<td>Formal Methods</td>
</tr>
<tr>
<td>SET</td>
<td>Software Engineering and Technology</td>
</tr>
<tr>
<td>SAN</td>
<td>System Architecture and Networking</td>
</tr>
<tr>
<td>OAS</td>
<td>System Design and Analysis</td>
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<tr>
<td>ALG</td>
<td>Algorithms</td>
</tr>
<tr>
<td>VIS</td>
<td>Visualization</td>
</tr>
<tr>
<td>SEC</td>
<td>Embedded Systems Security</td>
</tr>
</tbody>
</table>

The Laboratory for Quality Software (LaQuSo) is a separate unit that is firmly embedded within the division through staff members serving on the Board of LaQuSo and staff members and students participating in LaQuSo projects—see also Appendix A. LaQuSo was founded at the
TU/e, but it expanded and is now one of the NIRICT-labs, with an additional branch at the Radboud University Nijmegen.

Management. The style of management is geared towards reaching a broad base of support. In important decisions, the Department Board and the Division Board always consult the Council of Group Leaders (LEGO), which consists of representatives of the research groups in the division. The department is characterized by short communication lines. The Department Board issues communiqués on a regular basis to inform staff about recent developments, and its decisions are listed on a web page. Similarly, the minutes of the biweekly meetings of the Division Board of Computer Science are distributed by email among staff members. The Division Board meets monthly with the Council of Group Leaders, and the group leaders have informal meetings with their group members to report on these meetings and discuss current affairs. At a weekly basis, the full professors attend an informal lunch meeting to discuss running issues. Every year, the Division Board has lunch meetings with each of the research groups. Permanent staff members as well as PhD students and postdocs participate in these meetings.

Quality control and processes of improvement and innovation. The main internal mechanism for quality control in the Department are the annual performance evaluations of all employees. Chair holders are responsible for the management of their group and carry out annual R&D (Result and Development) interviews with their group members. The chair holders themselves are evaluated by the Department Board. In the R&D interviews, results of the past year are evaluated, new goals are set for the coming year, and the personal development and/or career development of the staff member are discussed. This may lead to offering courses to the employee, such as management courses and courses for personal development. It may also lead to agreements on career planning, ranging from investigating promotion possibilities within the present job, to investigating the possibilities for a career switch.

Distribution of research and teaching tasks is adapted to individual capabilities, and faculty staff is enabled and encouraged to take sabbatical leaves. Scientists are intrinsically motivated, they derive their satisfaction mainly from the kind of work they do. However, management has a number of means of motivation. It can award bonuses, pay rises and promotions to individuals. Both individuals and research groups can be rewarded for bringing in projects with external parties. Also on the level of research groups incentives exist. The Department board meets each chair holder on an annual basis to review the performance of the group, including the research strategy, funding and output.

Each research group has one PhD student paid by the department, but the Department Board can deploy additional PhD students and postdocs to encourage implementation of the research strategies.

The process of improvement and innovation of the department revolves around the five-year strategy plans for the divisions. The strategy plans describe the challenges the divisions are facing with respect to research and education, and make choices as to how to address the challenges. The strategy plan of a division forms the basis of the development of its research groups, and may lead to the discontinuation of groups or the start of new groups. The current strategy plan for the Division of Computing Science covers the period 2004–2009.

External research assessments are an important input for the strategy plans. The previous Assessment of Research Quality in Computer Science in the Netherlands covered the period 1996–2001. The external assessments also influence funding (of the Department as well as of the individual research groups) because the scores in these assessments form a parameter in the process of the Department Board's annual performance evaluations.

NIRICT, the Netherlands Institute for Research in ICT, is the joint ICT research institute of the three Dutch technical universities—see Section 3.c.
financial model of the TU/e. In addition to the national assessments, the three technical universities also jointly organize so-called Mid-Term Reviews. These follow the 3TU Evaluation Protocol, which is similar to the Standard Evaluation Protocol (SEP) on which the national assessments are based. The previous Mid-Term Review for computer science was conducted in 2007, and covered the period 2002–2005. For this a self-evaluation report was prepared, similar in structure to the current documentation. An external committee was appointed to give feedback on the division’s research, based on a site visit and the self-evaluation.

The department board also has an external advisory board, consisting of representatives of important industrial partners, for consultation on general research and education policies.

3. Strategy and policy

3.a. Strategy, policy and design in brief (incl. historical context; institute, departments, programmes)

In its research the Department focuses on generic aspects of the design of software systems. In particular, focus is on the following two related and complementary themes:

- **Design methods and algorithmics for large-scale, reliable software systems.**
  
  Current software systems are getting larger and larger, both in terms of the number of software components as well as in terms of the amount of data to be processed. One of the main challenges to date in the design of high-quality software systems is to cope with this increased complexity. Our first research theme deals with this: we study modeling and design methods for software components and their interaction, we study the interaction between complex software systems and their environment, and we study efficient algorithms which form the building blocks of such systems.

- **Analysis of software systems.**

  Ideally, software systems are designed and implemented in such a way that they provide the desired functionality in a reliable manner. Unfortunately, today’s systems often have problems related to their performance, reliability, and usability. Therefore, analysis techniques are needed to identify these problems and improve the quality of the systems. Through verification the logical correctness of the model (or the system itself) can be checked with respect to its desired properties. Techniques such as simulation can be used to analyze the (expected) performance of a system. Data and process mining techniques can be used to analyze systems in their natural habitat. Moreover, visualization of models, code, and system behavior can be used to identify problems and solutions.

These research themes represent two of the main challenges in the field of computer science and relate directly to two of the main themes from the NOAG-ict 2005–2010 (the Netherlands’ Research Agenda for ICT), namely Methods for Design and Construction and The Data Explosion. Moreover, the two themes fit in well with the expertise of the department in modeling and engineering of software and systems, and in algorithmics.

In our research we aim at developing universally applicable methods and techniques. As generic application areas we consider both embedded systems and information systems. These two types of systems lead to different scientific questions, because they interact with their environment in a different way: embedded systems operate within a more “technical” setting and interact

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2 Indeed, *How to manage the complexity of data and systems* is listed as one of the four challenges in the national *Masterplan ICT* that was published in 2009.
with the environment through sensors and actuators, and information systems operate within organizations and interact more directly with users. Table 1 shows how the research programmes are linked to our strategy.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Application area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design methods and algorithms</td>
<td>Analysis of software systems</td>
</tr>
<tr>
<td>AIS</td>
<td>⋆</td>
</tr>
<tr>
<td>DH</td>
<td>⋆</td>
</tr>
<tr>
<td>FM</td>
<td>⋆</td>
</tr>
<tr>
<td>SET</td>
<td>⋆</td>
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<tr>
<td>SAN</td>
<td>⋆</td>
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<tr>
<td>OAS</td>
<td>⋆</td>
</tr>
<tr>
<td>ALG</td>
<td>⋆</td>
</tr>
<tr>
<td>VIS</td>
<td>⋆</td>
</tr>
<tr>
<td>SEC</td>
<td>⋆</td>
</tr>
</tbody>
</table>

Table 1: Relation of the research programmes to the strategy of the division.

Work on concrete applications is done through cooperations with industry and other parties. We also have three part-time (and usually fixed-term) full professors from industry. The particular application areas that we focus on vary over time, and depend on current trends in science and industry. This way we are flexible enough to play a role in novel developments and take advantage of new funding opportunities. Empirical research, developing software tools (e.g. for verification and validation), and testing our techniques on concrete software systems are important aspects that complement our theoretical research. To this end we have started in 2003 the Laboratory for Quality Software (LaQuSo), whose purpose is exactly this. In addition, we have many collaborations with industry. In the area of embedded systems we can also profit from our cooperation with the Embedded Systems Institute (ESI), an institute performing applied research in the area of embedded systems and located in Eindhoven.

Changes since the Research Assessment 1996–2001. Compared to, and partially inspired by, the previous research assessments, several changes took place in the division.

First, we are proud to present three new research programmes: Algorithms (ALG), Software Engineering and Technology (SET), and Security (SEC).

In 2002, there was room to extend the division with one new research group. To bring more balance in the theoretically-inclined research of the division—which was oriented mainly towards formal methods—and since algorithms research forms a core area in computer science, it was decided that algorithms should be the focus of the new group. Thus prof. De Berg was appointed and the Algorithms Group was established in 2003.

In 2005 the department decided to run down the existing programme on Software Construction (SOC) when the chair of SOC left, and start a new programme with a more software-engineering oriented profile. This resulted in 2006 in the appointment of prof. Van den Brand as chair of the new programme in Software Engineering and Technology. A transition phase started, where SOC was slowly reduced in size while SET started to build up.

In the Strategy Plan 2004–2009, we identified four promising areas for establishing new research groups: architecture of large-scale systems, agent technology, security, and test methods and design for testability. The extra financial means that became available through NIRICT (see Section 3.c) gave us the opportunity to start a group in one of these areas. We choose to give priority to the area of security: this is nowadays an essential aspect of many software systems, and
therefore it is important to have expertise in this area.\(^3\) Thus in October 2007 prof. Etalle was appointed as chair of the new Security Group (SEC). Together with the Coding Theory and Cryptology group (prof. Van Tilborg) of the Division of Mathematics, SEC forms the core of Eindhoven Institute for the Protection of Systems and Information (EIPSI).

Second, there were some changes in the existing research groups. With the move of prof. Hilbers to the Department of Biomedical Engineering, the programme Parallel Systems changed its focus, and in 2002 it was renamed to System Architecture and Networking (SAN). Since then the group was effectively led by dr. Lukkien, who was promoted to full professor in 2008. Furthermore, in 2006 prof. Van der Aalst was appointed in the programme Architecture of Information Systems, as the early successor of prof. Van Hee, who was appointed as dean in 2005.

Finally, the following developments took place. In line with the encouraging remarks of the Assessment of Research Quality in Computer Science 1996–2001, the department continued with the creation of the Laboratory for Quality Software (LaQuSo) as a means to support the application of newly developed methods and techniques to real-life software and systems, and to increase the interest in software quality from industry in research. Moreover, the suggestions and advice of the Evaluation Committee of the Mid-Term Review 2007 stimulated the Department Board to start developing a policy for the registration of developed software, and to implement the renewal of its personal policy, in order to support the research groups in the implementation of their strategy.

3.b. Future developments (institute, departments, programmes)

In the period 2002–2008, the division of computer science has grown from seven to nine chairs. We feel that with nine chairs we have reached a good size of the division. The research groups together have a very good coverage of our focus themes—design methods and algorithmics for large-scale reliable software systems, and analysis of software systems—while the coverage of computer science in general is sufficient to run high-quality bachelor and master programs. We strongly believe in the themes we have chosen and therefore our future plans focus on further strengthening our expertise in this direction rather than broadening the scope of our research. Thus, we do not strive for a further enlargement of the number of chairs; if more staff is needed—for instance because of increasing enrollment—then we will appoint more junior researchers in the existing chairs.

The following developments in our educational system may influence our research and, in particular, the way in which the PhD program is set up.

Currently (2009) the TU/e Graduate School is being set up, in which the computer-science division is participating. This school will contain our master programmes—Computer Science and Engineering (with a special track on Information Security), Embedded Systems and Business Information Systems—our PhD programme, and our PDEng programme. Thus it gives a broad spectrum of opportunities for excellent students to develop into top engineers or researchers in computer science and related fields. This way we hope to attract more foreign students, especially those that already have a bachelor, but do not know yet if they want to pursue only a masters or perhaps continue into a PhD or PDEng track. This development also means that the clear cut between the masters and the PhD track may become more blurred. Increasing the number of masters students is also important because the number of computer-science engineers is not enough to fulfill the need of the market. At the moment this shortage is less visible because of the economic downturn, but the shortage will resurface shortly. Our past efforts, for instance the joint master program with the Manipal University in India, funded by an industrial scholarship program, already led to an increase in the number of foreign masters students to 30%.

\(^3\)Note that security has also been selected as one of the nine themes in the NOAG-ict 2005–2010.
Another development is the Honours Program that is being developed at the TU/e, with computer science taking the lead. The aim is to give the top students in our masters program the opportunity to do small research projects with several of our research groups, and take some courses at PhD level offered by one of the research schools we are participating in (IPA, ASCI, SIKS; see Section 4.a). Having done the Honours program may lead to a shortened PhD or PDEng study. In January 2009, we started a pilot for the Honours Program, with the six top first-year masters students.

4. Researchers and other personnel

Table 2 shows the research input of the division in full time equivalents (fte), subdivided over tenured staff, non-tenured staff, and PhD students. Details per programme are given in Section 7 of the programme descriptions, and also in Appendix B.

<table>
<thead>
<tr>
<th>Research input</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenured</td>
<td>9.9</td>
<td>10.6</td>
<td>11.5</td>
<td>11.4</td>
<td>13.7</td>
<td>12.3</td>
<td>10.7</td>
<td>80.11</td>
</tr>
<tr>
<td>Non-tenured</td>
<td>6.6</td>
<td>11.2</td>
<td>13.4</td>
<td>15.4</td>
<td>15.4</td>
<td>17.5</td>
<td>18.9</td>
<td>98.42</td>
</tr>
<tr>
<td>PhD students</td>
<td>20.7</td>
<td>21.2</td>
<td>26.7</td>
<td>29.2</td>
<td>30.0</td>
<td>33.8</td>
<td>36.0</td>
<td>197.58</td>
</tr>
<tr>
<td>Total</td>
<td>37.1</td>
<td>43.0</td>
<td>51.6</td>
<td>56.0</td>
<td>59.1</td>
<td>63.6</td>
<td>65.6</td>
<td>376.10</td>
</tr>
</tbody>
</table>

Table 2: Research input (in fte) of the division. Details per programme are in Appendix B.

In order to attract and keep high-level staff members, in 2008 a new personnel strategy was adopted, in which the formation-based career planning has made way for individual career tracks. As already remarked, the Department Board is involved in all staff appointments: full professors and associate professors are appointed by the Executive Board of the university on recommendation of the board, assistant professors and other staff are appointed by the board itself on recommendation of a hiring committee that always includes the relevant group leader, the Curriculum Director, and the personnel manager. The policy is to only hire staff members who are both strong researchers and (have the potential to become) very good teachers.

The department has an active policy of appointing part-time professors from industry, which provides a structured link with industrial applications and research institutes. To increase the number of female scientists, the department participates in the TU/e Women in Science program that was launched in 2005.

The university offers management training courses as well as didactic courses for its staff. As a matter of policy, new staff members with little teaching experience take the relevant didactic courses, and senior staff and others put in charge of important administrative duties take management training courses. The department encourages financed sabbatical leave by faculty members. A stay abroad is one of the requirements for promotion to associate professor.

4.a. PhD programmes and policies

The Netherlands has a system of research schools, which sometimes operate on a local (intra-university) scale, and sometimes operate on a national (inter-university) scale. An important task of the research schools is to provide training and education for PhD students. Research schools can be accredited by the KNAW (Royal Netherlands Academy of Arts and Sciences) if they meet certain quality criteria. It is a policy of the department that every research group participates in an accredited research school.

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4See Excellent People attract Excellent People. http://w3.tue.nl/fileadmin/dpo/UK-Formulieren/P-Z/excellent_people_tr.pdf
For computer science, there are three research schools: the Institute for Programming research and Algorithmics (IPA), the Advanced School for Computing and Imaging (ASCI), and the School for Information and Knowledge Systems (SIKS). All three schools operate on a national level and are accredited by the KNAW; they cover more or less all computer-science research groups in the Netherlands. The main research school for the Division of Computer Science is IPA. IPA is hosted in Eindhoven and most research programmes of the division (FM, SET, SAN, OAS, ALG, SEC) take part in IPA. VIS takes part in ASCI, and AIS and DH participate in SIKS. (Until september 2008, AIS also took part in the BETA research school for operations Management and Logistics.) The research schools provide courses and other scientific events at the PhD level, and function as a national network for the PhD students; the final responsibility for the PhD students, however, still lies with the department.

Training, education, and supervision of all PhD students follow the same outline, as explained next, but the details vary from student to student. The Human Resource department actively guards that every PhD student has a personal training and supervision plan (opleidings- en begeleidingsplan) for his/her project. The plan is drawn up by the supervisor(s) together with the student.

**Supervision and coaching.** A standard PhD student is hired by the department on a specific research project formulated by one of the permanent faculty members. These projects are usually funded from grants, for example from NWO\(^5\), other national or European granting organizations, or industry. In addition, each group has one PhD position paid by the division. When hired, the student becomes part of the scientific staff of the research group.

One of the permanent staff members of the group is appointed as the daily supervisor of the student. Staff members usually supervise at most two PhD students, so that they have sufficient time to coach the students and discuss the research project with them. The full professor heading the research group acts as the promotor of the PhD student, with the daily supervisor (if not the promotor) acting as co-promotor.

When the students have, for instance, problems with their research or motivation they can talk to their daily supervisor and/or the group leader. However, there could also be matters—in particular when they experience problems with the supervision—that they prefer to discuss with a different person. For this purpose the computer-science division has appointed a confidential adviser for PhD students. This way PhD students are facilitated to identify problems at an early stage so that the problems can be prevented from escalating into major conflicts.

**Training and education.** PhD students receive training in two areas. First of all, they receive scientific education: they learn theories and methods from their own or other areas within computer science, learn how to write papers, etcetera. A PhD project is not only a time of scientific growth, however, but also of personal growth. Hence, the second aspect of the training concerns personal development and education not directly related to their research.

- **Scientific education.**
  The daily supervisors play the most important role in the scientific education of PhD students: they guide their study of scientific literature, help them in writing papers and preparing presentations, and show them how to perform research by collaboration and coaching. The seminars run by the research groups also contribute to the scientific education.

In addition to the local training, which is directly related to the PhD project, the students also follow the educational program of the research school they participate in. This program typically consists of several advanced (post-master) courses that focus on the areas that the

---

\(^5\)NWO (the Netherlands Organization for Scientific Research) is the national granting organization, focussing mainly on grants for fundamental research.
research schools cover, and workshops on specific research themes organized by the research schools. Since these courses and workshops are often in areas that are somewhat, but not too closely, related to the research area of the student, they provide the student with a broader view of computer science. Participation in the activities of the research school also ensures an embedding into Dutch research community.

Finally, students attend international summer schools and international conferences in their own area of research. (Whenever a student attends an international conference or workshop, all costs are covered by the division or paid from the project they are working on.) Participation in these events allows them to set up a network in their area of research, which is very beneficial for their future careers.

- **Personal development.**
  The TU/e offers ample opportunities for personal development with a series of courses that are part of the TU/e PROOF program (PROviding Opportunities For PhD students). These courses make an excellent addition to the scientific education. Examples of courses are Planning and communication, Cultural Awareness, Scientific Integrity, and Career Orientation. The PROOF program also contains some courses of a more scientific nature, such as Presenting and Writing articles and abstracts.

  PhD students often also contribute to the bachelor or master program of the division, by acting as a teaching assistant (for at most 20 percent of their time). This gives them the opportunity to develop their teaching skills. Note that teaching is not required to get a scholarship; a (standard) PhD student in the Netherlands is a university employee with a regular salary.

**Quality control.** PhD students first get a one-year contract. After nine months a formal evaluation takes place to assess whether the PhD student is expected to finish the PhD project in four years. A negative evaluation leads to a termination of the contract, while a positive evaluation leads to an extension of the contract with another three years. This policy has resulted in an average duration of the PhD period (measured from start to PhD-defence date) over the students who successfully complete their PhD of 4.4 years, only slightly above the nominal four years and well below the national average.

The TU/e has strict regulations regarding the conferral of doctors degrees—see the Doctorate regulations 2008. These regulations stipulate, for instance, that the doctoral committee which decides on the approval of the dissertation should contain at least two professors from outside the TU/e.

**Success rates and career directions.** The tables below show the success rate of our PhD students and the career directions they pursue after graduating. Information on the number of PhD agrees awarded in each of the years 2002–2008 at the division level can be found in Section 10, while the numbers per research program are given in Part B of this documentation. A complete list of all PhD candidates is given in Appendix B.

As shown in Table 3, we have an average PhD success rate of 81% over the period 2000–2004. This is at the average level of the national research schools.

As shown in Table 4, about two thirds of our former PhD students pursue an academic career. They usually start as a postdoc, either in the Netherlands or abroad, and then move on to (first non-tenured, later tenured) faculty positions. Eleven of our former PhD students became full professor.

---


12 Research Evaluation Computer Science 2009* Part A
<table>
<thead>
<tr>
<th>Year</th>
<th>Enrollment</th>
<th>Finished</th>
<th># years until graduation</th>
<th>Still active</th>
<th>Discontinued</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤ 5</td>
<td>6</td>
<td>7</td>
</tr>
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<td>11</td>
<td>9</td>
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<td>6</td>
<td>5</td>
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<tr>
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<tr>
<td>2004</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
<td><strong>39</strong></td>
<td><strong>34</strong></td>
<td><strong>4</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

**Cumulative**

69% 79% 81% 81%

Table 3: Success rates of standard PhD candidates and years until graduation (rounded up).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>tenured Netherlands</td>
<td>41</td>
<td>25%</td>
<td>19%</td>
<td>22%</td>
<td>63%</td>
</tr>
<tr>
<td>abroad</td>
<td>5</td>
<td>3%</td>
<td>4%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>non-tenured Netherlands</td>
<td>16</td>
<td>10%</td>
<td>16%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>abroad</td>
<td>9</td>
<td>7%</td>
<td>10%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Non-academic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>trade and industry</td>
<td>54</td>
<td>33%</td>
<td>39%</td>
<td>32%</td>
<td>11%</td>
</tr>
<tr>
<td>government</td>
<td>8</td>
<td>5%</td>
<td>1%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>miscellaneous</td>
<td>2</td>
<td>1%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>unemployed</td>
<td>2</td>
<td>1%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
</tr>
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<td><strong>Unknown</strong></td>
<td>26</td>
<td>16%</td>
<td>5%</td>
<td>31%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Total number</strong></td>
<td>163</td>
<td></td>
<td>79</td>
<td>65</td>
<td>19</td>
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</table>

Table 4: Career destination (last known position) of our graduated PhD students in aggregated absolute numbers and percentages, and a breakdown per decade.

One third of our PhD students proceed with an industrial career. Most of them are working in the region of Eindhoven as senior industrial researcher, and several of them now lead their own company.

5. Resources, funding and facilities

**Resources and funding: overview.** Table 5 shows the funding sources for PhD’s and postdocs. Tables 6 and 7 show funding and expenditure for the Division of Computer Science, including LaQuSo. Both funding and expenditures include education as well as research.

<table>
<thead>
<tr>
<th>Funding sources</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
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</thead>
<tbody>
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<td>22%</td>
<td>19%</td>
<td>27%</td>
<td>24%</td>
<td>22%</td>
<td>21%</td>
<td>17%</td>
<td>22%</td>
</tr>
<tr>
<td>Research funds</td>
<td>69%</td>
<td>66%</td>
<td>56%</td>
<td>49%</td>
<td>48%</td>
<td>43%</td>
<td>39%</td>
<td>51%</td>
</tr>
<tr>
<td>Contracts</td>
<td>9%</td>
<td>15%</td>
<td>15%</td>
<td>24%</td>
<td>26%</td>
<td>32%</td>
<td>34%</td>
<td>24%</td>
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<tr>
<td>Other</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
<td>4%</td>
<td>4%</td>
<td>10%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Table 5: Funding sources for postdocs and PhD’s.
As can be seen from Table 6, direct funding has been increasing by around 5% each year since 2002 on average, until 2007. In 2008, the funding decreased slightly. Research funds have also been growing steadily since 2002 (except for 2005). Contracts have grown significantly. As a result, the contribution of direct funding to the total income has decreased from 75% in 2002 to 62% in 2008.

The expenditure has also been growing steadily since 2002, with personnel costs usually slightly above 90%. The total expenditure increased by 76% from 2002 to 2008. In the same period the total number of research fte increased by 73%, namely from 39.3 fte in 2002 to 67.8 fte in 2008—see Table 2.

In Tables 8 and 9 the breakdown in funding and expenditures at group level is given.

<table>
<thead>
<tr>
<th>Funding in k€</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct funding</td>
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<td>4178</td>
<td>4823</td>
<td>4856</td>
<td>5178</td>
<td>5394</td>
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<tr>
<td>Research funds</td>
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<td>824</td>
<td>1097</td>
<td>1035</td>
<td>1209</td>
<td>1319</td>
<td>1400</td>
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<td>Contracts</td>
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<td>778</td>
<td>1391</td>
<td>1508</td>
<td>1807</td>
<td>1823</td>
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<td><strong>Total</strong></td>
<td>5352</td>
<td>5891</td>
<td>6698</td>
<td>7282</td>
<td>7895</td>
<td>8520</td>
<td>8568</td>
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</table>

<table>
<thead>
<tr>
<th>Funding in %</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
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<tr>
<td>Direct funding</td>
<td>75%</td>
<td>71%</td>
<td>72%</td>
<td>67%</td>
<td>66%</td>
<td>63%</td>
<td>62%</td>
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<tr>
<td>Research funds</td>
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<td>14%</td>
<td>15%</td>
<td>15%</td>
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</tr>
<tr>
<td>Contracts</td>
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<td>12%</td>
<td>19%</td>
<td>19%</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expenditure in k€</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel costs</td>
<td>4648</td>
<td>5170</td>
<td>6221</td>
<td>6779</td>
<td>7191</td>
<td>7396</td>
<td>8182</td>
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<tr>
<td>Other costs</td>
<td>369</td>
<td>386</td>
<td>593</td>
<td>567</td>
<td>569</td>
<td>870</td>
<td>565</td>
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<tr>
<td><strong>Total</strong></td>
<td>5017</td>
<td>5556</td>
<td>6814</td>
<td>7346</td>
<td>7760</td>
<td>8266</td>
<td>8747</td>
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<table>
<thead>
<tr>
<th>Expenditure in %</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel costs</td>
<td>93%</td>
<td>93%</td>
<td>91%</td>
<td>92%</td>
<td>93%</td>
<td>89%</td>
<td>94%</td>
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<tr>
<td>Other costs</td>
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<td>8%</td>
<td>7%</td>
<td>11%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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</tr>
</tbody>
</table>

Table 6: Funding of the division.

Table 7: Expenditure of the division.

In Tables 8 and 9 the breakdown in funding and expenditures at group level is given.

<table>
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<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS</td>
<td>8%</td>
<td>7%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>10%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>DH</td>
<td>13%</td>
<td>12%</td>
<td>10%</td>
<td>12%</td>
<td>10%</td>
<td>7%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>FM</td>
<td>23%</td>
<td>21%</td>
<td>18%</td>
<td>15%</td>
<td>14%</td>
<td>13%</td>
<td>16%</td>
<td>17%</td>
</tr>
<tr>
<td>OAS</td>
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<td>15%</td>
<td>13%</td>
<td>10%</td>
<td>13%</td>
<td>12%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>ALG</td>
<td>-</td>
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<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>7%</td>
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<td>VIS</td>
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<td>10%</td>
<td>10%</td>
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<td>9%</td>
<td>9%</td>
<td>9%</td>
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<tr>
<td>SAN</td>
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</tr>
<tr>
<td>SEC</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6%</td>
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<td>1%</td>
</tr>
<tr>
<td>LaQuSo</td>
<td>10%</td>
<td>14%</td>
<td>12%</td>
<td>17%</td>
<td>4%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 8: Funding at programme level (in % of total).
Table 9: Expenditure at programme level (in % of total).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS</td>
<td>11%</td>
<td>12%</td>
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<td>8%</td>
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</tr>
<tr>
<td>DH</td>
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<td>13%</td>
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<td>11%</td>
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<td>9%</td>
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<td>FM</td>
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<tr>
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<td>12%</td>
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<td>ALG</td>
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<td>7%</td>
<td>6%</td>
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</tr>
<tr>
<td>VIS</td>
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<td>9%</td>
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<td>15%</td>
<td>11%</td>
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</tr>
<tr>
<td>SOC</td>
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<td>10%</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>6%</td>
<td>1%</td>
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<td>LaQuSo</td>
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<td>11%</td>
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<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Resources and funding: future developments. Recently the government decided to cut the university budgets (by about 100 M€ in total) and allocate these funds to NWO instead. This has a negative effect on our direct funding. Thus to keep the division financially healthy, we will need to increase our external funding.

Given our success in acquiring NWO grants over the past years, we hope to be able to profit from the extra funds for NWO. We expect, however, that more growth is possible in contract funding. Our goal is to increase this to about 2000k€ over the coming three years. To this end, we should increase our presence in representative bodies, so that we know early of new initiatives and can play a more important role in the consortia that need to be set up for large, national projects.

The shift towards more indirect funding also means that we should adapt our internal financial and administrative structure: we should use part of the continuous flow of research funds and contracts to hire permanent staff, and use temporary staff in a more structural way in our basic activities (teaching, committees, etc.).

Infrastructure. The technical infrastructure is very good. All staff members, including PhD students, have workstations or laptops, and where necessary groups have more specialized hardware (e.g. a grid cluster for process mining experiments and a computer with a 128 GB main memory that is mainly used for state space generation and the verification of modal formulas).

The department library is excellent. Besides the extensive physical collection, staff members and students have electronic access to all relevant journals and proceedings.

Finally, we note that the TU/e has advanced plans for a new building, which will also be the new home of the Department of Mathematics and Computer Science. Current planning is that the construction of the building will start in 2010 and that the department can move into its new quarters in 2012.

6. Processes in research, internal and external collaboration

The division is organized around research groups, each headed by a full professor and consisting of around four or five faculty members (assistant/associate/full professors) and several PhD students, postdocs, and support staff. This structure ensures a minimum critical mass for each research group, while at the same time allowing the division to cover a sufficiently wide range of topics. The group structure also ensures that every faculty member has other faculty members to collaborate with—namely the members of the group. This is one of the strong aspects of the system: new, junior faculty are automatically embedded in a research group, so they can profit...
from and be coached by the senior group members. New chairs are offered coaching by the division chair.

The division and university actively stimulates its research staff to submit grant proposals. Relevant calls for proposals are distributed on mailing lists, and the division chair discusses with the group leaders the possibilities for group members to apply for personal grants. For researchers invited for an interview for a personal grant (NWO Innovational Scheme, or an ERC grant) practice sessions are organized. To stimulate applying for these highly prestigious but very competitive grants, partial funding can be given from the TU/e Excellence Fund to proposals that just missed funding.

**Internal collaboration.** We value collaborations between different research groups in the department, and with research groups from other departments within the university.

Communication between groups is a necessary condition for cooperation, and is facilitated by the organizing of several activities. Every two weeks a division colloquium is organized, in which staff members present their research outcomes or plans. It also functions as a place where new staff members present themselves and their research. Once a year, a research meeting is organized in which staff members of the mathematics division and the computer science division present their research to each other. Figure 2 shows the collaborations within the division.

Several of the groups collaborate with groups from the mathematics division. In addition, there are many active collaborations with other departments. We have especially strong ties with the Department of Electrical Engineering, the Department of Mechanical Engineering, the Department of Biomedical Technology, and the Department of Industrial Engineering and Innovation Sciences.

**External collaboration.** Each of our research groups has collaborations with a wide variety of top institutions in their area, mostly in Europe and the US—see descriptions of the various research programmes in Part B for details. In addition, the division participates in a number of formal cooperations.

The department has an exchange programme with the Centrum voor Wiskunde en Informatica (CWI) in Amsterdam, where researchers from CWI and TU/e trade places for one day a week. Currently this programme involves one full professor and one associate professor of the division.

The Department participates in the Embedded Systems Institute (ESI), a national research institute located in Eindhoven. At the moment, this institute has as participants three universities (TU/e, TU Delft, and UT), three companies (ASML, Océ, and Philips), and TNO. This institute grew out of an initiative of the computer science division and the TU/e Department of Electrical Engineering, who jointly established in 1998 the Eindhoven Embedded Systems Institute (EESI).

Internationally, the division participates through IPA in the European Educational Forum (EEF). In EEF seven computer-science research schools from different European countries cooperate.
The Division is also a member of Informatics Europe, the association of computer science depart-
ments of universities and research laboratories, public and private, in Europe and neighbouring
areas.

Moreover, in 2006 the Department started a joint Master’s program with the Manipal University
(Manipal, India), where selected students do the first year of their Master’s studies in Manipal and
the second year at the TU/e (including an internship with one of the participating companies). Fi-
nally, the TU/e as a whole participates in the CLUSTER and CESAER networks of European
universities of science and technology. Conference of European Schools for Advanced Engineer-
ing Education and Research

Co-operation with other Technical Universities in the Netherlands. The three universities
of technology in the Netherlands, TU Delft, TU Eindhoven, and Universiteit Twente, have ex-
cellent cooperation in several areas, including ICT. This has resulted in the start of NIRICT, the
Netherlands Institute for Research in ICT, which is part of the 3TU Federation. NIRICT brings
together over 70 research groups from the disciplines Computer Science, Electrical Engineering,
Mathematics and several ICT application domains, which makes NIRICT an important academic
research partner in the Netherlands. NIRICT is governed by the Deans of EWI from TU Delft and
UT and the Dean of EE from TU/e. Prof. Apers is the scientific director of NIRICT. The NIRICT
Management Team consists of Prof.dr.ir. R.L. Lagendijk (TUD), Prof.dr. R.J. Wieringa (UT) and
prof.dr. J.C.M. Baeten (TU/e).

NIRICT’s research program consists of a Long-Term Research Agenda (LTRA), a Strategic Re-
search Agenda (SRA), and an Innovation Agenda. The first topic of the LTRA, Dependable ICT
systems, lead to the recently founded 3TU.Centre for Dependable ICT Systems (CeDICT). The
goal of CeDICT is to develop and apply methods and techniques to make dependable ICT sys-
tems a reality. As a concrete means to achieve this goal, six new chairs have been appointed,
three of which are in the CS departments: Dependable Multimedia Processing (TU Delft), Formal
Methods and Tools (UT), and Embedded Systems Security (TU/e). The SRA themes of NIRICT are:

- Broadband Communication Systems
- Computer Networks
- Multimedia and VR Systems
- Ambient Intelligence
- Security
- Enterprise Information Systems

These themes are closely linked to the national and international research agendas.

To implement the Innovation Agenda the joint 3TU.NIRICT Research Laboratories have been
founded: the Laboratory for Quality Software (LaQuSo; Radboud University Nijmegen also par-
ticipates in this lab), the Smart Environments Laboratory, and the Design Laboratory. All labs
have facilities at the three locations and are supported from the CeDICT program.

In December 2008, the 3TU.Federation signed the Joint Research Unit for Embedded System
Engineering, a collaboration agreement with the Embedded Systems Institute (ESI) in Eind-
hoven. The aim is to collaborate more closely within Dutch and European research programs
and projects.
7. Academic reputation

The department’s academic reputation is derived from the academic reputation of its research programs and its staff; details can be found in Part B.

The research staff contains several researchers with a high $h$-index. Six out of the nine group leaders have an $h$-index of 25 or more, of which Van der Aalst has in fact the highest $h$-index (61) of any computer scientist in the Netherlands.

Another sign of our reputation is our success in attracting funds from NWO. Over the period 2001–2008 we received 10 M€ of NWO funding, which is the third largest amount of all computer-science divisions in the Netherlands (source: NWO). This includes prestigious VICI (De Berg), VIDI (Speckmann) and VIDI-old style (Romijn, 2002) grants from NWO’s Innovative Research Incentives Scheme (Vernieuwingsimpuls).

The Elsevier magazine annually publishes in October rankings of the Dutch universities and departments. One of the rankings is on the scientific quality of the departments, as perceived by their peers. More precisely, all full professors in the Netherlands are asked to rank the universities—excluding their own university—with respect to quality of the publications in their field. In 2004, 2005, 2007, and 2008 Computer Science in Eindhoven was ranked number-one in this annual peer-assessment.

8. Internal evaluation

The researchers in the division generally appreciate the atmosphere in the division, and the facilities offered for their research. A TU/e-wide survey of the work satisfaction revealed that the research staff is very motivated and that the number of conflicts within the Department are below average. One weak point was the lack of career opportunities that was felt, especially by junior staff members. The new personnel policy adopted in 2008 (see Section 4) aims to resolve this issue.

This year (2009) the financial situation of the department has, unfortunately, become more difficult. This of course also has an impact on the division finances. Hence, it is of great importance to increase our external funding, to give us more room financially. Increased external funding also leads to more temporary staff, who can help reducing the teaching load which is felt to be on the high side.

9. External validation

The appreciation of our research by the outside (non-scientific) world can be seen in a number of ways.

One example is the industry funding that we have acquired over the years, which has grown from 576 k€ in 2002 to 1823 k€ in 2008, and the many research projects with industry participation. The fact that industry values our PhD program is also apparent from the fact that about one-third of our PhD students is hired by industry from the Eindhoven area (usually in their research labs). Our PDEng program also has an excellent reputation: there are always more companies that want PDEng students to do projects—not note that the companies must pay for the students doing a project—than we can accommodate. LaQuSo, our Laboratory for Quality Software, has helped us to further increase our visibility. The VVSS, the annual LaQuSo Day, attracts more than 250 participants, of which about half are from industry.

Our work is also recognized at a national level. In 2009, for example, two of the four nominations for the ICTRegie award were for work by researchers of our division. The ICTRegie award

\(^7\)source: Publish or Perish. http://www.harzing.com/pop.htm
is annually given to acknowledge proven success in the transfer of scientific knowledge to econom-ically or societally successful applications. It is awarded by ICTRegie, the Netherlands ICT Research and Innovation Authority. In 2009 one nomination was for ProM, the process mining toolkit developed by the AIS group; the other was for Magnaview BV, a spin-off of the VIS group that develops and markets information visualization tools. LaQuSo was involved in the development of OpenController of the M2M-consortium, which also got a nomination.

10. Overview of the results

The table shows the aggregated number of publications. Details per programme are given in Section 9.c of the programme descriptions in Part B. See also Appendix C.

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Table 10: Aggregated number of publications.

The academic output shows a steady and significant increase. On average 26% of the academic publications consists of papers in refereed journals, and 65% consists of papers in refereed conference proceedings.

11. Analysis, perspectives and expectations for the institute

To shed some light on the future perspectives of the division, we perform a brief SWOT analysis, followed by some conclusions.

SWOT analysis

Strengths. The TU/e is situated in a part of the Netherlands that is a center for high-tech in-dustry. Consequently, the Division of Computer Science is geographically close to a number of companies with substantial R&D-activities in soft- and hardware (Philips, ASML, NXP, Océ, and several smaller companies organized in DevLab). This proximity facilitates close cooperation with these companies, and it ensures that the research of the division is inspired by practice. Moreover, it helps to transfer results back into industry; here LaQuSo also plays an important role. In addition, the vicinity of the Department of Electrical Engineering and the Embedded Systems Institute has allowed the division to become an important site for embedded-systems research. Given these facts it is not surprising that TU/e has made embedded systems one of their eight research profiles, which further helps us to stay prominent in this area. The excellent cooperation
with the IE&IS Department as well as the fact that LOIS (Logistics, Operations and their Information Systems) is one of the other TU/e research profiles has allowed the department to become a main site for information-systems research.

Most staff members of the division are highly motivated to do research at a top international level. As a result, the division has an excellent scientific reputation. For example, the TU/e consistently ranks highly in the annual poll by Elsevier, where full professors in the Netherlands are asked to rank the Dutch universities in their field of research. Our scientific quality also shows in the ability to attract grants from NWO. Many of the scientific staff members, including several of the full professors, are relatively young. Hence, we expect that we can keep up (and hopefully even further increase) our high research level.

**Weaknesses.** The number of PhD students in the division is relatively low. This has a direct impact on the research that we can do, but it also has some negative indirect consequences. In particular, it has financial consequences (since part of the division budget depends on the number of awarded PhD diplomas) and it has consequences for the teaching load of the scientific staff members. With more PhD students, the average teaching load will decrease.

Although the division is successful in attracting NWO grants, in the past we have been less successful in attracting large projects through other channels (e.g., in previous FES rounds). Recently, we have been able to capitalize on LaQuSo and also on our new expertise in security, leading to a better representation in the consortia applying for large projects.

**Opportunities.** A significant part of the national funding for academic research has recently been re-allocated: instead of being directly paid to the universities, these funds are now distributed through NWO. Although this imposes difficulties—see under Threats—it also provides us with an opportunity, because our success rate with NWO is relatively high.

A major part of the governmental financial support is through special thematic, often large-scale, programmes. So far we have not been as successful in this area as we would like to be. If, however, we were able to increase our participation in these large-scale projects, then this could lead to a significant increase in our research funding. We intend to exploit the existence of LaQuSo and NIRICT, and the closeness of ESI and the local industry, to profit more from these large-scale funding opportunities.

**Threats.** The figures show that the total funding is increasingly based on project money, and we expect that this trend will only increase. Hence the number of scientific staff on temporarily contracts has grown, which is a threat to the consolidation of the knowledge within the division. Furthermore, in many cases external funding requires matching from our own funds. This can disrupt the good balance between fundamental, curiosity-driven research and more applied research (for which it is easier to obtain funding).

Another threat is the decrease in the number of bachelor students. For the bachelor program, enrollment has always fluctuated widely, following economic developments, ranging from 182 to 46, but is not picking up since the dotcom crisis in 2001. Also, the demographic development in the area our inflow mainly comes from is not favorable. Although we compensate the decrease in bachelor students with a growing intake of international master students from 11% (=14 students) in the academic year 2005 to 37% (=57 students) in 2008, we feel that the current number of students may be too low to keep the department financially healthy in the long run. Hence, we should continue our efforts to attract more (especially bachelor) students.

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8 *Fonds Economische Structuurversterking.* The FES money is meant to strengthen the Dutch infrastructure in various ways. Strengthening the knowledge infrastructure is one goal. Typical FES projects in this domain have a size of tens of millions of euros.
Conclusions

From the above analysis we conclude that our research focus fits in well with our environment. We believe that the quality and enthusiasm of our researchers will allow us to sustain and hopefully even improve our success in attracting external funding for our research. The expected increase in external funding will most likely come for a significant part from contract research. When trying to attract such funding, we should beware that we keep our mission and research agenda in mind.

Our main concern at this point is the low number of bachelor students. As already remarked, we have been able to counter the decrease in bachelor students by an increase in master students, but one of our priorities for the future is to interest more high school students in studying computer science. (In fact, this is a national concern—see the recent Masterplan ICT⁹.)

⁹http://www.nwo.nl/files.nsf/pages/NWOA_7RXEKC/$file/Masterplan%20ICT.pdf
Part B

Programme descriptions
Architecture of Information Systems

**Full title**
Architecture of Information Systems

**Programme leader**
prof.dr.ir. W.M.P. van der Aalst (from September 2006)
prof.dr. K.M. van Hee (until September 2006)

**Starting date**
before 1996

**Research area**
Information systems

**CR-classification**
H. Information Systems
D.2.2 Design Tools and Techniques
H.4.1 Office Automation
H.2.8 Database Applications

**Affiliations**

*research school*
SIKS (Research School for Information and Knowledge Systems)
BETA (Research School for Operations Management and Logistics)

*TU/e*
LOIS (Logistics, Operations and their Information Systems)

**Cooperations** (at most five per category are listed)

*national*
prof. Geert-Jan Houben (Delft)
prof. Roel Wieringa (Twente)
prof. Farhad Arbab (CWI)
prof. Rinus Plasmeijer (Radboud University Nijmegen)

*international*
prof. Wolfgang Reisig and prof. Jan Mendling (Humboldt-Universität zu Berlin)
prof. Arthur ter Hofste and prof. Michael Rosemann (Queensland University of Technology)
prof. Karsten Wolf (Universität Rostock)
prof. Mathias Weske (Hasso Plattner Institute)
prof. Kurt Jensen (University of Aarhus)
Mission statement

The Architecture of Information Systems (AIS) research group investigates methods, techniques and tools for the design and analysis of Process-Aware Information Systems (PAIS), i.e., systems that support business processes (workflows) inside and between organizations. We are not only interested in these information systems and their architecture, but also model and analyze the business processes and organizations they support.

Our mission is to be one of the worldwide leading research groups in process modeling and analysis, process mining, and PAIS technology. We aim at results that are highly original and applicable in real-life situations. Our motto is “Process Technology that Works”.

1. Leadership

The Architecture of Information Systems (AIS) group is chaired by prof.dr.ir. Wil van der Aalst. The permanent staff of AIS involved in research currently consists of dr.ir. Boudewijn van Dongen, prof.dr. Kees van Hee (0.2), prof.dr.ir. Wim Nuijten (0.2), dr. Natalia Sidorova, dr.ir. Eric Verbeek, and dr. Marc Voorhoeve. There are about five postdocs and seven PhD's. The group has weekly meetings where the staff and postdocs discuss ongoing matters. There is another weekly meeting where one of the group members presents his/her work. There is also a regular colloquium series involving AIS, DH (the group of Paul De Bra), and the IS group in the Department of Industrial Engineering & Innovation Sciences (former group of Wil van der Aalst).

All PhD students, postdocs, and staff members are member of the School for Information and Knowledge Systems (SIKS). The PhD students follow SIKS courses, take advanced courses at TU/e, and participate in summer schools. All PhD students have weekly meetings with their promotor and in most cases also a daily supervisor is assigned. Cooperation with other groups is stimulated and group members are encouraged to submit papers to competitive conferences like Caise, BPM, ATPN, etc. and journals such as Information Systems, Distributed and Parallel Databases, IEEE Transactions on Knowledge and Data Engineering, Data and Knowledge Engineering, Fundamenta Informaticae, Acta Informatica, and Cooperative Information Systems.

There is a strong emphasis on tooling and empirical validation. We aim at techniques that actually work under realistic circumstances and are inspired by the challenges posed by practical applications of our results, cf. our motto “Process Technology that Works”. Therefore, tooling is important. Moreover, the joint development of major software systems (such as the process analysis tool ProM) stimulates and facilitates cooperation within the group.

2. Strategy and policy

2.a. Design in brief

Until 2004 the group was named Specification and Modeling of Information Systems (SMIS). In 2004 the group was renamed to Architecture of Information Systems (AIS). Within the SMIS/AIS group there is a long-standing tradition in modeling and analyzing Process-Aware Information System (PAISs) using Petri nets. A PAIS is a software system that manages and executes operational processes involving people, applications, and/or information sources on the basis of process models. Example PAISs are workflow management systems, case-handling systems, middleware platforms, enterprise information systems, etc.

In the nineties the group worked on ExSpect (Executable Specification Tool, www.exspect.com), a specification language and corresponding toolset based on Petri nets extended with
data, time, and hierarchy. ExSpect has been used to specify a wide variety of systems (from entire supply chains to embedded software in e.g. copiers) and its simulation engine turned out to be very useful in all kinds of practical situations. In the late nineties the development moved to Bakkenist consultancy (now part of Deloitte), because most of the research challenges related to the execution and simulation of high-level Petri nets had been addressed. Despite several successful applications, Deloitte discontinued the development of ExSpect. In parallel the simulation engine of ExSpect was embedded in several other software products. Most notable is the embedding of ExSpect in Protos of Pallas Athena. Protos is the most widely used business process modeling tool in the Netherlands (over 1 million users and, for example, used by more than half of all Dutch municipalities). ExSpect is shipped with all versions of Protos and BPM|one.

Although tools such as ExSpect are highly generic and can be applied to a variety of systems and processes (e.g., embedded systems, supply chains, etc.), the main focus since the late nineties has been on PAISs (in particular workflow management systems). The AIS group was among the first groups to formalize workflow concepts in a systematic manner. Van der Aalst introduced the so-called WorkFlow nets (WF-nets) and a correctness criterion called soundness. WF-nets are a subclass of Petri nets tailored towards workflow modeling and analysis. The modeling of WF-nets and the analysis of soundness are supported by tools such as Woflan and Yasper. WF-nets and soundness have been widely adopted within the academic community and these techniques are increasingly used in all kinds of commercial software products (Protos, IBM WebSphere, etc.). Members of the AIS group worked on alternative soundness notions, verification techniques, and also applied these techniques to large sets of real-life process models. For example, we showed that more than 20 percent of the 600 process models in SAP’s well-known Reference Model contain errors.

In September 2006, Van der Aalst moved from the Information Systems group in the Department of Industrial Engineering & Innovation Sciences (IEIS) to the AIS group. Before his move, he was chair of the Information Systems group, and from 2000 until 2003 he was also a part-time professor within AIS. Currently, Van der Aalst holds part-time professorships in IEIS and the BPM group at Queensland University of Technology. Because of the move of Van der Aalst, Verbeek, and Van Dongen from IEIS to AIS, the focus of AIS was extended to also include process mining. To explain the relation between process mining and the earlier work of AIS on Petri nets and workflow verification, let us consider Figure 3.

This figure shows the role of (process) models in the PAIS context. Process models can be used to describe and analyze processes and to specify, configure, or implement information systems. The left-hand-side of Figure 3 shows some examples of design-time analysis: validation (i.e., testing whether the process behaves as expected), verification (i.e., establishing the correctness
of a process definition), and traditional (i.e., non-log based) performance analysis (e.g., using simulation to evaluate the ability to meet requirements with respect to throughput times, service levels, and resource utilization).

Traditionally, most of AIS’s research focused on design-time analysis. However, more and more information about (business) processes is recorded by information systems in the form of so-called “event logs”. IT systems are becoming more and more intertwined with these processes, resulting in an “explosion” of available data that can be used for analysis purposes. The goal of process mining is to extract process-related information from event logs, e.g., to automatically discover a process model by observing events recorded by some information system. However, process mining is not limited to discovery and also includes conformance checking (investigating whether reality conforms to a given model and vice versa) and extension (augmenting an existing model with additional insights extracted from some event log).

Since 2006, AIS is also focusing on process mining. In fact, Van der Aalst and his colleagues established process mining as a research field and developed the influential ProM framework. Currently, process mining is seen as one of the main innovations in business process management, and the ideas are rapidly being incorporated in commercial products (BPMone, Futura Reflect, ARIS PPM, etc.). The combination of knowledge about PAIS technology, process modeling notations, Petri net theory, process verification, and data mining turns out to be an excellent basis for process mining research. Classical techniques in the field of data mining and the so-called Business Intelligence (BI) tools used in industry do not explicitly focus on process models. As a result, the scope is limited to data dependencies and performance measurements. AIS’s unique set of capabilities can be used to bridge the gap between process modeling and analysis on the one hand and data mining and BI on the other. This provides an ideal starting point for scientific and technological breakthroughs in process mining.

2.b. Future Programme development

Current AIS research concentrates on formalisms for modeling and methods to discover and analyze models. On the one hand formal methods are being used, e.g., the group has a long tradition in Petri-net modeling and analysis. On the other hand, we are interested in modeling languages widely used in industry (EPCs, UML, BPMN, BPEL, etc.). Moreover, in contrast to many other research groups in this area, we do not blindly accept “man-made models” as an objective starting point, i.e., we also try to discover process models through process mining and check the conformance of models based on reality.

The goal for the next five years is to further develop the main three lines of research of AIS:

- **Research line 1: Process Modeling/Analysis.** While various types of process notations are used in industry, formal models such as Petri nets are more suitable for analysis purposes. Driven by questions from the other two research lines (process mining and PAIS technology), particular models (e.g., WF-nets, WF-nets with data and resources, history-dependent nets, open nets, nested nets, etc.) are used to answer questions related to correctness and performance. The main techniques that are used are model checking, structural techniques (invariants, etc.), simulation, and Markov (decision) processes. Moreover, quite some efforts are made to translate industry standards and proprietary languages (EPCs, UML, BPMN, BPEL, etc.) to formal models (typically Petri nets). One of the main goals in Research line 1 is to further improve verification techniques to check various properties such as soundness, data/resource soundness, accordance, controllability, and selected temporal properties. Here there is a need for more empirical research, i.e., analyzing large repositories of models like the SAP Reference Model. Moreover, pattern-based approaches can be used for correctness-by-design. Another goal is to develop innovative simulation approaches that better reflect reality and that can be used in an operational setting while using process mining results. A prerequisite for the above analysis approaches
Figure 4: The three main research areas and the most relevant tools.

is the consistent integration of the different perspectives.

- **Research line 2: Process Mining.** Process mining techniques are used to extract process-related information from event logs, e.g., to automatically discover models, check conformance, and augment existing models with additional insights extracted from some event log. The main difference with Research line 1 is that event logs play a central role (rather than predefined process models). One goal is to significantly improve the state-of-the-art in process discovery. A particular challenge is to deal with less structured processes and incomplete event logs. For this we want to improve our approaches based on region theory, fuzzy models, and genetic mining. Another goal is to advance the state-of-the-art in conformance checking, e.g., by refining our replay strategies and to allow for on-the-fly checking. Related is the challenge to predict problems, i.e., provide warnings based on historic information (e.g., a case will be late or an error is likely to occur). To achieve this, we plan to use pattern analysis, correlation analysis, and trace clustering.

- **Research line 3: PAIS Technology.** PAISs are used to manage and execute operational processes involving people, applications, and/or information sources. Examples are WFM (Workflow Management), BPM (Business Process Management), and ERP (Enterprise Resource Planning) systems. Increasingly, these systems are driven by models (connection to Research line 1) and produce high-quality event logs (connection to Research line 2). We are interested in the artifacts used and produced by these systems (i.e., models and logs) as these are essential for testing the techniques developed in the two other research lines. For example, it is interesting to convert and verify process models expressed in some particular industry language. This enables empirical research and triggers new questions. The same holds of course for event logs. We are also studying PAIS architectures. Note that service-orientation plays an important role here and this new architectural style poses new research questions. Although most PAISs are used in a business setting (governments, banks, insurance companies, supply chains, etc.), we are also interested in scientific computing and grid architectures. Note that the “process of process mining” can be seen as a scientific workflow. Moreover, for large scale process mining experiments, we are using our own grid with a dedicated grid architecture. In Research line 3 we heavily rely on the workflow patterns. This helps us to understand and characterize PAISs.

The three research lines are interconnected in various ways. PAISs are process-aware, use models, and provide for event logs. These models and logs can be analyzed using the techniques
developed in Research line 1 and Research line 2. Moreover, these analysis results can be used by the PAIS, e.g., for recommendations, predictions, and diagnosis.

Tools play a crucial role in the development of the three research lines. As Figure 4 shows, ProM is the central tool for realizing and evaluating our ideas. New techniques related to process mining and process modeling/analysis will be realized in ProM. ProM subsumes the functionality of Woflan (workflow verification) and Yasper (workflow modeling and analysis). Other relevant tools are Declare and YAWL. These are two open-source workflow management systems that are (partly) developed within AIS. Declare is a system aiming at more flexibility using a declarative style of modeling grounded in temporal logic. YAWL is a highly expressive workflow management system based on the workflow patterns and a result of our joint research with QUT. Both Declare and YAWL are tightly connected to ProM, e.g., ProM can analyze the logs and models of YAWL and Declare. Figure 4 also mentions some software systems not developed within AIS. In our teaching and research we are heavily using CPN Tools. CPN Tools is a standard Petri net tool for modeling and analyzing high-level nets. We are mainly using CPN Tools for simulation and conceptualizing ideas. BPMone of Pallas Athena and Websphere of IBM are two commercial PAISs were we will continue to invest in. Both BPMone and Websphere have adopted results from our research and are interesting commercial platforms for testing research ideas.

3. Processes in research, internal and external collaboration

As indicated earlier, there are two weekly group meetings. In one meeting, the permanent staff and the postdocs discuss the research strategy, the educational program, and operational matters related to research and teaching. In the other meeting, one of the AIS members presents ongoing work with the goal to get feedback from the rest of the group. There are also several other colloquia where AIS is involved in (e.g., the colloquium of both IS groups and the Computer Science Colloquium). There is also a biweekly ProM Developers Meeting and a monthly ProM Users Meeting. Hence, there are ample opportunities to exchange ideas.

Externally funded research projects are very important for realizing the research goals. Therefore, all AIS members are encouraged to submit proposals to NWO, STW, IOP, etc., and these proposals are discussed internally.

AIS works together with several organizations (universities, research institutes, software vendors, consultancy firms, and end-user organizations). Most notable are the cooperation with the Humboldt-Universität zu Berlin and Universität Rostock in the context of the B.E.S.T. program (Berlin - Rostock- Eindhoven Service Technology Program) and the cooperation with the BPM group of Queensland University of Technology. This is reflected by joint papers, joint PhD projects, and a continuous exchange of staff.

4. Academic reputation

W. van der Aalst

- Published about 190 papers since 2002 according to DBLP. Many of these papers are highly cited as is indicated by his Hirsch Index of 61 (Publish or Perish, July 2009) and, according to the Essential Science Indicators (based on the ISI Web of Science, July 2009), he is the highest ranked Dutch Computer Scientist.
- Associate editor of several journals, including IEEE Transactions on Services Computing, IEEE Transactions on Industrial Informatics, International Journal of Business Process Integration and Management, International Journal on Enterprise Modelling and Information

- Series Editor of Lecture Notes in Business Information Processing (LNBIP) by Springer.
- Member of the editorial board of Distributed and Parallel Databases and Business & Information Systems Engineering.
- Member of several steering committees, including International Conference Series on Business Process Management (chair), International Conference Series on Application and Theory of Petri nets and International Workshop Series on Web Services and Formal Methods.
- Program committee member of about 120 workshops and conferences since 2002.

K. van Hee

- Member of the editorial board of the International Journal of Business Process Integration and Management.
- Member of the editorial board of Transactions on Petri Nets and Other models of Concurrency.

N. Sidorova

- PC member of the following conferences and workshops: APNOC09 (co-chair), CASE 2009 (Associate Editor), FM 2009, PNSE09, OrgMod09, PNDS08 (co-chair), WS-FM 2008, EOMAS 2008, Confenis 2007, MSVVEIS'07, MSVVEIS'06, MSVVEIS'05.
- 12 publications in international peer-reviewed journals and 42 publications in international peer-reviewed conferences.
- Member of organizing committees of the following conferences: PaCT 97 and ICATPN2003

B. van Dongen

- Published about 28 papers since 2002 according to DBLP.

5. Internal evaluation

See Part A.8
6. External validation

6.a. Societal relevance

AIS researchers have worked on a wide range of topics including workflow management, process mining, simulation, Petri nets, business process management, process modeling, and process analysis. This resulted not only in landmark publications but also in software products and true impact in industry.

The notion of soundness has been widely adopted. Moreover, it is now possible to analyze the models used in industry (BPMN, EPCs, Protos, etc.). For example, we analyzed the entire SAP Reference Model and found that about 20 percent of its EPCs (Event-driven Process Chains) are flawed. This raised quite some interest from industry. For example, the German magazine for IT professionals (iX) featured an article “SAPs Referenzmodell: Sand im Getriebe” presenting our findings. Similar articles appeared in the Automatisering Gids, Computable, BPTrends, etc. and have made practitioners aware of the need for verification.

The Workflow Patterns initiative has influenced several standardization processes and has become a standard tool for the selection of WFM/BPM technology. In the last decade hundreds of patterns have been collected and these are distributed via the website www.workflowpatterns.com. This website was set up by Van der Aalst and has been the most visited website in the workflow area for many years. On a typical working day the site is visited by more than 500 unique visitors, thus illustrating the practical interest in the workflow patterns. Standards like BPEL, BPMN, etc. are influenced by the patterns. Moreover, several vendors have extended their systems based on the patterns (IBM, Staffware, Pallas Athena, JBoss, BizAg, Pectra, etc.).

More recently, the work on process mining had significant impact on the BPM field. The ProM tool, developed by members of the AIS group, has been applied in dozens of companies. Many of the ideas in ProM have been re-implemented in commercial tools such as Protos, BPM|one, Futura Reflect, ARIS PPM, etc. The work on process mining done at TU/e is seen as one of the most important innovations in the BPM field by Gartner. This is illustrated by the fact that Futura Process Intelligence and Pallas Athena were recently selected as “Cool Vendor 2009” by Gartner, because of their process mining capabilities. Both tools use genetic process mining algorithms developed for ProM. The work on process mining done within AIS was also nominated for the ICTregie Award 2009 because of the many real-life applications of ProM.

AIS also plays an important role in LaQuSo (Laboratory for Quality Software) where process mining is one of the main services. Through LaQuSo several process mining projects have been conducted in industry.

6b. Industrial contacts

### 7. Researchers and other personnel

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8. Resources, funding and facilities

8.a. Laboratory infrastructure

The AIS group has an excellent IT infrastructure for conducting research on process modeling and analysis, process mining, and PAIS technology. Many vendors have donated their software, e.g., we are frequently using WebSphere of IBM, BPMone of Pallas Athena, Staffware of Tibco, etc. To effectively use these packages, we have several powerful server machines. Moreover, for our process mining research we have set up a computer grid in 2008. This allows us to do the large scale experiments needed for evaluating various genetic process mining techniques, simulating redesign strategies, workflow planning techniques, workflow testing, verification, etc.

8.b Funding

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Table 11: Funding of AIS.

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Table 12: Funding of postdocs/PhD’s.

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

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<td>2007–2010</td>
<td>NWO(OC) : Providing full life cycle support for adaptive process by advanced mining approaches Schonenberg M.H.</td>
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<td>2007–2010</td>
<td>NWO(OC) : Workflow Management for Large Parallel and Distributed Applications Bratosin, Troka</td>
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</table>
Overview of the results

9.a. Key publications

   (This paper describes the first set of 20 control-flow patterns. This triggered a new line of research where patterns are being documented based on their actual use in practise. The paper has had a tremendous impact. The workflow patterns are known by all researchers in the workflow and BPM space. Moreover, the work is used in standards and triggered the modification of many workflow management systems.)

   (This book has become one of the standard reference books in this area. It has been translated into Chinese, Dutch, Russian, and Portuguese. The book stimulated researchers and practitioners to use Petri nets for the modeling and analysis of workflow systems. It is used as a textbook at many universities all over the world.)

   (This was the first paper on YAWL. The paper defines operational semantics for YAWL and shows its support for the workflow patterns. Since then, many researchers have used YAWL as a formal foundation for their work. Moreover, the software supporting the YAWL is one of the most widely used open-source workflow systems. The paper triggered a lot of research as is illustrated by the YAWL book published by Springer (in print).)

   (This paper provides an early survey on process mining and defines a tool independent XML format to store logs (MXML). It compares different approaches and identifies important challenges. It triggered new research and several research groups (including AIS) are still working on challenges identified in this paper. Moreover, MXML is still the standard format to store and structure events logs.)

This paper provides a theoretical analysis of the $\alpha$ algorithm developed by the authors. It shows which classes of processes can be discovered and which cannot be discovered. The $\alpha$ algorithm was the starting point for the process mining initiative at TU/e and resulted in the development of ProM, which is now the core tool within AIS.

9.b. Numerical overview

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<td>3</td>
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<tr>
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<td>19</td>
<td>16</td>
<td>67</td>
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2. Monographs

3. Ph.D. theses

4. Profess. publ. & products

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<th>Academic publications</th>
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<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>a. publications</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>b. software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
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<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

9.c. List of publications

Academic publications: refereed journals

2002.


2003


**W.M.P. van der Aalst** (2003). Don’t go with the flow: Web services composition standards exposed. *IEEE Intelligent Systems, 18*(1), 72-76.

10Names of authors participating in the research programme AIS are printed in boldface.


2004


2005


2006


of Web Engineering, 5(2), 175-200.


K.A.M. van der Sluijs, G.J.P.M. Houben (2006). A generic component for exchanging user models between web-based systems. International Journal of Continuing Engineering Education and Lifelong Learning, 16(1-2), 64-78. (also listed under DH)


2007


2008


equivalence based on observed behavior. *Data and Knowledge Engineering*, 64(1), 55-74.


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40 Research Evaluation Computer Science 2009 * Part B: AIS


**Academic publications: refereed conference proceedings**

*2002*


F. Frasincar, G.J.P.M. Houben (2002). Hypermedia presentation adaptation on the semantic


of the 14th International Conference on Advanced Information Systems Engineering (CAiSE’02), LNCS 2348 pp 535–552. Springer-Verlag, Berlin.


2003


2004


2005


of heterogeneous relational data with OWL. In C.S. Chen et al. (Eds.), *Proceedings of the 7th International Conference on Enterprise Information Systems (ICEIS 2005, Miami FL, USA, May 24–28, 2005)*, Volume 1 (pp. 11–18).


] 2006


2007


currency Specification and Programming (CS&P’07, Lagów, Poland, September 27-29, 2007).


2008


(pp. 152-171). Springer. (also listed under VIS)


Academic publications: book chapters

2002


2005


2006


Institute. (also listed under SET)


2007


2008


Academic publications : other academic publications

2002


2006

2007


Monographs

2002

2003

2004


PhD theses

2002

2004

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2007


PhD theses (member of this programme as second or co-supervisor)


Professional publications


Professional products: Software


10. SWOT-analysis

Strengths.

- The AIS group is seen as one of the globally leading groups in three areas: Process Mining, Petri nets, and Business Process Management.
- Each year, many researchers working in the above areas visit Eindhoven for a longer or shorter time.
- The publications of AIS are highly visible and often cited. Van der Aalst has an Hirsch Index of 57 and, according to the Essential Science Indicators (based on the ISI Web of Science, March 2009), he is the highest ranked Dutch Computer Scientist.
- The AIS group has an impressive track record when it comes to developing software tools, cf. ExSpect, Woflan, Yasper, YAWL, and ProM. These systems serve as a reference and are widely used. For example, YAWL has been downloaded more than 81,000 times and ProM approximately 25,000 times. The ExSpect simulation engine is used in Protos, the most widely used business process modeling tool in The Netherlands.
- The work of the AIS group has influenced the software industry. The work on the workflow patterns and YAWL has influenced the standardization of BPEL, BPMN, WSMX, and WS-CDL. Several vendors revised their systems to support more of our workflow patterns (IBM, Pallas Athena, Staffware, etc.). Our process mining techniques have been embedded in several commercial systems (BPM|one, Futura Reflect, ARIS PPM, etc.).

Weaknesses.

- In the past, AIS had only a few PhD students due to a vacant full professorship position. Although this has improved considerably, this will have a negative effect on the financial
position of the group in the next couple of years (due to the delayed effects in the budgeting system).

• Although the overall number and quality of publications of AIS is high, some group members should publish more, i.e., the distribution of scientific output is distributed unevenly.

Opportunities.

• The ProM framework provides an excellent starting point for new research on process mining, process modeling and analysis, and PAIS technology. The ProM framework provides good opportunities for valorization and internal cooperation.

• Several companies start to adopt our process mining research and there are several spin-offs from people within the group (Futura Process Intelligence and Fluxicon). This may result in additional funding and exposure.

• AIS is involved in organizations such as LaQuSo, NIRICT, CeDICT, etc. and could take more advantage of this.

• Ample opportunities for even more collaboration within the department, in particular with prof. Paul De Bra (DH) on data mining, prof. Jack van Wijk (VIS) on visualizing processes and data, prof. Sandro Etalle (SEC) on mining, security, and auditing, prof. Mark van den Brand (SET) on combining process and code mining, and prof. Jos Baeten (FM) and prof. Jan Friso Groote (OAS) on process verification. For example, people from AIS and DH already organized several joint workshops on process and data mining.

Threats.

• The weak financial position of the Department of Mathematics and Computer Science may negatively impact the AIS group. Restrictions on traveling, less support for LaQuSo, more teaching duties, etc. will make it more difficult to reach our research goals and may frustrate ambitious researchers within AIS.

• The AIS group has undergone a considerable transformation both in terms of staff and ambition level. Moreover, process mining has been established as a new research topic within AIS. Initiatives and responsibilities are still distributed unevenly making the group more vulnerable and dependent upon a few individuals.

• The group is not very active at the national level and has chosen to focus on international scientific networks rather than national ones. Since funding is being taken away from the universities and redistributed at the national level, national networks become more important.

The above analysis shows that the AIS group is well positioned for achieving breakthroughs in the development of methods, techniques and tools for the design and analysis of Process-Aware Information Systems (PAISs). The three research lines (process modeling and analysis, process mining, and PAIS technology) provide a broad but also coherent research agenda. This will allow AIS to remain one of the world-wide leading research group in the areas mentioned.
Databases and Hypermedia

**Full title**
Databases and Hypermedia (DH)

**Programme leader**
prof. dr. P.M.E. De Bra

**Starting date**
August 1, 1996

**Research area**
Information Systems

**CR-classification**
H. Information systems, and in particular
  H.1 Models and principles
  H.3 Information storage and retrieval
  H.4 Information systems applications
  H.5 Information interfaces and presentation

**Affiliations**
research school SIKS (Research School for Information and Knowledge Systems)

**Cooperations** (at most five per category are listed)

national
  prof. Geert-Jan Houben (TU Delft)
  prof. Anton Nijholt (University of Twente)
  prof. Lynda Hardman (CWI, Amsterdam)
  prof. Guus Schreiber (VU, Amsterdam)
  prof. Marcus Specht, (OU-NL, Heerlen)

international
  prof. dr Wolfgang Nejdl (L3S, Hannover, Germany)
  prof. Vincent Wade (Trinity College Dublin, Ireland)
  prof. Peter Brusilovsky (University of Pittsburgh, USA)
  prof. Bart Goethals (University of Antwerp, Belgium)
  prof. Hugh Davis (University of Southampton)
Mission statement

The development of new (formal) models, methods and practical (software) tools for the correct and efficient design, construction and use of online information systems. We are inspired by information handling problems (access, discovery, management) from the industry, society and academia and we will develop new theories, methods and tools that can be used by practitioners who are lacking deep theoretical knowledge.

1. Leadership

The DH group is headed by one full professor. There are currently (early 2009) two assistant professors who are encouraged to start forming their own subgroup. In the group there are regular private and plenary meetings, with PhD students, sometimes master students and assistant professors where the preliminary results are presented, and new problems are identified. The co-authorship for publications shows that the subgroups are beginning to form while maintaining the overall collaboration within the group. The cooperation and individual development of the group members and subgroups are the result of a coaching leadership style, which means that the focus of the group leader is on facilitating the group processes and giving the assistant professors enough room to develop their own profile and research focus in order to become recognized as top researchers in their own (sub)field. The other main tasks of the leader is to maintain common research goals and a common high quality standard.

2. Strategy and policy

Management of information is one of the most challenging computer science problems for the future. Discovering and extracting the most relevant information in large data sources, making information accessible to human users (as well as machines) and supporting the tasks of these users through information are becoming increasingly difficult as people and information are becoming permanently on-line and people start depending on on-line information for all aspects of their life. Information systems were traditionally built around a (relational) database on top of which custom-made application programs were built. Developing new ways of storing, retrieving and manipulating semantically enriched data is the main challenge for the future and requires new information system paradigms. We investigate both the theoretical foundations of and the development of practical tools for coping with the information explosion in our increasingly globally linked world.

2.a. Design in brief

We concentrate on three aspects of data access and management: (a) the management of semi-structured and semantically linked data, (b) data mining technology for aiding information discovery, (c) user modeling, personalization and adaptive information delivery.

The work on the management of semi-structured (and linked) data concentrates on representing and retrieving information, using semantically meaningful metadata. It ranges from the study of XML, RDF and XML and RDF query languages (XPath, XQuery, OWL) to concrete storage, indexing and retrieval technology to effectively and efficiently handle semi-structured data. This work has practical applications in Web-Information Systems, where we concentrate on the aspects of navigation and adaptation. We have just hired a new assistant professor, dr. George Fletcher, to strengthen this research direction.
The work on data mining technology for aiding information discovery combines fundamental research into data structures and algorithms for data mining (to improve the performance of data mining processes) with application-oriented research into specific data mining problems like detecting concept drift and classifying without discriminating. The former has concrete applications in many areas, including detecting trends and fluctuations in industrial processes but also detecting a shift in customer interest in on-line shops and predicting sales in order to optimize (wholesale) store inventory. The latter has applications in e-business where business decisions based on patterns discovered through data mining must obey certain anti-discrimination laws. For the data mining work we also collaborate with the AIS research group in which the topic of process mining is studied (which is essentially data mining on process data).

The work on personalization and adaptation in information access and delivery concentrates on designing and implementing generic (models and technology for) adaptive information systems. This work has applications in e-culture, e-entertainment, e-learning and e-business. Personalization is the only way in which humans can continue to use the ever increasing amount of information that is available on-line. Personalization and adaptation not only help the human information consumer but also the providers who can to more targeted information delivery.

2.b. Future Programme development

The research and development in "information management" is strongly inspired by good relationships with the industry and with other scientists in the world, but also by problems we encounter in our own environment of teaching, research and the business of running a university. We select and tackle problems that are relevant for the industry and that have enough scientific challenges. The main challenge for the future is making adaptation processes automatic. In the current projects (CHIP in cultural heritage, iFanzy in e-Entertainment, e-business (wholesale predictions for Sligro and on-line support services for Adversiteme) and the EU FP7 project GRAPPLE on adaptive learning a designer explicitly guides the adaptation processes through adaptation rules. Through the use of data mining and machine learning we will work towards the automatic generation of adaptation rules (thus making the adaptation adaptive). We will do this again in collaborative projects with industry.

3. Processes in research, internal and external collaboration

We maintain a strong focus on high scientific quality, while at the same time seeking out practical applications for the theory and the methods that we develop. This explains our strong relationships with industrial partners and the fact that many theoretical results and insights are translated into software tools (like our adaptive hypermedia environment) and practical applications (like the Rijksmuseum Art Recommender, the iFanzy TV guide which are publicly visible as well as tools used by industry for their internal processes, thus not publicly visible). There is an open culture in which each idea is welcome and in which there is a lot of teamwork (many co-authors in publications). While the group leader "binds" the research in a common context the assistant professors have a strong influence on the elaboration of new ideas and the technical guidance of PhD’s. Assistant professors are stimulated to find and promote their own niche within the information systems research and through contacts with industry, so as to lay the basis for their future academic career evolution.
4. Academic reputation

The DH group as a whole has high standing in the information systems research community. The group leader and the assistant professors individually have an even higher standing in their own niche. Their visibility as highly esteemed researchers demonstrates that the “facilitating management” approach really works. The DH group has hosted the Adaptive Hypermedia conference in 2004 and is hosting BNAIC (Benelux Artificial Intelligence Conference) in 2009. The group has delivered steering and program committee chairs and members for a large number of highly regarded conferences in the core of its research field, including the International World Wide Web conference, the International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems, the International Conference on User Modeling, the ACM Conference on Hypertext and Hypermedia, the International Conference on Web Engineering, the PODS (Principles of Database Systems), ACM SIGKDD (Knowledge Discovery and Data Mining), Advanced Visual Interfaces (AVI), EDM (Educational Data Mining), ED-MEDIA, E-LEARN, etc., etc., membership of editorial boards like the Journal on Web Engineering (JWE), the International Journal on Web Engineering Technology (IJWET), the Journal on Digital Information (JoDi), the New Review on Hypermedia and Multimedia (NRHM), ACM Transactions on the Web, IEEE Transactions on Learning Technology, etc. The DH group has been a core member of the PROLEARN Network of Excellence on Professional learning and has not only been invited to participate in many collaborative projects but has initiated and is leading the over 5 million euro FP7 project GRAPPLE (with 15 partners) on adaptive learning technology.

During a significant part of the review period the DH group had three assistant professors who have left the group to take on a new responsibility elsewhere (showing once more that the “facilitating management” approach really stimulates the researchers to become well known in their own niche and be offered better positions elsewhere). To keep our list of evidence of esteemed academic reputation reasonably short we only list the full-time staff members below who are currently in our group: the group leader (prof. dr. Paul De Bra) and two assistant professors (dr. Toon Calders and dr. Mykola Pechenizkiy). Also, we only list involvement in independent scientific events like conferences and not in workshops that are associated with conferences.

prof. dr. Paul De Bra

- Editor: Lecture Notes in Computing Science, volumes 2347 and 3137 (proceedings of the Adaptive Hypermedia conference in 2002 and 2004)
- Associate Editor: IEEE Transactions on Learning Technologies
- Editorial Board Member: The New Review of Hypermedia and Multimedia
- Guest editor: The New Review of Hypermedia and Multimedia, special issue on Adaptive Hypermedia
- IEEE Transactions on Learning Technologies, special issue on Personalization
- Program committee: ACM HT (PC member in several years, track chair in 2007), AH (PC member in several years, PC chair in 2002), UM (PC member in 2005), EC-TEL (PC member in several years), AACE E-Learn (PC member in several years), AACE ED-MEDIA (PC member in several years, steering committee member in 2006, 2007 and 2008).
- Organizing committee: general chair of AH 2004.
- Other international scientific committees: Director “at Large” of User Modeling Inc.
- Other national scientific committees: board member of the research school SIKS, program board member of the NWO CATCH research program, chair of the advisory board of the NLnet Foundation (until 2006), advisory board member of Inno.com.
- Published around 150 papers in peer-reviewed journals and conferences.
dr. Toon Calders

- Editorial Board Member: Data Mining and Knowledge Discovery (Springer, Impact Factor 2.42)
- Program committee: ECML/PKDD (Area Chair in several years), IEEE ICDM (PC member in several years, vice-chair and best-paper committee member in 2008), ACM Symposium on Principles of Database Systems (PC member in 2009), SIAM Conference on Data Mining (PC member in several years), ACM SIGKDD (PC member in several years), ACM SAC, Data Mining Track (PC member in several years), BNAIC (PC Chair for 2009)
- Organizing committee: BNAIC 2009
- Other international scientific committees: FNRS Doctoral school Computational Intelligence and Learning (2006)
- Published over 40 papers in peer-reviewed journals and conferences.
- Best paper awards:

dr. Mykola Pechenizkiy

- Program committee/organization, only as chair: IPM’08, ECML/PKDD’2008, IEEE CADML’07 (workshop co-chair), EC-TEL’2007 (workshop co-chair), IEEE CBMS 2006 (Special Tracks Co-Chair), PMKD’06 (Workshop Co-chair),
- Program committee, only as member, only independent conferences and workshops (not workshops at conferences): ECML/PKDD’08, EDM’08, Louhi’08, IEEE CBMS’08, IEEE CBMS’07, IEEE CBMS’06, IEEE CBMS’05, ISDA’06.
- Published over 60 papers in peer-reviewed journals and conferences.
- Educational Data Mining Frontiers. Education Day (Faculty of Electrical Engineering, TU/e), Turnhout, Belgium (May 2008)

5. Internal evaluation

See Part A.8
6. External validation

The database and hypermedia group performs research that is directly relevant for industry and society, and this shows through joint projects with institutes and companies in the areas of e-business, e-culture, e-entertainment and e-learning. The research on data mining was started in 2006 and has already had impact on industry to the extent that we have started long-term collaboration with Sligro and Advertising and have contacts with a number of other interested industrial partners. The research on personalization and adaptation has resulted in the most commonly used reference model for adaptive hypermedia (AHAM), the most often used and referenced adaptive hypermedia system (AHA!) and in a number of collaborative research projects and prototypes, including the CHIP project with the Rijksmuseum, iFanzy in collaboration with Stoneroos, resulting from the ITEA Passepartout project with many industrial partners, and the EU FP7 GRAPPLE project with 15 partners including 3 industrial partners. The research has also resulted in informal and formal collaboration with other companies, for instance ATSC and Turpin Vision (the latter is partner in the Socrates-Minerva project ALS (Adaptive Learning Spaces). The DH group was also a core partner in the PROLEARN Network of Excellence in Professional Learning, which shows its prominent position in the European TEL research community.

6a. Societal relevance

Personalization is becoming increasingly important in our society in which everyone is becoming on-line and people and services are increasingly also permanently on-line. Finding relevant information becomes more difficult unless systems can make use of user-models to better identify the user’s information need. We are working on personalization in the areas of cultural heritage, learning, entertainment and information services for a variety of organizations. (Some collaborations are confidential and cannot be reported here.) We are not only working in application areas that are very relevant for society but we also develop generic technology (especially the AHA! system) that enables others to introduce personalization in their own environment or for their own customers.

6b. Industrial contacts

Through the different collaborative projects, but also through master students, the DH group has contacts with numerous companies, not only in the Netherlands but also in other countries. The contacts include large companies: Philips, Sony-Ericsson, ATOS, and SME’s (or smaller parts of larger consortia): Giunti Labs (Sestri-Levante, Italy), IM-C (Saarbrücken, Germany), Softwin (Bucharest, Romania), ATSC, Turpin Vision, Magnaview, Stoneroos, V2, etc. There are also contacts with cultural institutes: RHC-e and the Rijksmuseum.
## 7. Researchers and other personnel

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
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<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
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<tbody>
<tr>
<td><strong>Full professor</strong></td>
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<td>De Bra, prof.dr. P.M.E.</td>
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<td>Aroyo, dr. L.M.</td>
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<td>0.32</td>
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<td>Cristea, dr. A.I.</td>
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<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.27</td>
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<td></td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total tenured staff</strong></td>
<td>1.52</td>
<td>1.52</td>
<td>1.52</td>
<td>1.52</td>
<td>1.31</td>
<td>0.80</td>
<td>0.57</td>
</tr>
</tbody>
</table>

|                        |      |      |      |      | 0.01 |      |      |

| **Assistant professor** |      |      |      |      |      |      |      |
| Calvi, dr. L.          | 0.30 |      |      |      |      |      |      |
| Fransincar PDEng, F.   |      |      | 0.08 | 0.20 | 0.12 |      |      |
| Vdovjak PDEng, R.      |      |      | 0.12 | 0.20 | 0.08 |      |      |
| Calders, dr. T.G.K.    |      |      |      |      |      | 0.10 | 0.40 | 0.30 |
| Pechenizkiy, dr. M.    |      |      |      |      |      | 0.10 | 0.40 | 0.40 |
| Aroyo, dr. L.M.        |      |      |      |      |      | 0.30 | 0.40 | 0.40 |

| **Researcher**         |      |      |      |      |      |      |      |
| Stash, ir. N.          | 0.80 | 0.80 | 0.33 |      |      |      |      |
| Santic, ir. T.         |      |      |      | 0.20 |      |      |      |
| Smits, D.              |      |      |      |      |      | 0.53 | 0.80 | 0.80 | 0.80 | 0.52 |
| Björkman, dr. M.L.     |      |      |      |      |      | 0.30 | 0.80 |      |      | 0.27 |
| van der Sluijs, ir. K.A.M. |      |      |      |      |      |      |      |      | 0.40 |
| Vasilyeva, dr. E.      |      |      |      |      |      |      |      |      |      |

| **Total non-tenured staff** | 1.13 | 1.23 | 1.29 | 1.33 | 2.13 | 2.05 | 2.33 |

| **PhD student**         |      |      |      |      |      |      |      |
| Cumberbatch             |      |      |      | 0.03 |      |      |      |
| Wu MSC, H.              |      |      |      | 0.67 |      |      |      |
| Barna PDEng, ir. P.     |      | 0.53 | 0.80 | 0.80 | 0.80 | 0.27 |      |
| Loebel, drs. S.G.       |      | 0.80 | 0.80 | 0.68 | 0.08 |      |      |
| Vdovjak PDEng, R.       |      | 0.80 | 0.56 | 0.40 | 0.17 |      |      |
| Frasincar PDEng, F.     |      | 0.80 | 0.64 | 0.40 | 0.23 |      |      |
| Stash, ir. N.           |      |      | 0.47 | 0.80 | 0.80 | 0.40 |      |
| Chepegin, V.I.          |      |      | 0.80 | 0.80 | 0.80 | 0.27 |      |
| van der Sluijs, drs. S.G. | 0.27 | 0.80 | 0.80 | 0.80 | 0.80 | 0.53 |      |
| Wang MSc, B.            |      |      |      |      | 0.40 | 0.80 | 0.80 |      |      |
| Bellekens, ir.ing. P.A.E. |      |      |      |      |      |      | 0.43 | 0.64 |      |
| Bakker PDEng, drs. J.   |      |      |      |      |      |      |      | 0.23 |      |
| Kamiran MSc, F.         |      |      |      |      |      |      |      |      | 0.68 |
| Knutov MSc, E.          |      |      |      |      |      |      |      |      | 0.73 |

| **Total PhD students** | 3.63 | 3.60 | 3.81 | 3.68 | 2.53 | 2.43 | 3.62 |

| **Total research staff** | 6.28 | 6.35 | 6.62 | 6.53 | 5.97 | 5.28 | 6.52 |
8. Resources, funding and facilities

8.a. Laboratory infrastructure

The Division provides a sufficient technical infrastructure with standard workstations and/or laptops, and basic software, for all its researchers. For more extensive experimental studies (data mining experiments, running adaptive learning environments, etc.) the group uses funding associated with research grants to buy real computers and software.

8.b Funding

<table>
<thead>
<tr>
<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct funding</td>
<td>61%</td>
<td>68%</td>
<td>67%</td>
<td>48%</td>
<td>55%</td>
<td>72%</td>
<td>62%</td>
<td>61%</td>
</tr>
<tr>
<td>Research funds</td>
<td>17%</td>
<td>15%</td>
<td>18%</td>
<td>11%</td>
<td>15%</td>
<td>20%</td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td>Contracts</td>
<td>22%</td>
<td>17%</td>
<td>15%</td>
<td>41%</td>
<td>31%</td>
<td>8%</td>
<td>20%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Table 13: Funding of DH.

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct funding</td>
<td>18%</td>
<td>12%</td>
<td>9%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
</tr>
<tr>
<td>Research funds</td>
<td>63%</td>
<td>66%</td>
<td>67%</td>
<td>57%</td>
<td>42%</td>
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Table 14: Funding of postdocs/PhD's.
Overview of the results

9.a. Key publications

   (This is an adaptive hypermedia document. The adaptive version can be accessed at http://aha.win.tue.nl/ahadesign/.)


9.b. Numerical overview

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9.c. List of publications

**Academic publications : refereed journals**

2002


2003


11Names of authors participating in the research programme DH are printed in boldface.


2004


2005


2006


T. Calders, L.V.S. Lakshmanan, R.T. Ng, J. Paredaens (2006). Expressive power of an algebra for data mining. ACM Transactions on Database Systems, 31(4), 1169-1214.(also listed under AIS)


K.A.M. van der Sluijs, G.J.P.M. Houben (2006). A generic component for exchanging user models between web-based systems. International Journal of Continuing Engineering Education and Lifelong Learning, 16(1-2), 64-76. (also listed under AIS)

2007


2008


Academic publications: refereed conference proceedings

2002


F. Frasincar, G.J.P.M. Houben (2002). Hypermedia presentation adaptation on the semantic


2003


web information systems. In J.M. Cuella Lovelle et al. (Eds.), *Web Engineering (Proceedings ICWE 2003, Oviedo, Spain, July 14–18, 2003)*, LNCS 2722 (pp. 529–538). Berlin: Springer-Verlag. (also listed under AIS)


**2004**


A.I. Cristea (2004). Adaptive course creation for all. In P.K. Srimani (Ed.), *Proceedings Inter-


4th International Conference, ICWE 2004, Munich, Germany, July 26–30, 2004), LNCS 3140 (pp. 60–73). Berlin: Springer-Verlag. (also listed under AIS)


2007


2008


Academic publications: book chapters

2004


2005


2006


2007


2008


M. Pechenizkyy, S. Puuronen, A. Tsymbal (2008). Does relevance matter to data mining research?. In T.Y. Lin, Y. Xie, A. Wasilewska, C.J. Liau (Eds.), Data Mining: Foundations and Practice (Studies in Computational Intelligence, 118) (pp. 251-275). Berlin: Springer.

Academic publications : other academic publications

None

Monographs

2003


PhD theses

2002


2004

96 Research Evaluation Computer Science 2009 * Part B: DH

2005


2006


2007


**PhD theses** (member of this programme as second or co-supervisor)

Note: the theses submitted at the Universiteit Antwerpen under the supervision of prof. Paredaens are not listed.

**Professional publications**

None

**Professional products: Software**

P. De Bra, D. Smits, N. Stash, AHA!, The Adaptive Hypermedia Architecture. Open Source adaptive environment, available from http://aha.win.tue.nl/. The most recent version is AHA! 3.0, published on July 2, 2007. (This software has been downloaded about 3.500 times, not including downloads from TU/e addresses.)

**Patents**

None
Edited Books


10. SWOT-analysis

**Strengths.**

- The DH group is widely recognized as one of the leading groups in the research field of adaptive hypermedia. The group has produced the leading reference model (AHAM) and the most widely used and referenced adaptive hypermedia system (AHA!). The research field is commonly said to be headed by Peter and Paul, meaning Peter Brusilovsky and Paul De Bra. The group has a strong presence in not just the AH community but also in E-Learning, E-Culture, Web Engineering and Semantic Web communities. The group was core member of the PROLEARN Network of Excellence and is now leading the FP7 project GRAPPLE with 15 partners, showing the group's leadership in the field.

- The “facilitating management” style in the DH group has enabled assistant professors to develop their own niche, be recognized by the international research community and then move on to better positions elsewhere. Dr. Lora Aroyo has moved to the Vrije Universiteit and dr. ir. Alexandra Cristea has moved to the University of Warwick.

- The DH group has recently (in 2006) hired new assistant professors for starting a research line in data mining. This enables the group to expand the personalization research from "authored" and "individual" personalization to "generated" and "group" adaptation. In the future personalization and adaptation will be performed completely autonomously by adaptive systems, and will make use of the behavior of the entire user population, not just a single user. With research in data mining the DH group is at the forefront again for this new research direction in the area of personalized information delivery.

**Weaknesses.**

- The small size of the DH group means that it can only achieve impact in the research community through quality, not through quantity. We do our utmost to hire the best possible people and we keep the research focused in order to stay a highly esteemed research group. In order to achieve our research goals we must rely on collaboration with other research groups (mainly throughout Europe) because we are too small in size and too narrow in scope to realize the projects we wish to undertake (like e.g. the GRAPPLE project for which we need 15 partners).

**Opportunities.**

- Because of the mobility of DH researchers the group automatically expands its network when researchers start their own group in other universities. Their departure also enables the group to shift topics in order to continue to tackle the most relevant issues in the field. Recently (2006) the group has hired data mining experts, which enables the research to evolve from authored, personalized adaptive hypermedia to generated and group-adapted hypermedia. Massive and fully automatic adaptation is going to be a hot topic for the coming 5 to 10 years, and the group has made the shift that was needed to become leading in that field.

**Threats.**

- Because of the limited financial means any new development in the DH group is threatened to be overtaken or superseded by efforts started in much larger research institutes. So far the group has managed to maintain its leading position by offering very unique and useful results (like AHAM and AHA!), that are widely adopted. There is a move towards research that may require more person-effort than the group can supply. Future success will depend
more on the successful establishment of a network of researchers in different institutes than the past research required. So far the group has been successful in creating and participating in such networks, but as research efforts grow the danger of a small group not being included increases.

Conclusion. The DH group has managed to become one of the leading groups in the research field of adaptive hypermedia, with applications in e-learning, e-culture, e-entertainment and e-business, all explored jointly with industry partners. This research field is moving from "authored" towards "generated" adaptation. The DH group is lucky to have been able to replace successful researchers who moved on in their career (dr. ir. Cristea, dr. Aroyo, dr. Aerts) by new high-potential researchers in the field of databases and data mining (dr. Toon Calders and dr. Mykola Pechenizkiy, and the newly appointed dr. George Fletcher). Databases and datamining are the research areas that form the basis for this new development of "generated" adaptation. Hence the DH group has laid the foundations for continuing to be leading in its research field as that field takes on a new direction.
Formal Methods

Full title  Formally Methods
Programme leader  prof. dr. J.C.M. Baeten
Starting date  before 2002
Research area  Formal Methods is part of Model-Based Engineering
We use algebraical, logical and assertional techniques in order to improve the design and analysis of (embedded) systems.

CR-classification  Main category:
F.3 Specifying and Verifying and Reasoning about Programs.
Other relevant categories:
C.3, D.4, F.1, F.4, G.3, I.1, I.6, J.2, J.7

Affiliations
research school  IPA (Instituut voor Programmatuurkunde en Algoritmiek)
3TU  NIRICT, CeDICT

Cooperations (at most five per category are listed)
national  prof. Koos Rooda (TU/e ME)
prof. Twan Basten (TU/e EE)
prof. Jaco van de Pol (UT)
prof. Wan Fokkink (VU)
prof. Jan Bergstra (UvA)
international  prof. Luca Aceto (Reykjavik University)
prof. Flavio Corradini (University of Camerino)
prof. Pedro D’Argenio (University of Cordoba, Argentina)
prof. Mario Bravetti (University of Bologna)
prof. Ursula Goltz (TU Braunschweig)
Mission statement

Formal Methods is part of Model-Based Engineering. Our aim is to provide an engineer realising software-driven systems with languages, methods, techniques and tools to improve the product: to detect and prevent errors, and to increase its dependability, clarity, and updatability. The languages, methods, techniques and tools are based on solid mathematical principles, and have a formal syntax and semantics. We want to be among the leading groups in Formal Methods worldwide, by publishing widely, and participating intensively in conferences, committees, editorships etc. We cooperate with Mechanical Engineering and Electrical Engineering in multi-disciplinary systems engineering.

1. Leadership

The style of management in the group is informal. Social cohesion is actively maintained. During regular staff meetings, consensus is always sought concerning policy and strategy. By pursuing an open door policy, it is easy for any group member to have access to any other member. At the same time, all members of the group are held to very high standards, and targets are set and discussed at every yearly evaluation discussion. Every group member needs to develop his/her own research niche and publication record, working in different partnerships.

2. Strategy and policy

2.a. Design in brief

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 is concerned with the formalisation of fundamental constructions in computer science, describing them precisely with a formal syntax and supplying them with a formal semantics. This provides software engineers with a language and a calculus, based on solid mathematical principles, in which they can model their systems and do their calculations. Thus, research in Formal Methods helps to establish computer science as an engineering science. Formal Methods increase understanding of systems, increase clarity of description and help solve problems and remove errors. Use of Formal Methods increases dependability and usability of constructions and systems in computer science. Increasingly, we look for connections with other departments to contribute to multi-disciplinary systems engineering. We study and use Formal Methods with applications in mind. Thus, our choice of research topics is inspired by the practice of computer science. To support application, we use existing tools if possible. If needed, we develop new tools. We are not studying methods only academically, but intend to have them used in practice. For this reason, we have many joint projects with industry. In the reporting period (2002-2008), the main areas of interest can be specified as follows:

2. Assertional Methods and Logic.

Embedded systems form the main application area of our research.
2.b. Future Programme development

Compared to the previous research evaluation, we discontinued the research on visual specification languages, in particular MSCs. Also, we discontinue research on type theory. We started up research in security. In 2007, a new chair was established in security, to which most of our security activities were transfered. A new subject is the application of formal methods in systems biology.

1. Systems Behaviour. We continue research on process algebra and its applications.
   We are working on the integration of concurrency theory and the theory of automata and formal languages, in order to give a more coherent and modern presentation of the foundations of computing. As a byproduct of this research, we have designed a new undergraduate course on the foundations of computing that treats the basics of automata theory, formal language theory, and concurrency theory in an integrated manner.
   We look at systems with explicit timing, stochastic systems and hybrid systems, performing case studies, application projects with industry and use and design of tooling.
   We seek to integrate concurrency theory with control theory, starting with supervisory control.

2. Assertional Methods and Logic. We continue research on verification and testing, especially of component based embedded systems. Approaches for specification at the interface level are formalised. Recent advances in specification languages and theorem proving further focussed research to developing more modular proof systems for OO languages and extend theorem provers to support this.

3. Formal Methods in Security and Systems Biology. In security, we look at the design and analysis of security protocols for various applications, such as authentication and voting. Research on formal methods in systems biology was recently started, and first results are emerging.

3. Processes in research, internal and external collaboration

There is an open research culture in the group. Most publications are teamwork, in many cases involving more than one person of the group, in many cases involving people from other groups within the university, or people outside the university both nationally and internationally. Every staff member supervises 1 or 2 PhD students, and meets with them at least weekly. Every PhD student follows the IPA education program, involving also a summer school visit and conference participation.
   There is a weekly informal group meeting, several annual social events, and so social cohesion is high.
   There is a staff meeting monthly, where research strategy and research proposals are discussed. Together with the OAS group, there is a biweekly seminar ProSe (Process Seminar).
   Every group member will have a yearly evaluation discussion with his/her supervisor and the group leader, where targets are set for the next year and career development is discussed. The group leader in turn will have a yearly evaluation with the department board, where all members of the groups are discussed.
In the area of Model-based Engineering, we work closely with the groups OAS, SET and AIS. With the group Systems Engineering of Rooda in Mechanical Engineering, we have longstanding and ongoing collaboration. Also with the group Design Methodology for Electronic Systems (Basten, Corporaal, Voeten) in Electrical Engineering we have longstanding and ongoing collaboration.

To further specify the research with Systems Engineering, the thesis of Bos and Kleijn gave syntax, semantics and tooling of the multi-disciplinary language Chi, the discrete event part, the thesis of Man and Schiffelers extended this to timed and hybrid systems, the thesis of Van Osch explored model-based testing using Chi, and the thesis of Braspenninck model-based integration using Chi. Currently, focus is on control synthesis with Chi.

There are research visits back and forth with other collaborators mentioned on the first page.

4. Academic reputation

Jos Baeten

- Editor: Journal of Logic and Algebraic Programming (JLAP).
- Program committee: MTCS’02, CONCUR’02, EXPRESS’03, FORMATS’03, ICALP’03, EXPRESS’04 (co-chair), EXPRESS’05 (co-chair), CONCUR’05, ICALP’05, CONCUR’06, MFCS’07, CONCUR’07, CONCUR’08, FOSSACS’09, CAI’09, ICALP’09, CONCUR’09, FM’09.
- Organizing committee: ICALP’03 (chair), FM’09 (chair).
- Other national scientific committees: NVTI (Dutch association for theoretical computer science) (board member), NWO Exact Sciences Evaluation Committee (chair), NGI (National computing association) Section Science and Education (chair), Scientific director national research school IPA (until 2004 and as of 2009)
- Published 5 books, 8 book chapters, and over 80 papers in peer-reviewed journals and conferences.

Sjouke Mauw

- Presently full professor "Security and trust of software systems", Univ. of Luxembourg.
- Editor: International Journal On Advances in Internet Technology (IARIA)
- Program committee: FORTE’02, SAM’02, SDL Forum’03, SFEDL’04, SAM’04, ARSPA’05, STM’05 (co-chair), SAPS’05, CiSC’05, FCS-ARSPA’06, STM’06,WISSec’06, IS’06, IC- SNC’06,WISSec’07 (co-chair), IS’07, MOTHIS’07, ICSNC’07, VOTE-ID’07, EuroPKI’08 (co- chair), ICSNC’08, WISTP’08, STM’08, SESS’08, IS’08, MOTHIS’08, ICISC’08, SMPE’09, FM2009, ICSNC’09 (co-chair), SESS’09.
• Other international scientific committees: ERCIM working group on Security and Trust Management (steering committee).

• Other national scientific committees: SAFE-NL (steering committee), NVSO.

• Published over 60 papers in peer-reviewed journals and conferences.


Erik de Vink

• Guest editor: LCMAS’03, LCMAS’04, LCMAS’05.

• Program committee: AAMAS’03, SEC’03, AAMAS’04, SOS’04, VODCA’04, AAMAS’05, SEC’05, SOS’05, SYANCO’07, GlobalComp’08, VODCA’08.

• Organizing committee: ICALP’03 (workshop chair), FM’09 (workshop chair).

• Other international scientific committees: IFIP WG 11.2

• Other national scientific committees: SAFE-NL (steering committee), Sentinels PC

• Published 3 edited workshop proceedings and 27 papers in peer-reviewed journals and conferences.

• Invited lectures: VODCA 2006

Bas Luttik

• Guest editor: JLAP 2006

• Program committee: EXPRESS’06, EXPRESS’07, EXPRESS’08.

• Other international scientific committees: IFIP WG 1.8.

• Published over 15 papers in peer-reviewed journals and conferences.

5. Internal evaluation

See Part A.8.

6. External validation

The FM group performs research in three different directions: first in order to advance science, second to apply scientific results in industry, and third to have an impact on education. The advancement of science can be seen in the quality and impact of our publications and our academic reputation, the application in industry in the large number of projects with industry and the large number of industrial contacts, and impact on education in a number of textbooks. Besides, there are contributions in popular media such as Automatiseringgids. We organise large scientific events in Eindhoven, such as ICALP 2003 and FM 2009.
6.a. Societal relevance

Every individual, and the whole society are more and more depending on correctly functioning software systems, and the impact of malfunctioning software increases daily. Our research aims to alleviate this situation. We seek applications mainly in embedded software, with an emphasis on complex industrial software-intensive systems of industries in the Eindhoven area. See the list of external projects and industrial contacts.

6b. Industrial contacts

Industrial contacts of FM are: Philips Research, ASML, Prorail, Assembleon, Chess, Philips Healthcare, BrightSide, ImTech, Ministerie Binnenlandse Zaken, LogicaCMG, Capgemini, Oce, STmicroelectronics, Cordys, ISAAC, Verum, Hoffman, Sioux, FEI.

7. Researchers and other personnel

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<td>Roubtsov, dr. S.</td>
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<td>Jojov, dr. G.I.</td>
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<td>Dechesne, dr. F.</td>
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<td>Verschuren, ir. J.H.S.</td>
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<td>van Osch PDEng, ir. M.P.W.J.</td>
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<td></td>
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<td>0.73</td>
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<tr>
<td>Total non-tenured staff</td>
<td>2.90</td>
<td>2.37</td>
<td>1.79</td>
<td>1.22</td>
<td>1.48</td>
<td>2.45</td>
<td>2.87</td>
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</table>
8. Resources, funding and facilities

8.a. Laboratory infrastructure

Use of standard infrastructure. More extensive facilities through LaQuSo.

8.b Funding

<table>
<thead>
<tr>
<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
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<tbody>
<tr>
<td>Direct funding</td>
<td>63%</td>
<td>60%</td>
<td>69%</td>
<td>73%</td>
<td>71%</td>
<td>71%</td>
<td>73%</td>
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<tr>
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<td>16%</td>
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<tr>
<td>Contracts</td>
<td>18%</td>
<td>25%</td>
<td>16%</td>
<td>17%</td>
<td>17%</td>
<td>13%</td>
<td>16%</td>
<td>17%</td>
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Table 15: Funding of FM.
<table>
<thead>
<tr>
<th>Percentage %</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
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</thead>
<tbody>
<tr>
<td>Direct funding</td>
<td>20%</td>
<td>23%</td>
<td>34%</td>
<td>37%</td>
<td>25%</td>
<td>33%</td>
<td>30%</td>
<td>29%</td>
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<tr>
<td>Research funds</td>
<td>78%</td>
<td>62%</td>
<td>48%</td>
<td>30%</td>
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<td>18%</td>
<td>32%</td>
<td>37%</td>
<td>33%</td>
<td>37%</td>
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<tr>
<td>Other</td>
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<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
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</table>

Table 16: Funding of postdocs/PhD’s.

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

<table>
<thead>
<tr>
<th>period</th>
<th>external funding (2002–2008): research grant</th>
<th>budget (k€)</th>
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<tbody>
<tr>
<td></td>
<td>Willemse</td>
<td></td>
</tr>
<tr>
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<td>Andova</td>
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</tr>
<tr>
<td></td>
<td>Goga</td>
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<tr>
<td>2000–2004</td>
<td>NWO (EW): Use and meaning of open terms in interactive formal problem solving</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>Jojgov</td>
<td></td>
</tr>
<tr>
<td>2000–2004</td>
<td>SOBU : Hintikka’s revolution in the foundations of mathematics</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Dechesne</td>
<td></td>
</tr>
<tr>
<td>2000–2004</td>
<td>STW (Progress) : SPEC TEC – Specification tooling for embedded software components</td>
<td>213</td>
</tr>
<tr>
<td></td>
<td>van Gool, Roubtsov, Roubtsova</td>
<td></td>
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<tr>
<td>2001–2003</td>
<td>NWO (EW): Logic and linguistic aspects of message sequence charts</td>
<td>55</td>
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<tr>
<td></td>
<td>Tagvishvili</td>
<td></td>
</tr>
<tr>
<td>2001–2005</td>
<td>STW (Progress) : AMPATS – Modelling and performance analysis of telecommunication systems</td>
<td>190</td>
</tr>
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<td></td>
<td>Chkliac, Sokolova, Tran</td>
<td></td>
</tr>
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<td></td>
<td>Albu, Dechesne, Jojgov</td>
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<tr>
<td></td>
<td>Cremers</td>
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<tr>
<td>2003–2007</td>
<td>NWO (OC) : TIPSY – Tools and techniques for integrating performance analysis and system verification</td>
<td>140</td>
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<tr>
<td></td>
<td>Trčka</td>
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<tr>
<td>2005–2009</td>
<td>STW (Sentinels) : PINPAS-JC – Program inferred power-analysis in software for Java card</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Pan</td>
<td></td>
</tr>
<tr>
<td>2006–2009</td>
<td>NWO (OC) : VEMPS – Verification and epistemics of multi-party protocol security</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>Dechesne</td>
<td></td>
</tr>
<tr>
<td>2007–2009</td>
<td>NWO : Comforts</td>
<td>164</td>
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<td></td>
<td>Orzan, Wesselink</td>
<td></td>
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<tr>
<td>2007–2011</td>
<td>NWO (OC) : models of computation</td>
<td>178</td>
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<td></td>
<td>van Tilburg</td>
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Overview of the results

9.a. Key publications


9.b. Numerical overview

<table>
<thead>
<tr>
<th>1. Academic publications</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>total</th>
</tr>
</thead>
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<tr>
<td>a. in refereed journals</td>
<td>9</td>
<td>7</td>
<td>8</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>62</td>
</tr>
<tr>
<td>b. in refereed proceedings</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>23</td>
<td>28</td>
<td>16</td>
<td>21</td>
<td>130</td>
</tr>
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<td>c. book chapters</td>
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<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<td>d. other</td>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
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<td>23</td>
<td>25</td>
<td>39</td>
<td>39</td>
<td>28</td>
<td>32</td>
<td>211</td>
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<td>2. Monographs</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1</td>
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<tr>
<td>3. Ph.D. theses</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>4. Profess. publ. &amp; products</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
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<tr>
<td>a. publications</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>b. software</td>
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<td></td>
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<td>6</td>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>12</td>
<td>12</td>
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</table>


2. Monographs: 1

3. Ph.D. theses: 2

4. Profess. publ. & products: 2, 1

Patents: 1

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9.c. List of publications

Academic publications : refereed journals

2002


2003


2004


\textsuperscript{12}Names of authors participating in the research programme FM are printed in boldface.

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2005


2006


S.M. Orzan, J.C. van de Pol (2006). Distribution of a simple shared dataspace architecture. Fundamenta Informaticae, 73(4), 535-539.[also listed under OAS]

2007


J.C.M. Baeten, M.A. Reniers (2007). Duplication of constants in process algebra. The Journal of Logic and Algebraic Programming, 70(2), 151-171.[also listed under OAS]


2008


**Academic publications : refereed conference proceedings**

2002


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2003


2004


2005


2006


cation of Chi models using PHAVer (extended version). In I. Troch, F. Breitenecker (Eds.), Proceedings of the 5th MATHMOD Conference (Vienna, Austria, February 8-10, 2006), CD-ROM. Vienna: ARGESIM.[also listed under OAS]


2007


2008


Academic publications: book chapters

2002


2003


2004


2005


2006


2007


2008

Other academic publications

2002


2003


2004


2005


2006


2008


Monographs

2002


2004


**PhD theses**

2002


2003


2004


2005


2006


PhD theses (member of this programme as second or co-supervisor)

2002


2004


2005


2008

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**Professional publications**

2004


2005


2007


2008


**Professional products: software**

- Calisto. Support for Interface Specification approach ISpec as developed by H.B.M. Jonkers and used by various Philips divisions. The tool supports gathering the information as provided in, e.g., different UML views into a consistent model, structured using ISpec templates. The tool supports different plug-in specification languages. Version 1 2002 Calisto Software Engineering Project (SEP). Version 2 2003 Arkas (this is the web version) SEP Pilot project (student stage) at Oce to specify and partially redesign a copier component. Version 3 2005 Thelxinoe SEP. Version 4 ongoing - redesign E.J. Luit. E.J. Luit and S. Roubtsov, various SEP projects and student(assistant) contributions. www.win.tue.nl/calisto


- Contributions to the Chi toolkit, a toolkit for the design and analysis of complex, multidisciplinary industrial systems, http://se.wtb.tue.nl/sewiki/chi/Start.
• CoffeeDregs (initiated by C. Huizing, R. Kuiper, 2008), a visualization tool for Java (acknowledged by the NetBeans IDE developers as an Innovation Grant participant, netbeans-grant@netbeans.org). The tool visualizes an execution model for OO: the dynamically changing object structure as well as the evolving objects themselves at the level of statement execution and data values. The tool is currently used in the curriculum for educational purposes, but is envisaged to support automated assertional verification.

Patents


Edited books


10. SWOT-analysis

Strengths.

• Quality publications in leading journals and conferences.
• International visibility in formal methods.
• Steady output of quality PhD's.

Weaknesses.

• Retirement of Rob Nederpelt in 2005 and leaving of Sjouke Mauw in 2007 led to decrease in productivity and external projects.
• Heavy managerial duties of Jos Baeten leads to decreased research output.

Opportunities.

• Young, enthusiastic staff is growing in academic visibility.
• New funding opportunities are under discussion (FES, Point One).

Threats.

• Economic downturn may lead to budget cuts in R&D.

Conclusion

The FM group has adequate size, is healthy, and the young, enthusiastic staff is growing in academic stature. A number of possibilities for additional externally funded projects is opening up, and so financial status will remain healthy.

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We contribute to model-based engineering of software-intensive systems, working in various partnerships with various companies, with a current focus of integrating control synthesis in our methods. We integrate process algebra with automata theory, thereby improving the foundations of computer science. We improve the use and teaching of object-oriented languages.
System Design and Analysis

Full title: System Design and Analysis

Programme leader: prof.dr.ir. J.F. Groote

Starting date: September 1, 2000.

Research area: Modelling and analysis of discrete system behaviour.

CR-classification: Main category: 68Q60 (Specification and verification (program logics, model checking, etc.))
Other relevant categories: 68N30 (Mathematical aspects of software engineering), 68Q85 (Models and methods for concurrent and distributed computing, (process algebras, bisimulation, transition nets, etc.)), 68Q42 (Grammars and rewriting systems).

Affiliations:

research school: IPA (Institute for Programming Research and Algorithmics)

Cooperations (at most five per category are listed):

national:
- prof. vd Pol (Formal Methods and Tools, Twente University)
- prof. Klint (CWI, SEN1 (Interactive Software Development and Renovation))
- prof. Fokkink (VU, Section Theoretical Computer Science)
- prof. Hesselink (Rijks Universiteit Groningen, Fundamental Computing)

international:
- prof. Aceto (Reykjavik University, Iceland)
- prof. Giesl (RWTH Aachen, Programmiersprachen und Verifikation)
- prof. Waldmann (Hochschule für Technik, Wirtschaft und Kultur Leipzig)
- prof. Brandt (Department of Computer Science, Université du Luxembourg)
- dr. Ulidowski (Department of Computer Science, University of Leicester)
Mission statement

The OAS group studies techniques to model and analyse discrete system behaviour in a mathematically rigorous way. The modelling techniques must be capable to effectively design reliable software based systems. As the models are large and the behaviour complex, it is required to study and develop automated tools and techniques for these models, and it is necessary to maintain a software infrastructure to experimentally show the effectiveness of the techniques.

1. Leadership

OAS is shaped as a group of cooperating professionals. The formal leader of the group is prof.dr.ir. J.F. Groote. There is one part-time full professor (prof.dr. Geuvers) also appointed at Nijmegen University. Furthermore, there were two associate professors, one of whom left for an appointment as full professor in Twente (prof.dr. van de Pol) and one who now holds a part time chair in Nijmegen (prof.dr. Zantema). Besides that the group consists of assistant professors, a programmer, a teacher, postdocs and PhD. students.

The primary model of scientific leadership is that all group members have their own field of expertise from which they derive their identity and motivation. The group provides a social context, a research attitude and major research theme. Supervision of PhD students can be done by all scientific members of the group, where there are typically one or two supervisors per student. Every two weeks there are research meetings for the whole group, which are alternated by the departmental colloquium (we have reinstated and largely organized both since 2000). For the development of software there are weekly technical meetings. Every year there are evaluation meetings between the group leader and all the members of the group where progress, output, plans, needs for education, career changes and related matters are discussed.

2. Strategy and policy

2.a. Design in brief

The decade between 1980 and 1990 was dominated by the development of a number of new description paradigms for systems with complex behaviour. Specification languages were being designed to describe parallel, interacting systems. In this period, process algebras, abstract data types, temporal logics and other formalisms were used to experiment with the description of system behaviour. An interesting observation from this period is that describing system behaviour formally, has a profoundly positive effect on the quality. Typical questions from this period regard the semantics of languages, expressiveness and axiomatic characterisation.

In the next decade, modelling the behaviour of actual systems became possible. The lesson from this period was slightly unexpected. Real systems are complex. Hence, the models are complex. In order to guarantee their quality, tools are needed, not only parsers and typecheckers, but also provers, simulators, state space generators, visualisation tools and model checkers. Otherwise residual errors will certainly remain. So, analysis of models using tools came in focus.

At the beginning of 2000 we had substantial experience with modelling system behaviour (mainly with $\mu$CRL but also with proposition logic). One of the conclusions was that in order to obtain practical applicability it is needed to leave the semantically influenced approach to define simple and straightforward modelling languages (such as $\mu$CRL), but to make the language much more expressive, especially regarding data types. This was done by defining the modelling language mCRL2, which not only allows the use of abstractly defined data types, but also allows the use of...
higher order functions, sets, lists, numbers (including reals), quantification, lambda abstraction, etc. Adhering to our desire to keep the language mathematically clean, all these types represent their mathematical counterpart. A lot of energy went into the efficient implementation of these data types where the main workhorse is term rewriting (we developed several high performance compiling rewriters). Equally important was the capability to effectively deal with open terms and infinite data structures (e.g. sets of real numbers) in a setting where regularly state spaces of up to $10^9$ states are generated. As it stands, the language mCRL2 is unique when it comes to expressiveness in combination with its analysis capabilities.

A second important observation was that modal logic is very important for system designs. Many behavioural models are so complex that it must be doublechecked that they do not contain flaws. One successful technique is to formulate and verify behavioural properties. We enhanced the modal mu-calculus with time and data in the style as within mCRL2, making what is undoubt-edly the most expressive modal logic currently available. In order to effectively verify such rich logical formulas on such a rich modelling language, we translate them to parameterised boolean equation systems (PBESs) which we subsequently solve. Although we can verify PBESs of in the order of $10^6$ boolean variables, we expect to increase the capabilities here substantially in the coming years.

Although the investigation of state space exploration has taken off (not in the least due to the increased capabilities of computers), it is clear that for really big models, symbolic verification techniques are needed. To this end we investigated propositional proof techniques (culminating in the proof that BDDs and resolution are polynomially incomparable), built equality extended BDD provers, and deeply investigated ways to automatically prove termination of rewrite systems, which led to the award winning TORPA tool and the equally impressive TPA system (see below).

From our experiments it is obvious that it will not be possible in the foreseeable future to have tools prove all aspects of the correctness of models (although in their dedicated fields humans are not able to beat the current analysis tools anymore). In those cases where tools fail, we still want to employ the precision of a machine in combination with human ingenuity. This is the reason why we are very interested in computer assisted proof tools such as Coq and PVS. We have ample experience in their application not only in modelling abstract algebra but also in proving the correctness of intricate wait-free protocols. Particularly noteworthy is our work on TPA, an automatic termination prover, of which all the proofs are automatically verified using Coq.

In combination with the VIS group work has been done to visualize state spaces. Again, we can report impressive successes in the sense that we managed to present 3D visual representations of up to 1M states which are really providing insight in the behaviour of systems.

In order to guarantee the applicability of the research, it is important that it is constantly put under the strain of applications. An important finding is that methods and algorithms that are theoretically very promising, need to be transformed into techniques and tools that are sufficiently efficient to do the job. Within this field, it is easily possible to implement an algorithm into tools that differ several orders of magnitude in their memory use and speed. In other words: the difference between doable and impossible. By constant application and evaluation thereof, we guarantee that our methods and tools are among the best when it comes to practical applicability. As it stands our tools have not only been used within many small and most larger industrial companies in the vicinity (Océ, Philips Medical Systems, Aia Software, ProRail, VanderLande Industries) but there is also growing interest from large technical research laboratory that have large in-house software projects (CERN, ESO). We also actively contributed to the quality of international communication standards by modelling and analysis (IEEE 1394.2 Firewire standard and the HL7 (Health Level 7) protocol), where we had advisory roles within the standardisation bodies. It is also noteworthy that the first ‘quality certificate’ awarded by the Laboratory of Quality Software (LaQuSo, www.laquso.com) is based on an mCRL2 model of the software.
2.b. Future Programme development

We will prolong the research along the same lines: model and analyse the behaviour of systems using an expressive, integrated and mathematical modelling language, assisted by a powerful versatile and reliable toolset containing state of the art algorithms both from the realm of explicit state and boolean equation analysis, as well as based on symbolic analysis techniques. We consider it very important that the results of our research are accessible to others. This not only means that publication is important, but this also means an extended effort in making the mCRL2 toolset a usable platform for other tool developers (see www.mcrl2.org). Therefore we distribute the tools in source code under the liberal open source Boost license to allow absolute free use of the material.

For the coming years we foresee the following research questions, which we consider as the major points of attention, alongside the running research activities.

1. Improving our capability to solve PBESs and consequently solving modal formulas will be an important research issue in the coming years. We expect a lot from using the automatic proof techniques for termination as symbolic ways to find solutions of minimal fixed point equations (and dually methods for non-termination as ways to solve maximal fixed point equations). Furthermore, we want to extend our research on patterns in PBESs as a way to solve these PBESs directly.

2. Currently, we are looking into the integration of technology for regions and zones to improve our capacity to verify timed systems. From our applications it has become obvious that a full modelling language should also contain ways to model and analyse stochastic behaviour in the way this is done by tools such as PRISM. This will be our next substantial extension of the language.

3. As said elsewhere practical application of the technology is the best way to test its quality. This means that we want to have continuous application in larger projects. We have already set this in motion with Philips Medical Systems (who is funding a PhD student for this purpose) but a continuous collaboration with for instance CERN or ESO, as recently set in motion is also very promising here. We want these kind of collaborations replace our work in standardisation bodies as we found that there are many interests in such committees, where the quality of the protocols is not always number one.

3. Processes in research, internal and external collaboration

Internally, we follow the model of independent researchers with their own interest and lead. There are bi-weekly research meetings that function to funnel the interest along the main theme of group. In general this works very well. The group consists of independent, strongly motivated and internationally recognized researchers. PhD students and postdocs have essentially also this independent position, but they also have a direct supervisor among the permanent staff and in some cases work in projects with their own obligations.

Every year there is a performance evaluation between each member of the group, the group leader and the direct supervisor, in which achievements, future plans and other desires are evaluated and written down. At irregular intervals there are also management meetings, in which the permanent members discuss about managerial issues of the group. Cooperation of group members both internally, and externally are strongly encouraged (by funding research visits).

The essential quality control mechanism of the group is that of international peers. All researchers in the group are expected to take part in international publication circuits and get their articles published. Internally, group members assist each other by for instance reviewing each others papers before they are being submitted.
The group has one full time teacher (0.65fte) and two programmers (1.4fte) of which one has a half time researcher position. Their task is to assist in teaching, and to take care that the software infrastructure is stable and smoothly running, respectively. As such they have a less independent, more servile role than the researchers.

4. Academic reputation

The OAS group is an internationally recognized group known for its capacity to be able to transform theoretical concepts such as modal logic, term rewriting systems, process algebra’s, operational semantics into an industrially applicable set of modelling and analysis methods and tools. The mCRL2 tools can best be compared to the CADP and FDR2 toolsets, but contrary to these it is open source. Compared to known tools such as Uppaal and SPIN, it is much more expressive and versatile.

M.R.V. Chaudron

- PC chair of the workshop on Software Infrastructures for Component-based Applications for Consumer Devices, 16 September 2002, Lausanne, Switzerland.
- PC chair for the IPA days on Middleware (spring 2002).
- PC member of the Hardware/Software co-design track of the Design Automation (DATE) Conference (Munich, 2002).

J.H. Geuvers

- Member of the programme committee of HOR2007, MKM2007.
- Member of the Steering Committee of the EU Coordination Action “Types”.
- Member of the organizing committee of Symposium Reflections on Type Theory, Lambda Calculus, and the Mind, celebrating Henk Barendregt’s 60th birthday, 17-12-2007, Nijmegen, The Netherlands.
- Full Professor of Computer Science (Computer Assisted Reasoning) in the Section Intelligent Systems (IS) of the ICIS (Institute for Computing and Information Science) of Radboud University Nijmegen.

N. Goga

- For the work made for ISO/IEEE 1073, at the proposal of Prof. Dr. Ir. Florica Moldoveanu, the Politechnic University of Bucharest awarded dr. Goga a second PhD “Cum Laudae”, 2005.

**J.F. Groote**

- Director of education of the 5 year programme Computers Science, the bachelor Computer Science, the master Computer Science and Engineering (CSE) and the master Embedded Systems (ES), Eindhoven University of Technology, 2000–present.
- Moderator of the concurrency mailing list (approx. 1000 subscribers), 1997–present.
- Member of board, Eindhoven Embedded Systems Institute, 2002.
- Program committee: ARTS 2004, TACAS’03, PSI03, LPAR’03, PSI’06, ICALP06, CERT-SOF'06, FSEN ’07, SOFSEM’09, FSEN09, PSI09, NIOC, 2009 (Educational, tutorial chair)
- Session chair: VCL2002, ICALP’03
- Member of the IFIP working group WG1.8 on concurrency theory, 2005-present.
- NIRICT Coordination committee for long term challenges, 2005.
- Member of the Normeringscommissie Institute of Certified ICT Professionals (ICIP), 2007-2008.
- Reviewer for the KTVFM project: Study on relevance of formal methods for the Royal Netherlands Navy. Project is executed by NLR and CWI. (2002).
- Sabbatical at Philips Medical Systems, Department CTO, Best, The Netherlands (Apr-May, 2005) for 2–4 days a week, 2005.
- Published over 87 refereed papers (source DBLP). H-index of 31. Stable position among the top 25 most cited computer scientists in the Netherlands.

**M.R. Mousavi**

- Organizer of a one-day symposium on Semantics of Concurrency, Eindhoven, September 26, 2005.
- Workshops Co-Chair of ICALP’08, the Doctoral Symposium of FM 2009.

**J.C. van de Pol**

- Secretary NVTI (Nederlandse Vereniging voor Theoretische Informatica), 2005.
- Vice-chair ERCIM working group FMICS (Formal methods in Industrial Critical Systems), 2005.
- National Symposia organization:
  Symposium Embedded Software Quality, Amsterdam, August 31, 2005.
  Symposium Processes, terms, and cycles: steps on the road to infinity in honour of Jan Willem Klop (JWK 60 year + 25 years at CWI), Amsterdam, December 19, 2005.
- Full professor at the Chair Formal Methods and Tools at the University of Twente. since September 2007.
M.A. Reniers

- Member of program committee of SOS 2008.

J.M.T. Romijn

- NWO project IQPS was long listed for the Vosko Trofee 2005.
- PC member of IFM, Nederlandse Testdag
- Member of the jury for NWO VIDI funding proposals (2004–2006).
- Program chair IPA Lentedagen "Testen" (Vught), 2006.
- VIDI grant (NWO-Vernieuwingsimpuls), 2001 for the research project “Improving the quality of protocol standards”.

T.A.C. Willemse

- Member of the organizing committee Nederlandse testdag 2007.
- PC-member of WS-MaTe 2007

H. Zantema

- Member of editorial board, Journal of Logic and Algebraic Programming, 2002-present.
- The tool TORPA, developed by H. Zantema, was the winner in the category string rewriting in the Termination Competition, reported at the International Workshop on Termination, Aachen, June 1–2, 2004.
- The tool TORPA, developed by H. Zantema, was the winner in the category string rewriting in the International Termination Competition, held in the week of April 11, and reported at the 16th Conference on Rewriting Techniques and Applications (RTA), Nara, Japan, April 19–21, 2005.
- Member of the Program Committee of Conference on Rewriting Techniques and Applications
- Member of the IFIP working group WG 1.6 Term Rewriting, 2007-present.

5. Internal evaluation

See Part A.8
6. External validation

6.a. Societal relevance

The goal of the research within the group is to improve the quality of software by models and esp. analysis of these models. Society benefits hugely from computer and networking technology, and therefore, we see that computers are massively applied. At the same time we see that damage due to not properly functioning computer programs, or the inability of constructing computer programs is immense. E.g. appr. 70% of the computer programming activities is not the success people had hoped for. These last problems find their origin in the less than professional way software is made. By introducing reliable models in the software design trajectory, we expect to substantially further the benefits that computers bring to society. By teaching the techniques, by tutoring on conferences, by writing professional and academic publications and by research visits we want to communicate the technology to a larger audience.

6b. Industrial contacts

Collaboration existed in the past years a.o. with Chess, Philips Research, Philips Medical Systems, Assembleon, Philips CFT, ASML, OCE, NBG, TNO Automotive, Verum, ProRail, Nyquist (now Bosch-Rexroth), Bosch CVT, VanderLande Industries, EldoLed, Vitatron, Fenix, Logica, ESO, CERN, NXP.

7. Researchers and other personnel

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### PhD student

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<th>2006</th>
<th>2007</th>
<th>2008</th>
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### Total research staff

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### 8. Resources, funding and facilities

The Division provides a technical infrastructure with adequate workstations and/or laptops, and the relevant software, for all its researchers. The 128 GB main memory linux machine ‘Olifant’ is extensively used for larger model analysis projects.

#### 8.a. Laboratory infrastructure

#### 8.b Funding

#### 8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.
Table 17: Funding of OAS.

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<th>2006</th>
<th>2007</th>
<th>2008</th>
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<td>65%</td>
<td>60%</td>
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<td>33%</td>
<td>40%</td>
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Table 18: Funding of postdocs/PhD’s.

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<td>STW (Progress) : Analysis and synthesis of embedded systems with discrete and continuous control</td>
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<td>2001–2005</td>
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<td>2001–2006</td>
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<td>NWO (OC) : Verification and rewriting</td>
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<td>Koprowski</td>
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<td>2005–2009</td>
<td>NWO (OC) : VOLTS – Verification of large transition systems</td>
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<td>2006–2008</td>
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<td>Raffelsieper, Wesselink, Groote, Zantema, Mousavi</td>
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<td>2008–2011</td>
<td>Philips Medical Systems: – Evaluating the effectiveness of formal embedded system design in a production environment</td>
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Research Evaluation Computer Science 2009 * Part B: OAS
Overview of the results

9.a. Key publications


9.b. Numerical overview

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<td>4</td>
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9.c. Full outcome list of OAS

Academic publications : refereed journals

2002


\textsuperscript{13}Names of authors participating in the research programme OAS are printed in boldface.


2003


2004


2005


2006


2007


2008


tems. Communications in Statistics. Part B, Simulation and Computation, 37(2), 346-359.[also listed under AIS]


Academic publications : refereed conference proceedings

2002


2003


2004


Symposium, Buenos Aires, Argentina, April 5–8, 2004), LNCS 2976 (pp. 530–539). Berlin: Springer-Verlag.


2005


2006


P.J.L. Cuijpers, M.A. Reniers, (2006). Modeling an impact control strategy using HyPA. In C.G. Cassan-


2007


in Computer Science (pp. 683-689). Berlin: Springer. [also listed under FM]


2008


D.A. van Beek, M.A. Reniers, J.E. Rooda, R.R.H. Schifflers (2008). Concrete syntax and semantics of the compositional interchange format for hybrid systems. In 17th IFAC World Congress (IFAC’08, Seoul, Korea, July 11-16, 2008). [also listed under FM]


Academic publications: book chapters

2002


2003


2005


2007


2008


Other academic publications

2004


2006


Monographs


PhD theses

2002

2004

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2005


2006


2007


2008


PhD theses (member of this programme as second or co-supervisor)


Professional publications and products: publications

2005


2006

2007

2008

Professional publications and products: Software

- Torpa (A termination proof tool for string rewriting systems.) First release: 2003. Main developers: H. Zantema
- deskSquad (A common user interface for the mCRL2 toolset.) First release: 2006. Main developers: J. van der Wulp.

Patents

None

Edited Books


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10. SWOT-analysis

Strengths.

- The OAS group is a strongly motivated group of researchers in computer science that is not only strong from the theoretical perspective but that has also a substantial experience in both industrial application and software development. The software infrastructure for modelling and analysis of behaviour of systems that the group has constructed is one of the most versatile and powerful currently in existence.

Weaknesses.

- The group consists of strong individuals with their own focus around the common research theme. The group would be stronger if the individuals would team up more than they are currently doing. As the researchers associate their own identity with their focus this does not happen sufficiently. This is a pity, because the kind of research that we are doing is very labour intensive and therefore requires more concentration of workforce.

Opportunities.

- We are one of the very few groups that has their own stable tool environment for behavioural analysis that has a long history of industrial application. At the same time the group has a strong theoretical background, allowing to appreciate and formulate fundamental breakthroughs. This puts the group into an excellent position to become the technology leader if it comes to modelling and analysis of behaviour. The universality of our formalisms, the theoretical underpinning and the open, accessible structure of the toolset certainly make this possible. But although the determination is there, this is not an easy goal to achieve.

Threats.

- There are two main threats. The first one is that developing and maintaining the software infrastructure requires too much energy. This is caused by continuous changes in developing tools and user requests, but also due to our own desire to adapt and improve the software environment. Without active countermeasures, maintenance duties can become killing for any progress in research. Opportunities, as sketched in the previous paragraph, can go up in smoke, if this is not managed well.

The second threat lies in the success of formal analysis techniques. We expect that somewhere in the coming decades formal modelling and analysis of behaviour will become an integrated part of software design. Modelling and analysis environments with a commercial backing will be able to muster more power and no doubt that we will have to redefine our position and research strategy if this will have happened.

Conclusion.

In the coming years we will continue to develop our mCRL2 framework, such that all aspects of behavioural modelling and analysis relevant for applications can be carried out with the provided means. We will shift to far more substantial applications, due to both a growing interest in the technology from industry and large scientific laboratories. Very important for the coming years is the establishment of a common research community, with a convergence of theory and notation, exchange standards, common software libraries, etc. which is not sufficiently strongly developed in the field, and to which we hope to contribute.
Algorithms

Full title  Algorithms
Programme leader  prof.dr. M. de Berg
Starting date  2003
Research area  Algorithms

In particular, we study computational geometry, I/O-efficient algorithms and graph drawing, and their application in GIS and automated cartography.

CR-classification

Main category:
F.2 Analysis of Algorithms and Problem Complexity.

Other relevant categories:
E.1 Data Structures; G.2 Discrete Mathematics.

Affiliations and cooperations

Below the formal affiliations and main cooperations (limited to at most five per category) are listed.

Affiliations

research school  IPA (Institute for Programming Research and Algorithmics)
mathematics cluster  DIAMANT (Discrete, Interactive and Algorithmic Mathematics, Algebra and Number Theory)

Cooperations (at most five per category are listed)

national  M. van Kreveld
F. van der Stappen (Utrecht University)

international  P. Agarwal (Duke University, USA)
L. Arge (Aarhus University, Denmark)
B. Aronov (Polytechnic Institute of NYU, USA)
D. Eppstein (UC Irvine, USA)
J. Gudmundsson (NICTA, Australia)
Mission statement

We want to perform top-quality fundamental research in algorithms, focusing on algorithms and data structures for spatial data and inspired by application areas such as GIS and automated cartography.

1. Leadership

We give all group members the freedom (and responsibility) to pursue their own research interests as much as possible. In particular, staff members develop their own line of research. Coherence is achieved through the hiring policy: staff members are hired based on their quality but in addition their research interests should fit well within the research interests of the group as a whole. Because of the common interests of the group members and the informal atmosphere, internal collaboration and communication are natural processes. This is further enhanced by our weekly seminar, and the other activities that we organize. The fact that we strive to publish our work in the major international conferences and journals, and the many researchers we receive as visitors, stimulate everybody to get the best out of their research.

This policy means that coaching is the main aspect of the group management. In addition to the day-to-day informal contacts, every group member has a more formal meeting once a year with the head of the group and, where applicable, the daily supervisor. In this meeting the past year is evaluated, strong and weak points are discussed, and plans are made to further improve the performance.

2. Strategy and policy

2.a. Design in brief

The design and analysis of algorithms and data structures forms one of the core areas within computer science. The Algorithms Group performs fundamental research in this area, focusing on algorithmic problems for spatial data. Our research can be grouped into four closely related and partially overlapping areas.

Computational geometry. In many areas of computer science it is necessary to store, analyze, or manipulate spatial data. Examples are geographic information systems (GIS) and automated cartography, robotics, computer graphics, and CAD/CAM. Computational geometry is the field within algorithms research dealing with the design and analysis of algorithms and data structures for spatial data. It can be seen as the fundamental study of algorithmic problems arising in the areas mentioned above. As such, it forms the core of our research program. Although our research in computational geometry is of a fundamental nature, we keep the applicability of the theory we develop in mind: we want to develop concepts and algorithmic techniques, prove properties of these, and provide a theory that will predict which approach must be taken in which setting to obtain geometric algorithms and data structures that are efficient for the task at hand. Especially the last aspect is lacking in the traditional theory.

I/O-efficient algorithms. Modern computer systems have an increasingly complex memory architecture, where memory is organized hierarchically into layers of increasing size but decreasing speed: registers, several cache levels, main memory, and disk (or other external memory devices). An effective use of this memory hierarchy is often essential to obtain the best performance. For example, when an algorithm operates on data residing on disk, it is usually much more important to design algorithms in such a way that the number of I/O's (disk accesses) is minimized, rather than the CPU computation time. Traditional algorithms theory does not take this aspect into account. Hence, a new subfield of algorithms has emerged, which takes I/O- and caching behavior into account in both the design and the analysis of algorithms. Our research in this area mainly concerns problems involving spatial data, so it fits in well with our other research.

Graph drawing. Networks play an important role in real life—think for example of road networks, computer networks, or social networks—and it is therefore not surprising that their mathematical counterpart, graphs, forms a central concept in computer science. To get more insight into a graph structure, it often helps to
visualize it. The subarea within algorithms research studying the visualization of graphs is called graph
drawing. Since the area is closely related to computational geometry and finds many applications in auto-
mated cartography (one of our main application areas—see below), we have been expanding our research
in this area over the past few years.

**Algorithms for GIS and automated cartography.** Geographic information systems (GIS) and automated
cartography are areas where spatial data plays a central role. There are many challenging algorithmic
problems to be found in these areas, and computational geometry can help to formulate and solve these
problems in a rigorous way. Moreover, geographic information systems often deal with massive amounts
of data, so there is a clear need for I/O-efficient algorithms. Thus GIS is an application area that nicely fits
with our other research efforts. Topics that we study in this area include indexing structures (i.e. spatial data
structures), algorithms for terrains (e.g. to compute watersheds and other structures relating to the flow of
water), and automated cartography (e.g. the computation of cartograms or metro maps, both of which can
be considered graph-drawing problems).

### 2.b. Future Programme development

The group was established in 2003, and initially mainly focussed on computational geometry, where the
group members (De Berg, Cheong, Speckmann) already had an excellent reputation. Research in I/O-
efficient algorithms was intensified in 2004, when Haverkort joined the group. In the past few years Speck-
mann has extended her research in algorithmic foundations of GIS and automated cartography, and our
work in graph drawing was further strengthened with the arrival of Wolff in 2006.

We have a coherent and still sufficiently varied program, and do not foresee any major changes in focus. The
main goal for the coming years will be to consolidate our strong position in the algorithms and computational-
geometry community, while further increasing our visibility in GIS and automated cartography.

### 3. Processes in research, internal and external collaboration

We believe that collaboration is very important in research. Hence, much of our research is performed in
external collaborations: over the period 2003–2008 we collaborated with many institutions from all over the
world, including top universities such as Stanford, MIT, Duke University, ETH Zürich, and Tel-Aviv University.
We attract many guest researchers, both for short research visits and for longer stays. Our external contacts
also help us to identify and explore promising new research directions.

The common focus of our research allows us to have extensive internal collaboration as well: group members—
faculty, PhD students, as well as postdocs—regularly publish joint papers in varying collaborations. We
actively involve PhD students and postdocs in our external collaborations, and we stimulate them to not limit
their work to their own research topic but to also consider other topics. We have weekly meetings where
one of the group members, or one of our guests, gives a presentation about their research. All of this leads
to a lively, internationally oriented research group. Within the computer-science department we collaborate
with the Visualization Group and within the mathematics department with the Combinatorial Optimization
Group.

Our goal is perform our research at the highest level, and so we strive to publish our papers in the best
journals and conferences in the field. (Over the period 2003–2008 we published 29 papers in total in the
**ACM Symposium on Computational Geometry (SoCG)**, the most prestigious conference in our field, and in
the **ACM-SIAM Symposium on Discrete Algorithms (SODA)** and the **European Symposium on Algorithms
(ESA)**, the top conferences in algorithms in general). We also published 12 papers in the top journals in our
field: **Discrete & Computational Geometry**, **SIAM Journal on Computing**, and **Algorithmica**.) Our focus on
quality also means we try to hire only the best students for PhD positions. As a result, all students finishing
their PhD during the past period did so within the nominal period of four years.
4. Academic reputation

The group started in 2003, and the staff members received their PhD’s relatively recently (M. de Berg: 1992; H. Haverkort: 2004; B. Speckmann: 2001; A. Wolff: 1999). Nevertheless, the group already has an excellent reputation in computational geometry and in the algorithms community in general, as witnessed by the many algorithms conferences for which our staff members serve on the program committee. Despite the relatively small citation scores in mathematically inclined areas of computer science, our permanent staff members all have a respectable h-index relative to the time since their PhD (De Berg: 25, Haverkort: 8, Speckmann: 13, Wolff: 13).

Over the past few years, we have been building up our reputation in the GIS and graph-drawing communities, resulting in invitations of group members to serve on program committees in these areas (AGILE, SDH, GD). To further increase our visibility in the area of graph drawing, we will host the 19th International Symposium on Graph Drawing in 2011.

Below we list some of the activities and positions of the current permanent staff members during the period 2003–2008. All staff members regularly go on research visits, are invited participants to many Dagstuhl seminars and other workshops, have given invited lectures in seminar series in various universities, referee papers for all major conferences and journals in the area, and so on; these activities are not listed. As can be seen in the list below, two of the group members received a prestigious personal grant in NWO’s Innovational Research Incentives Scheme (Vernieuwingsimpuls): Mark de Berg received a VICI grant and Bettina Speckmann a VIDI grant. In the same Scheme, J. Gudmundsson received a VENI grant to do a postdoc in our group.

M. de Berg

- Organizing committee: 21st European Workshop on Computational Geometry (EuroCG), 2005 (chair).
- Other international scientific committees: International Computational-Geometry Steering Committee (secretary), 2003–2006; Scientific Advisory Board of Custom-Fit, an Integrated Project in the 6th Framework sponsored by the EU, 2004–2008.
- Scientific director of the Institute for Programming research and Algorithmics (IPA), a national research school with about 100 participating PhD students.
- (Co-)author of two books, one of which has become the standard textbook on computational geometry.
- VICI grant (2003) for the research project “Towards a Practical Theory of Geometric Algorithms”.
- Number of publications (DBLP): 149.

H. Haverkort

- Organizing committee: Dagstuhl workshop on computational geometry and geometric networks (2007).
- Number of publications (DBLP): 38.

B. Speckmann


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14 Note that program committees for algorithms conferences are typically quite small, consisting of only 15–20 people.

15 NWO awards these grants to outstanding researchers. VICI grants are targeted to researchers with up to 15 years of experience since their PhD; VIDI grants to researchers with up to 8 years experience. Each year only one or two (and sometimes no) computer scientists receive a VICI grant; the same is true for the VIDI grants.
5. Internal evaluation

See Part A.8

6. External validation

6a. Societal relevance

We live in a three-dimensional world. It is not surprising, therefore, that in many applications it is necessary to store, analyze, or manipulate spatial data. This ranges from robotics and CAD/CAM to GIS and virtual reality and games. Due to several technological advances, the size of typical data sets and the complexity of geometric models in these applications are getting larger and larger. For instance, modern 3D scanners can scan 3-dimensional objects at the rate of 100,000 or more measurements per second, leading to models of individual objects consisting of millions of triangles. Similarly, satellites provide enormous amounts of geographically-referenced data (for example elevation data). The need for efficient geometric algorithms and data structures is therefore only growing.

6b. Industrial contacts

Keygene (Wageningen), Synopsys (Roermond), TNO Industrial Technology, section Industrial Prototyping (Eindhoven), Kadaster (Apeldoorn), Nationaal Lucht- en Ruimtevaartlaboratorium – NLR (Amsterdam), Mapscape (Eindhoven).
7. Researchers and other personnel

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<td></td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td>Total PhD students</td>
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<td>3.37</td>
<td>4.00</td>
<td>4.00</td>
<td>3.83</td>
<td>3.73</td>
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<tr>
<td>Total research staff</td>
<td>-</td>
<td>2.35</td>
<td>5.68</td>
<td>6.91</td>
<td>8.05</td>
<td>8.07</td>
<td>6.23</td>
</tr>
</tbody>
</table>

8. Resources, funding and facilities

8.a. Laboratory infrastructure

The Division provides a technical infrastructure with workstations and/or laptops, and the relevant software, for all its researchers. No additional facilities are needed.

8.b Funding

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.
Table 19: Funding of ALG.

<table>
<thead>
<tr>
<th>Percentage %</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct funding</td>
<td>84%</td>
<td>65%</td>
<td>48%</td>
<td>53%</td>
<td>54%</td>
<td>54%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>Research funds</td>
<td>16%</td>
<td>35%</td>
<td>52%</td>
<td>47%</td>
<td>42%</td>
<td>46%</td>
<td>41%</td>
<td></td>
</tr>
<tr>
<td>Contracts</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>0%</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

Table 20: Funding of postdocs/PhD’s.

<table>
<thead>
<tr>
<th>period</th>
<th>external funding (2003–2008): research grant</th>
<th>budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003–2004</td>
<td>NWO (VENI) : Geometric networks</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>Gudmundsson</td>
<td></td>
</tr>
<tr>
<td>2003–2007</td>
<td>NWO (OC) : Multi-functional geometric data structures</td>
<td>144</td>
</tr>
<tr>
<td></td>
<td>Streppel</td>
<td></td>
</tr>
<tr>
<td>2004–2007</td>
<td>NWO (OC) : Kinetic data structures</td>
<td>341</td>
</tr>
<tr>
<td></td>
<td>Abam, Poon</td>
<td></td>
</tr>
<tr>
<td>2004–2010</td>
<td>NWO (VICI) : Towards a practical theory of geometric algorithms</td>
<td>1,250</td>
</tr>
<tr>
<td></td>
<td>De Berg, Gaooc, Gray, Thite, Hachenberger, Schroders, Tsiorogiannis</td>
<td></td>
</tr>
<tr>
<td>2007 –2011</td>
<td>NWO (OC) : Optimal Geometric data Structures</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>Khosravi</td>
<td></td>
</tr>
<tr>
<td>2008–2012</td>
<td>NWO (VIDI): Drawing Geometric Networks</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>Speckmann, Verbeek</td>
<td></td>
</tr>
<tr>
<td>2008–2012</td>
<td>NWO (Aspasia)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Buchin</td>
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</tbody>
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<tbody>
<tr>
<td></td>
<td>De Berg, Van Walderveen</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>period</th>
<th>external funding (2003–2008): Other</th>
<th>budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004–2008</td>
<td>Scholarship Ministry of Science, Research and Technology, Iran : PhD</td>
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<tr>
<td></td>
<td>Farshi</td>
<td></td>
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</tbody>
</table>

Overview of the results

9.a. Key publications

We have chosen our five key publications to illustrative each of our main areas of research, so that the reader can get a good feeling of the type of work we are doing.


R-trees are widely used I/O-efficient data structures in GIS that usually perform well in practice. We designed the first R-tree variant, the PR-tree, with performance guarantees. The worst-case complexity of answering range queries in our PR-tree is optimal, and experiments show that for well-behaved data sets it has the same performance as the best known structures from the literature, while for more extreme data sets it performs much better (as predicted by our theoretical analysis).


The worst-case behavior of geometric algorithms often only shows up for contrived input sets. The paradigm of realistic input models states that one should define some extra parameters of the input, e.g. concerning the shape or distribution of the input objects, and do a refined analysis in terms of these parameters. The goal is then to develop algorithms that are provably efficient if these parameters have realistic values. This paper is an example of our work in this area.


Map labeling is one of the fundamental problems in GIS and automated cartography. Traditionally, a map is drawn at a fixed scale so only one labeling needs to be computed. Interactive maps, however, allow continuous zooming. This paper addresses the algorithmic challenges arising from this new setting.


Cartograms are maps where the regions have been deformed so that their areas correspond to some geographic variable for that region. This paper studies rectangular cartograms, where the deformed regions are required to be rectangular. Such cartograms were already introduced in 1934 by Raisz. In a recent survey paper W. Tobler states that no algorithms are known for computing rectangular cartograms. We gave the first algorithm to automatically compute rectangular cartograms, and our experimental results show that it performs very well in practice.

9.b. Numerical overview

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<th>2006</th>
<th>2007</th>
<th>2008</th>
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<td>c. book chapters</td>
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<td></td>
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<td></td>
<td>3</td>
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<td>8</td>
<td>9</td>
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<td>4. Profess. publ. &amp; products</td>
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</tbody>
</table>

9.c. List of publications

**Academic publications : refereed journals**

2003


168 Research Evaluation Computer Science 2009 * Part B: ALG


2004


2005


2006


2007


2008


Academic publications: refereed conference proceedings

2003


2004


2005


173 Research Evaluation Computer Science 2009 * Part B: ALG


2006


2007


M. de Berg, H.J. Haerkort, S.V. Thite, L. Toma (2007). I/O-efficient map overlay and point location in low-


2008


P. Laube, M. de Berg, M.J. van Kreveld (2008). Spatial support and spatial confidence for spatial association


**Academic publications : book chapters**

*2005*


*2008*


**Academic publications : other**

*2004*


of the Advanced School for Computing and Imaging, Port Zélande, Ouddorp, The Netherlands, June 2-4, 2004 (pp. 29-36). Delft: ASCI.


2005


2006


2007


2008


PhD theses

2007


2008


PhD theses (member of this programme as second or co-supervisor)


Monographs

2004


2005


2008


Professional Publications and Products

None

Patents

None.
10. SWOT-analysis

Strengths.

- A strong, internationally oriented group, all of whose members want to perform research at the highest level.
- Excellent reputation and collaborations within the algorithmic community.

Weaknesses.

- Until recently, we had only a limited number of MSc students.

Opportunities.

- With our expertise in geometric algorithms combined with our expertise in I/O-efficient algorithms, and graph drawing we have a strong background to further expand our research in GIS and automated cartography.
- Recently the government transferred a significant part of the research funding from the universities to NWO.

Threats.

- Funding for fundamental research is generally scarce.

Conclusion. Based on the SWOT analysis, we do not see any need to adjust our strategy.

The number of MSc students we have attracted had been growing over the years. Moreover, even though the total number of MSc students in our group is not very high, we attract a large fraction of the top students from the department. For example, from the six students in the pilot of the Honours Program that started in 2009, four are doing their main research project with us.

We are already well under way to establish our reputation in the (algorithmic) GIS community—for example, Speckmann will be one of the project leaders in MOVE: Knowledge Discovery from Moving Objects, an EU-funded project involving researchers from computers-science and geography departments which will start in 2009—and we will continue building up our contacts in this area in the coming years.

Finally, even though the funding situation for fundamental research is difficult, we have been rather successful in obtaining funds in the past. With the transfer of research funding from the universities to NWO, we believe we can continue this success in the future.
# Visualization

**Full title**  
Visualization

**Programme leader**  
prof.dr.ir. J.J. van Wijk

**Starting date**  
June 1998

**Research area**  
Visualization

**CR-classification**  
I.3 Computer graphics  
H.5 Information interfaces and presentation

**Affiliations**  
research school  
ASCI (Advanced School for Computing and Imaging)

**Cooperations** (at most five per category are listed)  
national  
prof.dr.ir. J.F. Groote, TU/e  
prof.dr. J.-B. Martens, TU/e, ID  
dr. A. Vilanova, TU/e, BMT  
prof.dr. A. van Deursen, TUD  
dr. M. Worring, University of Amsterdam

international  
prof.dr. M. Rumpf, Univ. Bonn  
prof.dr. S. Dickinson, Univ. Toronto  
Mission statement

The aim of the Visualization group is to develop new methods and techniques for data visualization that enable users to understand the contents of large data sets effectively and efficiently. This includes methodological issues (i.e., how to develop such methods in general), technical issues (i.e., how to present and interact with data), and validation and application in practice (i.e., does a method meet its aims). Furthermore, we aim at offering students challenging, useful, and interesting courses and projects on computer graphics in general and on visualization in particular.

1. Leadership

The Visualization (VIS) group is headed by prof.dr.ir. J.J. van Wijk, and the staff currently consists of prof.dr.ir. R. van Liere (1 day per week), dr. A. Jalba, dr. M. Westenberg, and dr.ir. H.M.M. van de Wetering. The composition of the group has changed considerably during the years. This has been positive in several aspects: the advent of new staff members brings new knowledge and ideas; departures enable people to develop their career or to find positions that match better with their capacities, while simultaneously the network of the group grows. As an example, Dr. A.C. Telea has obtained in 2006 a position as associate professor (adjunct hoogleraar) in Groningen.

The group has weekly meetings where the staff, PhD-students and postdocs participate to discuss ongoing matters. Each month one of the group members presents his recent work. Each year the group leader has evaluation interviews with all members. Exceptionally good results are rewarded by bonuses or promotion. In case of performance below expectations, temporary positions were not prolonged.

Publications in international journals and at international conferences are viewed as the main outlet and forum for evaluation of research results. Members of the group are strongly encouraged to submit, especially to leading journals and conferences in our field. Information on special issues of journals and deadlines for conferences are broadcast. To stimulate submission, conferences can always be attended, as long as a paper is accepted for presentation. Attendance of conferences gives important information on current trends in our field, equally important in this regard is a strong participation of the group in editorial boards, conference organization committees, panels, workshops, etc., to spot and sometimes even set new trends before they have been published.

All PhD-students and staff members are member of the Research school ASCI (Advanced School for Computing and Imaging). PhD-students follow courses offered by ASCI, and are strongly encouraged to participate in its yearly conference, as well as in other national events, such as organized by NWO.

Besides academic activities, we view application and validation in practice as vital. Collaboration with end-users is actively sought, and also, our relation with our spin-off company Magnaview and our collaboration with LaQuSo give an inside view on the needs and wants of the market for Information Visualization.

2. Strategy and policy

2.a. Design in brief

Modern society is confronted with a data explosion. Acquisition devices like MRI-scanners and DNA-sequencers, large scale simulations on supercomputers, but also stock trading at stock exchanges produce very large amounts of data. Visualization of data makes it possible for researchers, analysts, engineers, and the lay audience to obtain insight in these data, thanks to the unique capabilities of the human visual system, which enables us to detect interesting features and patterns in short time.

Data Visualization has attracted much attention since about 1985, as a result of both the large amounts of data that are produced by simulations and measurements, as well as the development of fast graphics hardware. The aim of visualization is to develop methods and techniques using interactive computer graphics
such that most insight in large data sets can be obtained; The central research question is how data should be presented and how users should be enabled to interact with these such that this process is most efficient and effective.

Within Visualization we are active in the following areas:

1. **Information Visualization.** We study how large amounts of abstract data, such as tables, trees, networks and combinations of these, can be visualized. Typical use cases are the visualization of the contents of a computer hard disk and the visualization of the structure of a large software system.

2. **Scientific Visualization.** Scientific visualization concerns data from simulations and measurements, defined over geometric spaces. Within this area we study feature extraction, flow visualization, mathematical visualization, and, in cooperation with the TU/e Department of Biomedical Engineering, medical visualization.

3. **3D interaction.** Visualization requires often interaction with 3D data and objects for interrogation and navigation. In cooperation with CWI we study how affordable desktop Virtual Reality systems (hard- and software) can be designed to simplify these tasks.

Our approach is characterized by the following aspects:

1. We have a strong background in 3D computer graphics. Within computer graphics many methods and techniques have been developed to generate images of real world scenes, for instance for geometric modelling, shading, and texturing. The application of this knowledge can help to produce visualizations of data that are easier to understand and comprehend. Realism here is not a goal, but a useful means to an end.

2. Visualization is almost by definition application oriented. We therefore build many prototypes, use real world test cases, perform user studies, and closely cooperate with domain experts.

3. Scalability is a key issue. Many techniques work well for tens of items, but fall short when used for ten thousands or even millions of items. We aim at the development of methods that can cope with the large data sets that professional users often have to handle. Efficiency of the algorithms is one aspect here, but more often the visualization method itself is a bottle-neck.

In the period 1998-2008 our work in Information Visualization has focussed on Software Visualization. This is a challenging and attractive field, for various reasons. Software systems are large and complex. Systems consisting of multiple millions of lines of code are not uncommon. Often many different versions (in time, per model, per country) exist. Almost all possible types of abstract data play a role in software visualization, and should ideally be shown simultaneously. Software is organized hierarchically, calling structures are graphs, components have high-dimensional attribute sets (especially metrics), on the lowest level text is important. Software visualization is also attractive because software is familiar to us and our students, and because it fits well within other activities in our department.

Our focus on software visualization has led to a variety of new methods and techniques, described in a large number of articles and four PhD theses, focussing on large graphs (Van Ham, 2005), software evolution (Voinea, 2007), state spaces (Pretorius, 2008), and compound graphs (Holten, 2009), and two spin-off companies (Magnaview and SolidSource).

An important focus of our work in Scientific Visualization has been feature based visualization. For very large data sets representation of the data at a higher semantic level is beneficial, with respect to ease of understanding by the user as well as faster processing. This has led to two PhD theses, on skeletonization of binary volumes (Reniers, 2009) and on feature based visualization of mass spectroscopy data (Broersen, 2009).

The focus of our work on interaction, directed by prof. van Liere, is on the development of methods and techniques to enable users to get insight in complex 3D structures, such as the human body and corals. Virtual reality has been a promising direction for a long time, but the cost of the equipment, the quality of the results and integration with tasks of users have been major problems. Desk-top virtual reality systems fit much better in research and analysis environments, but also here still effort is required to render this technology useful for practical purposes. Our research has led to three PhD theses, focusing on user-configurable input devices (Van Rhijn, 2006), interactive measurements of 3D objects (Kruszynski, 2009), and on a programmable display architecture for VR applications (Smit, 2009), and a spin-off company (Personal Space Technologies).
2.b. Future Programme development

In the preceding an overall view was given, which served as our inspiration for the period from 1998-2008. Most of it will continue to hold true for the next period, but growing insight, the advent of new staff, and new opportunities for cooperation led to expansions of the focus.

Our core business was and will continue to be the development of innovative methods and techniques for the visualization and interaction with data. We have done so successfully, and hope to continue this. Nevertheless, we have found that there is a need for better foundations of our discipline, as well as closer cooperation with end users.

The development of visualization systems is now often rather an art than a science. In the next period we pay more attention to more fundamental issues, including methodological issues (how to develop systems and how to evaluate them) and a better foundation on supporting disciplines, including for instance statistics, HCI, perception, and cognitive psychology. One route to this is by focussing on cross-cutting concerns in visualization, i.e., to identify and analyze aspects that show up in many visualization applications. In this respect, we intensified our cooperation with prof. J.-B. Martens, Dept. of Industrial Design, who is an expert in perception, usability studies, and statistical analysis, and we increasingly publish our work at ACM CHI.

Another important trend is **Visual Analytics**: The science of analytical reasoning, supported by interactive visual interfaces. The concept of Visual Analytics was founded in 2004, with the influential publication *Illuminating the path: The research and development agenda for visual analytics*, edited by James Thomas and Kristin Cook. Integration of other data analysis methodologies (statistics, data mining); heterogenous data; and consideration of the complete data analysis process, from collection to presentation, are key aspects. Since 2006 we are moving in this direction.

We participate in the EU VisMaster project, which aims at setting up a European research agenda for Visual Analytics; Shrinivasan focuses in his PhD project on support for navigation and knowledge capture in visualization. In the POSEIDON project we cooperate with Thales and prof. E. Postma, University of Tilburg, on visual analysis of vessel movement data; we have started cooperation with dr. M. Worrin, University of Amsterdam, on interactive multimedia analysis; we have started cooperation with prof. W. van der Aalst on interactive process mining. We have cooperated with PRI, Wageningen, on visualization for bio-informatics; with the advent of dr. M. Westenberg to our group, this topic has obtained a strong boost.

With the advent of dr. A. Jalba, we have brought expertise on numerical methods for image analysis and visualization within our group, which strengthens our interest in scientific visualization. Cooperation with the groups of prof. L. Florack (TU/e Mathematics) and dr. A. Vilanova (Department of Biomedical Engineering) has started up.

3. Processes in research, internal and external collaboration

Research is done by the staff, postdocs, PhD-students and master students, each with its own duties. The staff is responsible for supervision, submission of research proposals, and identification of new research opportunities. Concerning the latter, attendance of conferences, discussions with external partners (varying from our colleagues within computer science to industrial partners abroad), and also carrying out small research projects are important means for inspiration.

PhD-students do most of the research. They are strongly stimulated to aim at contributions to international conferences and journals. Their projects are typically split into periods of 6–9 months, where each period leads to concrete results, usually a combination of an insight how a problem can be solved, a working prototype, and an international publication.

Cooperation with end-users and validation of results with them is strongly encouraged, and also, cooperation between them is stimulated. Currently, PhD-students are sharing two office rooms, and also, most of them work in Information Visualization. This makes it easy to find colleagues to discuss all kinds of different matters.

We have a long cooperation with prof. J.F. Groote on visualization of state spaces. In 2004 the department of Computer Science TU/e has started LaQuSo, our Laboratory for Quality Software. The aim of LaQuSo
is to develop and test methods and tools for assessing and approving software systems, based on variety
of sources, ranging from high-level models to the code itself. Software visualization fits naturally in this. Externally we cooperate with prof. A. van Deursen (TU Delft). The focus here is on reconstruction of software architectures.

Master students actively participate in the research of our group, especially via their final projects. We find it important that students are enabled to do research themselves. Their projects range from applied to more basic research; and are carried out within industry, in cooperation with other research groups, or within our own group. Master projects are a very effective way to start up external cooperations. In the period 2002-2008 the work of masters students has led to thirteen papers presented in international journals and conferences. Finally, active participation of Master students is important for recruitment of new PhD students. Four of our previous and current PhD students completed their masters in our group.

4. Academic reputation

The group has a strong visibility in the international visualization community. In the period 2002-2008 we were granted seven best paper awards (IEEE InfoVis 2003, IEEE Vis 2005, IEEE InfoVis 2006, ACM SoftVis 2006, VRST 2008, IEEE/EG VG’08, Henry Johns Award 2009), and the IEEE 2007 Visualization Technical Achievement Award. Below accomplishments of the staff are enumerated. Dr. A. Jalba and Dr. M. Westenberg joined our group half way 2008, and are not included.

J.J. van Wijk

- Member Steering Committee: IEEE InfoVis, 2008–.
- Participant NSF/NIH workshop on Visualization Research Challenges 2005.
- Chair of VIEW committee NWO, 2005–2008 (Dutch research program for the stimulation of visualization and virtual reality research, supported by NWO).
- Published about 45 papers in peer-reviewed journals and conferences (2002-2008).
- Keynote speaker: Symp. on Transdisciplinary Fluid Integration 2006, Matsushima, Japan; SimVis 2008, Magdeburg, Germany; Keynote speaker PacificVis 2009, Beijing, China.

R. van Liere

- Guest editor: Computers and Graphics: vol. 33 nr 2 "Virtual Environments".
- Published about 35 papers in peer-reviewed journals and conferences (2002-2008).
- Best Paper Award VRST 2008.

A.C. Telea

- Member Program Committee: IEEE Vis 2005 and 2006, EUROMICRO’05, IEEE SPBG’05, ACM SoftVis’06.
- Co-chair: IEEE MSR’06.
- Best Paper Award ACM SoftVis’06.
H.M.M. van de Watering

- Visiting scholar at Xi’an Jiaotong University, Xi’an, China, September 2005 - February 2006.
- Best Paper Award IEEE VG’08.

5. Internal evaluation

See Part A.8

6. External validation

6.a. Societal relevance

Large data sets are ubiquitous, more insight in these can lead to more efficient processes, less waste, and shorter development times. We cooperate with several academic research groups and partners from industry, with varying interests, ranging from numerical mathematics, process simulation, bioinformatics, business data, software development, and medical imaging.

Besides direct cooperation with applicants, we aim at dissemination of our tools by making tools and libraries available. Our disk visualization tool SequoiaView has been downloaded 950,000 times since 2001. Also, this tool has led to a spin-off company: Magnaview B.V., with TU/e as one of the shareholders. Magnaview offers products and services for visualizing business data, based on technology developed in the VIS group. Started in 2005, the company currently employs 17 people (11 fte) and hosts a number of students. Cooperation is close and fruitful. Magnaview offers challenging projects to students, insight in the needs and wants of end-users inspires our research. Another spin off is SolidSource, directed by Lucian Voinea, the research of prof. R. van Liere has led to Personal Space Technologies.

6b. Industrial contacts

- Magnaview, Eindhoven
- Thales, Hengelo
- Philips Research, Eindhoven
- Philips Medical Systems, Best
- Tiobe, Eindhoven
- Cap Gemini, Utrecht
7. Researchers and other personnel

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8. Resources, funding and facilities

8.a. Laboratory infrastructure

The Division provides a technical infrastructure with high-end workstations and/or laptops, and the relevant software, for all its researchers. In addition, our group has available a number of workstations equipped with state-of-the-art graphics cards. No additional facilities are needed.
Table 21: Funding of VIS.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
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<td>74%</td>
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<td>6%</td>
<td>16%</td>
<td>27%</td>
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<td>30%</td>
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<td>8%</td>
<td>14%</td>
<td>6%</td>
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Table 22: Funding of postdocs/PhD's.

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<th>2004</th>
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<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>average</th>
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<td>7%</td>
<td>4%</td>
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<td>67%</td>
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<td>0%</td>
<td>0%</td>
<td>0%</td>
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</table>

8.b Funding

8.c. List of external funds

Below the external funds are listed for each project the researchers that are (partially) funded from the project.

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<th>budget (k€)</th>
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<td>Barosan</td>
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<td>2004–2008</td>
<td>NWO (OC) : VOLTS – Verification of large transition systems</td>
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<td>2005–2009</td>
<td>NWO (Jacquard) : RECONSTRUCTOR – Reconstructing software architectures for system evaluation purposes</td>
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<td>Holten</td>
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<td>2005–2009</td>
<td>NWO (OC) : Multiscale skeleton features for visualization</td>
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<table>
<thead>
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<th>period</th>
<th>external funding (2002–2008) : Contracts</th>
<th>budget (k€)</th>
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<td>ITEA (02016) : SPACE4U – Software platform and component environment for you</td>
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<td>2005–2007</td>
<td>ITEA (04003): TRUST4ALL – A trustful software middleware architecture for embedded systems</td>
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<td>2007–2011</td>
<td>BSIK (Embedded system Institute- Research Project) : Poseidon</td>
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190 Research Evaluation Computer Science 2009 * Part B: VIS
Overview of the results

9.a. Key publications


9.b. Numerical overview

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</tbody>
</table>

9.c. List of publications

Academic publications : refereed journals

2002


2003


\textsuperscript{18}Names of authors participating in the research programme VIS are printed in boldface.
2004


2005


2006


2007


2008


**Academic publications : refereed conference proceedings**

**2002**


**2003**


Technische Universiteit Eindhoven University of Technology

Eurographics Association.


2004


2005


A.C. Telea, S.L. Voinea (2005). Interactive visual mechanisms for exploring source code evolution. In S. Ducasse et al. (Eds.), Proceedings 3rd IEEE International Workshop on Visualizing Software for Un-


2006


197 Research Evaluation Computer Science 2009 * Part B: VIS


2007


2008


200 Research Evaluation Computer Science 2009 * Part B: VIS
Academic publications: book chapters

2002


2005


2006


2007


2008


Academic publications: other

2006


2007


Monographs

2003


PhD theses

2004


2005


2007


2008


Professional publications and products: Software

10. SWOT-analysis

Strengths.
- Strong visibility in Visualization community.
- High quality results.
- Direct link with practice via spin-off company.
- Solid background staff in computer graphics, geometric modelling, 2-D and 3-D image processing, applied mathematics, design.

Weaknesses.
- Limited background staff in perception, cognitive psychology, HCI, statistics, data-mining.
- Group depends on a few researchers.

Opportunities.
- Visualization fits well in many research programs (computational science, data explosion, software visualization, cultural heritage, etc.).
- Complexity and size of data will continue to grow, also for private use (email visualization, net-community visualization, etc.).
- Visual Analytics is new approach that rapidly gains momentum, and which matches well with our expertise.

Threats.
- Hard to find high quality candidates for PhD-positions.
- Spreading of scarce time over too many topics.
Direct advantages of visualization are difficult to quantify.

**Analysis.** Our group has obtained a solid position in data visualization research. Since there are many challenges ahead and opportunities for cooperation in our field, we do not see a reason to adapt our strategy. Acquisition of funding and attracting high quality PhD-students continue to require much attention.
System Architecture and Networking

**Full title**  
System Architecture and Networking

**Programme leader**  
prof. dr. J.J. Lukkien

**Starting date**  
1-1-2002

**Research area**  
Resource Constrained Networked Embedded Systems

**CR-classification**  
C. Computer systems organization, in particular:  
C.1 Processor architectures,  
C.2 Computer-communication networks,  
C.4 Performance of systems.  
D. Software, in particular:  
D.2 Software engineering,  
D.4 Operating Systems.

**Affiliations**  
research school  
IPA (Institute for Programming Research and Algorithmics)

**Cooperations**  
(at most five per category are listed)  
prof. de With, Prof. Bergmans, Prof. Corporeal, (TU/e (EE))  
prof. Eggen, Prof. Feijs (TU/e (ID))  
prof. Nijmeijer, Prof. Steinbuch (TU/e (ME))  
prof. Lagendijk, prof. Epema, prof. Sips (Tu Delft)  
prof. Havinga, prof. Smit (Twente University, Enschede)  
dr. Chaudron (Leiden University)  
dr. Lokhorst (Wageningen University)

**International**  
prof. Henschel (Cottbus University)  
dr. Nolte (Malardalen University)  
prof. Fohler (University of Kaiserlautern)  
prof. DeCotignie (EPFL)  
prof. Khong (National University Singapore)
Mission statement

We want to understand how to design flexible and predictable resource-constrained networked embedded systems. We want our research to be practically applied and available as software and tools, such building a competence in this domain. We organize and present the results of this research in order to educate and actively involve young people.

1. Leadership

The System Architecture and Networking (SAN) programme started in 2002. The group is led by prof. dr. Johan Lukkien. The permanent staff further consists of dr. ir. Reinder Bril, dr. Tanir Ozcelebi, dr. Rudolf Mak, and dr. ir. Richard Verhoeven. Valuable extra input and a good industrial cooperation is coming from 2 part-time full professors (prof. dr. ir. Kees van Berkel and prof. dr. Antonio Liotta) and 1 part-time assistant professor (dr. Dmitri Jarnikov). At the time of writing there are 7 PhD students and 1 postdoc.

The research activities are planned and discussed by the staff as a whole and executed mostly in research projects. Emphasis in the projects is put on empirical validation in the form of software results. Staff members are encouraged to setup their own research projects and obtain funding for their own PhD students. In bi-weekly meetings, results of group members are presented in our group meetings.

In weekly meetings the staff discusses progress of students, educational concerns and the initiation of new research projects. PhD students have weekly meetings with their supervisors.

2. Strategy and policy

2.a. Design in brief

The group was established in 2002, partly as reorganization of the former group “Parallel Systems” (PS). The programme of PS was aimed at large-scale simulations in biology and chemistry. The first years of SAN shows output in this area through the cooperation between prof. Lukkien and prof. Hilbers and two PhD students, as well as a small line of activity around the simulation tool CARLOS.

Since 2002 the programme is focused on resource-constrained networked embedded systems (RCNES). While networking and distribution is at the heart of modern ICT systems, embedded systems evolved to-
wards networking more recently. Originally embedded systems just replaced mechanics but in the course of time we see programmable and communicating electronics in all kinds of equipment that surround us. In the literature this development is termed *ambient intelligence* (i.e., the convergence of networking, user interfaces and embedded computing) or *pervasive computing*.

Figure 5 gives a simplified picture of an RCNES. Research topics within SAN focus on distributed aspects of RCNES (middleware and networked services), on the platform (predictable and reliable resource management) and on efficient embedded computations (typical for signal processing). These three overlapping topics are discussed in some more detail below. Example application domains include distributed media systems, wireless sensor networks, automotive electronics and, more recently, lighting.

**Coordinated applications**

The application components in Figure 5 typically expose functionality, resources and content as services to the network. Applications on top of RCNES are formed through (external) composition of these services in ways not known during their construction. This leads to a separation between functionality on the one hand and coordination, management and control on the other hand, which is found in standards like UPnP and OSGi.

We have studied distributed multimedia applications based on this concept from the perspectives of system architecture, service quality, service management and system design. For service access control and management we developed the concept of virtual community at the service level; for service quality management we studied resource monitoring concepts.

One of the addressed issues is how and where to install new application components, and where the control of this should be. We have cooperated in a series of projects in the development of a component framework. The insight coming out of this work is that components should be represented as a set of related models that give views for different purposes. More recently, we have applied our work to sensor networks where we developed a service-based language. The central idea is to program the sensor network as a single entity, with application components for each sensor generated by a compiler. In several projects we have collaborated with industrial partners, leading to price-winning designs and results.

**Predictable platforms**

Predictable RCNES require predictability of both platform (OS) and network (see Figure 5). This amounts to scheduling and resource management, as well as control of the installed application components. For real-time scheduling we study applications of *fixed priority scheduling with deferred preemption* (FPDS), which is underlying some real-time connection technologies such as CAN; we combine FPDS with *budget-based scheduling*. In order to predict the behavior of a platform plus installed application components we investigated how to specify the resource use of components and how to predict resource properties of compositions. We studied both analytical and scenario-based approaches.

In some RCNES, resources may be varying or there may simply be too little available to serve all applications. We developed methods and application components to adjust quality to available resources and applied this to the context of media processing.

**Embedded computations**

Although embedded systems are severely resource constrained they still have to perform significant computations. For example, low-level signal processing is required for wireless communication. Modern RCNES like mobile telephones support many different wireless standards leading to a computation demands that are many tens of GOPS. Since strict budgets of computation, time, memory and energy apply, resource management and predictability are again vital. The challenge is to map these computations as efficiently as possible to a hardware platform, typically consisting of special-purpose (co)processing hardware. We have worked on embedded vector processing and more recently on systematic mappings of computations onto FPGA-based systems.

**2.b. Future programme development**

The contributions of the group have been in system architecture, system predictability and resource management. The research is performed in externally funded projects that determine the application domain. During the reporting period we have had projects mainly in the area of mobile multimedia. In current and
future projects we seek the application domains of intelligent environments and of in-vehicle networks. In this context we have started collaborations with the departments of industrial design (in the new laboratory for lighting) and mechanical engineering (in the new automotive master), besides the ongoing collaboration with the department of Electrical Engineering. Within the department, we collaborate with prof. Jan Friso Groote in an automotive project and we are setting up a project with the group of prof. Jos Baeten.

We continue to work on the questions of control and management in a distributed system of small devices to support applications of pervasive systems. We also continue to investigate applications of FPDS and budget scheduling for resource management. For the latter we are currently reviewing the scheduling analysis in automotive network technologies. We are working on implementation methods for FPDS in several open-source real-time operating systems. Regarding embedded computations, we extend this work into in the 4G wireless domain where the challenge is to perform embedded TOPS/W (tera-operations per second per watt). We foresee the need here to have multiple levels of concurrency (MIMD as well as SIMD).

At the time of writing the group is involved in 3 newly started projects around these questions and 3 more project applications. We expect to grow with 7 new PhD and postdoc positions in the course of 2009.

3. Processes in research, internal and external collaboration

Staff members are responsible for directing the research. They coach junior researchers that work in (thematic) teams and are usually associated with a project. Research status and results are communicated within the group in weekly presentations. This supports collaborations, gives feedback to the researchers and helps them improve their communications skills.

New group members take courses to improve their research and presentation skills. PhD students and postdocs are involved in educational activities of the group. Many PhD students have worked for some time in an industrial laboratory. SAN members are members of the research school IPA. PhD students take IPA spring and fall schools and contribute to these. We exchange teachers in our courses with universities in Europe using the Erasmus and Socrates programmes. We give courses to industry around us. We also organize exchange visits with foreign universities for both PhD students and master students and we have joint publications in this way.

Our research is organized in projects, national as well as international. In this way, and through our part-time professors, there is a natural collaboration with the department of Electrical Engineering, with Philips Research, NXP Research, ST-Ericsson, IrDeto and with SMEs in the Eindhoven region. In these projects we establish not only theoretical results but also deliver proofs of concept in the form of working software. This makes it possible to advance our work by building on previous results and it also makes us an attractive partner within projects.

In addition to these externally funded projects we define small projects ourselves to initiate new research directions. In the reporting period we have been involved in 17 projects of which 13 were funded externally.

4. Academic reputation

Prof. dr. J.J. Lukkien

- Published over 70 papers in peer-reviewed journals and conferences.
- Scientific director of the postmaster Software Technology Programme at Eindhoven University.

Prof. dr. ir. C. van Berkel

- Organizing committee: ISSCC Highlights Event, Eindhoven, 2009 (chair)
- Other national scientific committees: IPA board, since 2008
• Filed over 10 patent applications
• Published over 60 papers in peer-reviewed journals and conferences.
  (over 20 papers during 2002-2008)
• Invited lectures:
• Invited paper "Multi-Core for Mobile Phones" DATE 2009, Nice.
• IEEE Distinguished Lecturer, since Jan 2009.

dr. M.R.V. Chaudron

• PC member of over 15 conferences and symposia in the area of component-based Software Architecture
• Organizing committees:
  – Component-Based Software Engineering, 11th International Symposium, CBSE 2008 co-chair with Clemens A. Szymerski, Karlsruhe, Germany.
  – Co-organizer of the workshop on Metrics and Models, satellite event of the Models/UML conference October 2007, Tenessee, USA.
  – Co-organizer of the workshop on Quality in Modelling, satellite event of the Models/UML conference 30 September 2006, Genoa, Italy.
• Published over 54 papers in peer-reviewed journals and conference proceedings.
• Best paper awards
  – Two awards (http://www.irit.fr/models/awards.html), viz. the ACM Most distinguished paper award and the Best Paper Award Offered by Springer in 2008 for Empirical Analysis of the Relation between Level of Detail in UML Models and Defect Density - Ariadi Nugroho, Bas Flaton, Michel Chaudron

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Prof. dr. E.H.L. Aarts who moved to the department of Industrial Design in 2007 is vice president and scientific program director of Philips Research. He was chairman of the NWO Physical Sciences Council and also active in many boards and committees on a national level. He was involved in the introduction of the concept of ambient intelligence and has published several books on the topic. He has supervised numerous PhD projects. He recently founded the new laboratory on lighting.

dr. T. Ozcelebi who recently started as an assistant professor published over 20 papers in peer-reviewed journals and conferences.

Other results

- Our work on a component framework for RCNES has been part of a series of international projects; two of these project have won prices. The developed software architecture itself has become the reference middleware architecture in the MPEG standard.
- A framework for media distribution within RCNES in the presence of varying resource availability (including network bandwidth, processing capability, buffer capacity and display) has been developed.
- The CARLOS simulation software developed in the group is currently being marketed as a product by an external company.

The Trust4All project received the brons ITEA achievement award. The results of this project and its two predecessors are a reference for MultiMedia Middleware in the MPEG standardization group.

The surveillance demonstration in the CANDELA project has received an ITEA award, was further developed by Bosch into the IVA 3.5 system and received the Detektor International Award ‘highly recommended’.

5. Internal evaluation

See Part A.8

6. External validation

6.a. Societal relevance

Staff members are active in responding to review and analysis requests from small companies or governmental organizations. Through LaQuSo, the Laboratory for Quality Software at Computer Science we perform small research and advice projects for industry. We have performed a performance review of the systems at ABP (the governmental pension organization). Software reviews have been performed for ASML, Philips, Hermes, the city of Amsterdam, and the public transportation service of the city of Eindhoven. A system analysis has been done for ICTRO. For the police we have done a project to aid forensic analysis of Windows computer. Our programming system for sensor networks is used by Wageningen University for the monitoring of cows. SAN-supervised master students are going to many different companies in the area.

In addition to research-related activities, SAN staff participates in courses. This concerns in particular a contribution to the masterclass security of TIAS and real-time systems courses taught at Philips Research. Research results are incorporated into the courses taught bij SAN staff such that students have the knowledge required by our industrial contacts. Master students take part in the research projects as can be observed from the publication list.

6b. Industrial contacts

The prime industrial impact of the group is through the collaboration in research projects. This has already been explained in enough detail. Other contacts are on an incidental basis, related to a particular question
or small project (e.g. for LaQuSo or within the Software Technology programme), or for a case study in existing research.

The companies we have, or have had, substantial cooperation with are: Philips Research, Philips Medical Systems, ASML, Océ, LogicaCMG, CapGemini, Getronics PinkRoccade, Nokia, VIT, Ikerlan, Robotiker, ESI (European software institute), Bosch Security, Sioux, Microsoft (Germany), VDG Security, Vinotion.
## 7. Researchers and other personnel

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8. Resources, funding and facilities

8.a. Laboratory infrastructure

The Division provides a technical infrastructure with workstations and laptops and the relevant software for all its researchers. In addition, SAN maintains a cluster used both in education and scientific research (simulations mainly). We have a room especially for experimental setup, currently used for teaching and experimenting with FPGA programming. Demonstration platforms like PDAs, small laptops and sets of wireless sensors are readily available through the projects SAN is involved in. For more advanced setups we are currently cooperating within the Nisric laboratoria, and within the TU/e lighting laboratory initiative. We also work with our project partners (Wageningen University, Imperial College London) in their laboratories.

8.b. Funding

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<td>Contracts</td>
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<td>30%</td>
<td>46%</td>
<td>47%</td>
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<td>0%</td>
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</tr>
</tbody>
</table>

Table 24: Funding of postdocs/PhD’s.

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

<table>
<thead>
<tr>
<th>period</th>
<th>external funding (2002–2008): research grant</th>
<th>budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998–2002</td>
<td>NWO (SION): Quality of service for multimedia systems Aerts</td>
<td>98</td>
</tr>
<tr>
<td>2001–2005</td>
<td>NWO : SACC – Software architecture = components + coordination Russello</td>
<td>68</td>
</tr>
<tr>
<td>2003–2009</td>
<td>STW (Progress EES) : Internet based monitoring and control of embedded systems Bosman, Mazuryk, Tjong, Tran</td>
<td>278</td>
</tr>
<tr>
<td>2006–2009</td>
<td>STW (Progress DES) : FINESSE – Fault diagnosis for embedded systems dependability</td>
<td>...</td>
</tr>
</tbody>
</table>
Overview of the results

9.a. Key publications

We selected these publication with the intent to have a fairly complete coverage of our research activities.


This book chapter summarizes the entire work on a component-based system for RCNES. This system is used as the reference architecture for Multi-Media Middleware in the MPEG working group.


This paper explains and corrects a mistake in the analysis of CAN and is found to be so important that it is freely accessible online. The actual mistake was reported in a Technical Report and a workshop contribution. The complete analysis is published in a paper in the Real-time systems journal in 2009.


9.b. Numerical overview

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
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<td>a. in refereed journals</td>
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<td>6</td>
<td>8</td>
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<td>9</td>
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<td>b. in refereed proceedings</td>
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<tr>
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<td>2</td>
<td>4</td>
<td></td>
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</tr>
</tbody>
</table>

9.c. List of publications

Results below include output of prof. Hilbers only to the extent of the cooperation, i.e., publications with PhD students of SAN.

Academic publications : refereed journals

2002

M.T.M. Koper, J.J. Lukkien\textsuperscript{19} (2002). Modeling the butterfly : influence of lateral interactions and adsorption geometry on the voltammetry at (1 1 1) and (1 0 0) electrodes. Surface Science, 498(1–2), 105–115.


2003

\textsuperscript{19}Names of authors participating in the research programme SAN are printed in boldface.

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2004


2005


2006


IEEE Transactions on Biomedical Engineering, 53(8), 1499-1511.


2007


2008


**Academic publications: refereed conference proceedings**

2002


2003


2004


2005


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2006


2007


S.V. Nedea, A.J. Markvoort, A.A. van Steenhoven, P.A.J. Hilbers (2007). Heat transfer predictions for micro/nano-channels at atomistic. In Fifth International Conference on Nanochannels, Microchannels and Minichannels will be held during June 18-20, 2007 at the Universidad De Las Americas Puebla, Mexico (pp. ). Mexico, Puebla.


M.J. Holenderski, R.J. Brii, J.J. Lukkien (2008). Using fixed-priority scheduling with deferred preemp-


Academic publications: book chapters

2003


2004


2005


2006

E.H.L. Aarts (2006). Foreword. In Y. Cai, J. Abascal (Eds.), Ambient Intelligence in Everyday Life (Lecture
Notes in Artificial Intelligence, 3864) (pp. vii-viii). Berlin: Springer-Verlag.


2007


Academic publications : other

2004


2005


2006


Monographs

2003

PhD theses

2002


2003


2004


2005


2006


2007


PhD theses (member of this programme as second or co-supervisor)


Professional publications: Software

We have developed the following software tools as part of our research.

- **CARLOS**, a programm for the simulation of catalytic surface reactions, first release in 1997, version 4.1 in 2002, version 5.0 in 2008. website: http://www.win.tue.nl/~johanl/projects/Carlos, main developer prof. dr. J.J. Lukkien. This code has been developed in the period 1995-2004 with the department of Chemical Engineering, with minor maintenance since. The tool has been shared within a group of academic partners and has been used in numerous simulation studies. Currently the code is transferred to an English company that is in the business of marketing simulation codes.

- **SAAT**, Software Architecture Analysis Tool, first release in 2002, main developer Johan Muskens. This tool is capable of evaluating quality attributes of software architectures. It is available through LaQuSo.

- **MetricView**, a tool to visualize software architecture metrics (obtained e.g., from SAAT), first release 2005, main developer Christian Lange, website http://www.win.tue.nl/empanada/metricview. This tool, developed in the Empanada project gives a complete view on a software architecture and allows users to obtain an understanding of the metrics.

- **OSAS**, Open Service Architecture for Sensors, first release in 2008, main developers Richard Verbhoeven, Remi Bosman, website: http://www.win.tue.nl/san/osas. This work comprises a toolchain for programming wireless sensor networks developed in the WASP project. Currently it is bound by the conditions of the WASP project and used only by the partners in that project.

In addition we are developing and contributing additions to real-time operating systems like LINUX-RTAI, see e.g. http://wiki.wikked.net/wiki/FPDS_and_Reservations_in_RTALinux.
Patents

2002


2003


2004


R.J. Bril. *Method and system for restrained budget use with controlled budget transfer.* Application WP2005083566 ;international publication date 09-09-2005.


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### 2006


### 2007


**Edited books 2006**


### 10. SWOT-analysis

**Strengths.**

- The group is innovative and capable of linking theory to practice by having both theoretical results as well as concrete products in the form of software and tools (CARLOS, SAAT and recently the OSAS system for wireless sensor networks).
- The group has a practical orientation which is also visible in the number of patent applications.
- The group has realized a large number of PhD theses.
- In the Netherlands, few parties work on real-time systems and reservation-based resource management. This work is typically needed by the industry in the Eindhoven area. Our results in the area of FPDS are globally recognized.
The group has an open attitude to industry and a well functioning industrial network. Through this, the group is very successful in acquiring funding.

**Weaknesses.**

- Typical for a university environment is a frequent change of people. We have seen many changes the past years which endangers continuity.
- The output of the group is not distributed evenly over the group members.
- For staff members, it has been difficult to reserve enough time for research (besides education and project overhead).
- We have had a number of two-year projects; these are too short for junior researchers to establish significant output.

**Opportunities.**

- We are involved in two new promising application domains, viz., automotive electronics through the HTAS programme (in collaboration with prof. Jan Friso Groote and the department of Mechanical Engineering) and in the new laboratory for lighting research (in collaboration with 5 other faculties of the TU/e).
- We are well connected to NIRICT, CeDICT and the new FES programme.
- We have an opportunity to work with Electrical Engineering on massively parallel computations, using BEE3 as a shared vehicle.
- The current economic situation has a multitude of opportunities for intensifying existing and establishing new cooperations.

**Threats.**

- Although SAN has been financially very healthy and has many opportunities for acquiring funding for its research, the current financial situation of the department limits the ambitions. Unlike before, the extra benefits of the acquired funding do not flow back automatically into the budget of the group. The freezing of the current staff member vacancy inhibits a healthy growth in output or worse, could discourage further ambition.
- It remains difficult to attract good researchers in our area because of the competition with industry, both for postdoc positions and for assistant professor positions.

**Conclusion**

In our way of working we combine our research interests with application areas. We see this strategy as a success formula and we plan to continue in this way, moving our emphasis from multimedia to automotive and lighting applications. By involving master students more systematically in our research we are able to recruit new PhD candidates more easily. The limitations coming from financial problems at the faculty level are currently countered by applying for postdoc positions in new projects. We avoid to have junior researchers in two-years projects, and also participate mainly in longer-lasting projects.
Software Engineering and Technology

Full title: Software Engineering and Technology

Programme leader: prof. dr. M.G.J. van den Brand

Starting date: 2006

Research area: Methods and tools for efficient development and maintenance of reliable software

CR-classification:
- D. Software:
  - D.1 Programming techniques
  - D.2 Software engineering
  - D.3 Programming languages

Affiliations:
- Research school: IPA (Instituut voor Programmatuurkunde en Algoritmiek)
  - Delft: SERG (head by prof. dr. Arie van Deursen)
  - Enschede: TRESE (head by prof. dr. Mehmet Aksit)
  - National: SEN1 (headed by prof. dr. Paul Klint) at CWI
    - UU (headed by prof. dr. Doaitse Swierstra)
    - RUL (dr. Michel Chaudron)
    - Systems Engineering (TU/e) (headed by prof. dr.ir. Koos Rooda)
    - Embedded Systems Institute
- International: Pareo, LORIA/INRIA, Nancy (group headed by Pierre-Etienne Moreau)
  - LINA, University of Nantes (group headed by Jean Bezivin)
  - Royal Holloway University (group of Adrian Johnstone)
  - Research group on Algebraic and Logical Design Methods, Swansea University (group of Peter Mosses)
  - Lehr- und Forschungsgebiet Informatik 2, Fachgruppe Informatik, RWTH Aachen (group of Jürgen Giesl)
Mission statement

The mission of SET consists in developing methods and tools for time- and cost-efficient evolution of high-quality software systems: from inception, through development and maintenance to phase out. SET recognizes the importance of both legacy systems and state-of-the-art development methodologies, such as model-driven software development driven by (formal) models, domain-specific modeling and generic tooling. Therefore, SET will not limit its investigations to recent software development phenomena, but will also focus on a variety of other topics dealing with software migration, reengineering and reuse. SET believes that it is of the utmost importance to integrate the daily software development practice with cutting-edge research and high-profile education. SET welcomes cooperation with industrial and academic parties that will foster a better understanding of the nature of software and software-related processes.

1. Leadership

During the period covered by this visitation the SET group has undergone significant change. Formerly it was called SoC (Software Construction) and headed by prof. Bruce Watson. In February 2005 prof. Watson’s temporary appointment ended. The faculty board decided to give the vacant position a more software engineering oriented profile. Meanwhile the group was lead by dr. Kees Hemerik. In January 2006 prof. Mark van den Brand was appointed as new head and the name of the group was changed to SET (Software Engineering and Technology).

The transition from SoC to SET marks a change in direction. The SoC group was mainly education oriented. It had only 1.5 PhD student (one full, one shared with the Formal Methods group) and little externally funded research. A major goal of the transition is to establish a better balance between education and research by focusing and extending research activities. Internally, this is achieved by discontinuing existing research themes and by defining new research themes in which all group members could participate. The staff members where encouraged to actively participate in research and to attempt acquisition of external funding. A new and promising staff member was hired. This new policy has also led to the redefinition of tasks of some of the group members. Externally, contacts have been established or intensified with the Embedded Systems Institute (ESI) and the high-tech industry, a.o. NXP, Philips Research, ASML, and Vanderlande Industries. The results are encouraging: since the change from SoC to SET, 4 new PhD positions and 1 junior researcher position have been acquired. Furthermore, 2 part-time externally funded PhD students are active in SET.

2. Strategy and policy

2.a. Design in brief

Historical context

The former SoC group had a long-standing tradition in the formal derivation of small algorithms and programs. The guiding principle is that a program and its proof of correctness should be developed hand in hand. This approach is sometimes called correctness by design. Little attention has been given, however, to scaling up of the method and to supporting tools. A notable exception is the Cocktail system (dr. Franssen) for interactive development of small imperative programs and their correctness proofs. However, the scalability of this tool was restricted.

One exception with respect to scaling up the correctness by design approach was developed in the TABASCO project. TABASCO (TAXonomy BAseD Software CoMponents/CoNstruction) was a long-term research project of SoC. Its goal was to bring order to the many related algorithmic problems and solutions in a particular problem domain (e.g. sorting, pattern matching, parsing) and to codify the results in a library of algorithms or components. The main results of this work were algorithm taxonomies (in a precise technical sense), which provided structure and insight in the algorithmic problem domain, and very coherent toolkits. This research is discontinued with the finalization of the PhD thesis of ir. Cleophas.
As a side effect of dr. Verhoeff’s involvement in the organization of national and international programming contests, he and ir. Scheffers have developed PEACH (Programming Education and Contest Hosting/Verification System) and PEACH3 (see http://peach3.nl). This work has necessitated research on automatic testing, similarity checking and assertion checking.

The expertise of Prof. van den Brand is on developing and applying generic language technology. Generic language technology can be characterized as a language independent technology and focuses on formalisms to describe syntax and semantics of (programming) languages and the automatic derivation of tools from these descriptions. It is applied in domains like reverse engineering and the development of domain specific languages. Domain specific languages play an important role in the area of model-driven software engineering. An important application of generic language technology is the analysis of source code. This activity will be continued in close cooperation with LaQuSo. At CWI, his former employer, van den Brand was involved in the development of the ATerm library, a powerful library to represent tree-like data structures with optimal subtree sharing and automatic garbage collection. Given the fact that the ATerm library is also used within the OAS group, for the development of mCRL2, it was decided to transfer the support and maintenance from CWI to SET.

Analysis

The state-of-the-art software engineering research is currently focused on model-driven software engineering. The underlying principles of model-driven software engineering are not new. The ultimate goal of model-driven software engineering is increasing the quality of the resulting products and the reduction of development costs. The latter can be achieved by re-use of developed models, reduction of their maintenance, and application of software generation tools. The basic idea of model-driven software engineering is that based on a model (design documents) the application (or at least most of it) is generated, based on libraries or some framework. The software development process itself does not become less complex by the introduction of model-driven techniques and it does not automatically imply an increase of quality. This is caused by the fact that the quality is now determined by three different sources: the model, the transformer/generator, and the framework. SET focusses on tackling the quality aspect of model transformations and code generators. Model transformations and code generators have become important artifacts in the software life-cycle. This means that not only their external software quality attributes, such as correctness and robustness, become crucial but also their internal software quality attributes, such readability, maintainability, and reusability.

An approach complementary to model-driven development assumes the software system to be given and aims at deriving information about it. Specifically, SET looks at deriving structural and behavioral models by means of reverse engineering and statistical analysis, as well as directly proving different aspects of program correctness, including but not limited to type-correctness and termination. Our focus on the analysis of the existing systems necessitates close collaboration with LaQuSo and with industrial partners. So far this collaboration resulted in development of Cpp2XMI and SQuAVisiT analysis tools, a number of case studies carried out for the industry and five scientific publications.

For the SET group there are many opportunities to participate in these recent developments. The background and expertise in specification formalisms, integrated tooling, and generic language technology provides a solid foundation for work in the field just outlined.

Ideals

The Ideals project aims were to develop a software design methodology that realizes the structured composition of software from separate modules, while handling system-wide interacting aspects of a problem domain. The results of the project are essential for the engineering of next generation complex embedded systems. The proposed methods include the analysis and incremental renovation of existing software systems. ASML wafer scanners were taken as a case study and act as drivers for the project. SET participated in a subproject that focused on investigating how model-driven software engineering techniques can be used to model parts of the software (including interfaces to the hardware) of the wafer scanner. These models are used as input for model transformations and software generators.

Falcon

The Falcon project concentrates on the relationship between systems engineering and component engineering with all integration and optimization aspects involved. It investigates and deploys model-based
system design and optimization methods and tools to analyze and synthesize multi-level systems. As a result layered systems can be designed, which will meet their stringent requirements and constraints on performance, reliability, cost, development time etc. Large logistic systems (distribution centers and warehouses) are examples of complex multi-level systems. They range from the level of vast parallel flows of goods (discrete items) down to the level of each specific order composition. For the Falcon project these logistic systems are the research driver and the industrial reference frame. The goal will be the design of a new generation of automated distribution centers and warehouses, this research will be done in close cooperation with Vanderlande Industries and the Embedded Systems Institute.

Definition of main research themes

The definition of the main research themes of SET is based on the following decisions:

1. Strengthen research activities (together with industrial partners) in the area of model-driven software engineering.
2. Strengthen research activities (in close cooperation with LaQuSo) in the field of reverse engineering and model extraction of existing source code.
3. Continue, in a restricted form, the research in the area of integration of programming and proving and the development of new tooling based on Cocktail. However, scalability is an important issue. Furthermore, this research will be done in close cooperation with dr. Kuiper of the Formal Methods group.

These decisions result in the following research themes for SET:

1. Model-driven software engineering. This theme contains among others the subjects:
   - Generation of code from models (continuation of the Ideals project and high-fidelity software generator Repleo)
   - Reconstruction of models from code (in cooperation with LaQuSo)
   - Analysis and transformation of models and code (Falcon project)

2. Verified Integrated Development Environment:
   - Integration of specification language and programming language
   - Methods for consistent incremental development of specifications and code
   - Static assertion checking

3. Construct tooling for
   - Generic language technology
   - Open tool platform (IDE) for verified software development
   - PEACH3

2.b. Future Programme development

Due to the transition from SoC to SET, as well as some other personnel changes, some lines of research had to be terminated and some new projects are still in a planning or start-up phase.

In close cooperation with LaQuSo the previous work of van den Brand on generic language technology will be continued. The focus will be on the integration of generic parsing technology in the SQuAVisiT toolset and on the development of (new) techniques to perform model extraction from existing software. In cooperation with LaQuSo employees, OOTI and MSc students a tool Cpp2XMI is developed to extract class, sequence, activity and state machine diagrams from C(++) code. The extracted models will service as input for various types of analysis tools based on Petri-nets and model checking. This work will continue in cooperation with LaQuSo. The focus will be both on integration with model checking and generic language technology, apply the same technology to other languages than C(++).

The model-driven software engineering activities are focussing on three main lines of activities. The first line is design and implementation of domain specific languages/models. The second line is high quality model transformations, both from an internal as well as external point of view. The third line is code generations. The projects Ideals, finished in 2007 and Falcon, started in 2006 can be characterized as projects in the field of model-driven software engineering. In both projects models, model transformations, and software
generation play an important role. The research activity of Ideals has been continued by an "eerste geldstrom" PhD student. The focus of this research is on the development of a domain specific language that combines textual and graphical modeling, the development of model transformations to obtain executable (C-)code, and the correctness of these model transformations. Next to this research based on model transformations, SET also works on high-fidelity software generators based on the concept of syntactically correct templates. The research activity of Falcon is focussing on the internal quality of model transformations, such as reusability, maintainability, etc. and on model and model transformation version management.

SET and FM share a PhD student, ir. Middelkoop. His research topic is the application of a Hoare like specification and verification style on object-oriented programs. He focuses on the proof obligations of design patterns. This work will continue as Verified Integrated Development Environment as a cooperation between dr. Franssen en dr. Kuiper.

A project proposal has been accepted on certification of software artifacts (models, code) in the context of outsourcing. Project will be carried out in collaboration with LaQuSo.

3. Processes in research, internal and external collaboration

The research culture before 2006 can be characterized as individual. Each member had his or her own research topic. The research of the PhD student Cleophas was inline with research performed by Watson and Hemerik, the latter was and is responsible as daily supervisor.

The goal since beginning 2006 is to define a common research theme given the mission statement of the group and to align the research topics of the individual members have to fit in this theme. The senior group members will be responsible for the supervision of PhD students. To increase the research atmosphere the group has regular meetings where research topics are discussed.

4. Academic reputation

The change of leadership and the shift of focus in 2006 is triggered by improving the academic reputation of the group. The leader of the group is a well-established researcher in the field of generic language technology and software engineering in general. This observation is based on the editorship of special issues of Science of Computer Programming and his keynote talks at JFLA 2006 and SLE 2008. His research in the field of reverse engineering is recognized via participation in the program committees in this field. Alexander Serebrenik is a promising researcher in the field of program analysis. He has an impressive publication record and is involved in quite a number of program committees. Tom Verhoef is actively involved in computer science and education and he has been member of the program committee of ISSEP (International Conference on Informatics in Secondary Schools: Evolution and Perspective) a number of times.

The ATerm library developed at CWI and maintained within SET is used at used within a large number of academic research projects. PEACH3 developed within SET is used at a growing number of institutes.

M.G.J. van den Brand

- Since 1st of May 2009 appointed as visiting professor at Royal Holloway, University of London.
- Organizing committee: Profes 2006 (Organizing Chair)
- Member of the steering committee of LDTA (Language Descriptions, Tools and Applications) and SLE (Software Language Engineering).
- Member of the scientific committee of IPA, NWO VIDI committee in 2007 and 2008.
• Published over 55 papers in peer-reviewed journals and conferences.
• Invited speaker at JFLA 2006 (Journées Francophones des Langages Applicatifs) and SLE 2008 (Software Language Engineering).

A. Serebrenik

• Published over seventy papers in peer-reviewed journals and conferences.

T. Verhoeff

• Chair of Scientific Committee of the International Olympiad in Informatics (until 2007); received the IOI Distinguished Service Award in 2007.
• Senior technical and organizational committee member for the ACM International Collegiate Programming Competition (until 2006).
• Received (together with recently retired SET member Ria van Ouwerkerk) the European Founders Award for longstanding contributions to organizing and promoting the ACM International Collegiate Programming Contest (2004).
• Member of the editorial board of Informatics in Education.
• Invited lecturer of the NMA (National School Student Academy), Lithuania, Summer Session 2006 and 2008, Informatics.
• Co-designer (with E.T.J. Scheffers) of PEACH3

T. Tourwé

• Board member of the ERCIM (European Research Consortium for Informatics and Mathematics) working group on Software Evolution.
• Active member of the Analysis, Slicing and Transformation Research Network (ASTReNet), financed by the Engineering and Physical Sciences Research Council (EPSRC), United Kingdom.
• External advisor of the Research Center on Structural Software Improvement, an FNRS research collaboration between the Université Catholique de Louvain, the Université Libre de Bruxelles and the Université de Mons-Hainaut, all in Belgium.
• Program committee memberships: SCAM 2006, ICSM 2006.

C. Lange

• Organizing committee membership: QAOOSE 2008 (Quantitative Approaches in OO Software Engineering, workshop co-located with ECOOP)
• Program committee: QiM 2008 (Quality in Modeling, workshop co-located with MoDELS 2008)

5. Internal evaluation

See Part A.8

6. External validation

6.a. Societal relevance

The ATerm library, initially developed at CWI and currently maintained at the TU/e, has quite a number of applications inside and outside academia. The ATerm library is for instance used to represent the state spaces of the mCRL2 toolset developed by OAS. Various term rewriting based systems, ASF+SDF, TOM, Stratego, use the ATerm library to represent terms. Furthermore, the ATerm library is used in the field of software renovation, among others by Bell Labs, and for the representation of semantic web ontologies.

The high-fidelity code generator Repleo, developed by drs Arnoldus, is used in a number of case studies, among others at Ericsson (Gilze-Rijen).
PEACH3 is actively used to support numerous informatics courses at TU/e and the second and third round of the Dutch Informatics Olympiad (NIO), and occasionally for other contests and training. PEACH3 is currently in beta state, soon to be released under an open-source license. It provides an administrational framework for registering participants in courses, presenting assignments, and recording results. However, its main power lies in the ability to configure an automatic evaluation process for submitted work, such as compilation, execution with various data sets, and checking of output. Furthermore, PEACH3 incorporates automatic fraud detection, by comparing submitted work for the same assignment, even across years.

In close cooperation with LaQuSo the source code analysis tools SQuAVisiT and Cpp2XMI are developed. Both tools are intensively used in industrial case studies carried out by LaQuSo.

6b. Industrial contacts

The industrial contacts expanding over the last three years. In a few cases this has resulted in joint research projects, both for PhD students and MSc students.

SET has cooperations with Vanderlande Industries BV, Veghel (Falcon project), ASML, Veldhoven (Ideals project), Philips Research, Eindhoven (MSc projects), NXP Research, Eindhoven (external PhD student), Ericsson, Gilze-Rijen (MSc projects), ICT NoviQ, Eindhoven, Centric IT Solutions, Goud, Philips Lighting, Eindhoven, Philips Healthcare, Eindhoven, and Silicon Hive, Eindhoven.
# 7. Researchers and other personnel

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<td>5.14</td>
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</table>
8. Resources, funding and facilities

8.a. Laboratory infrastructure

The Division provides a technical infrastructure with high-end workstations and/or laptops, and the relevant software, for all its researchers. For more extensive experimental studies the group can benefit from its participation in LaQuSo.

8.b Funding

<table>
<thead>
<tr>
<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
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<th>2007</th>
<th>2008</th>
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<td>0%</td>
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<td>-</td>
<td>6%</td>
<td>13%</td>
<td>16%</td>
<td>10%</td>
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</table>

Table 25: Funding of SET.

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<th>Percentage</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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<td>Direct funding</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>58%</td>
<td>48%</td>
<td>44%</td>
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<td>-</td>
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<td>0%</td>
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<td>13%</td>
<td>40%</td>
<td>29%</td>
<td>30%</td>
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<td>-</td>
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<td>14%</td>
<td>27%</td>
<td>23%</td>
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</table>

Table 26: Funding of postdocs/PhD’s.

8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

<table>
<thead>
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<th>period</th>
<th>external funding (2002–2008): research funds</th>
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<table>
<thead>
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<th>period</th>
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<tr>
<td>2003 -2008</td>
<td>Senter (ICT-doorbraak) : IDEALS – Idiom design for embedded applications on large scale Van den Brand, Engelen, Tourwe) (also Van Gool, SAN) 287</td>
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<tr>
<td>2006–2008</td>
<td>Open Universiteit: DU-project, supervising master-students, referee Van den Brand: 10</td>
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<tr>
<td>2007–2011</td>
<td>RU Groningen/ Nuffic: Strengthening ICT training and research capacity in the 4 public universities in Uganda; Dajsuren; Ssanyua 170</td>
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<td>2006–2008</td>
<td>LaQuSO: M2M Transponder DNE (Octrium B.V.) 89</td>
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<tr>
<td></td>
<td>Schimmel, Van den Brand, Petkovic, Serebrenik, Lukkien, Usenko, Roubtsov, Post, Heck.</td>
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</table>
Overview of the results

The scientific results over the last three years are already strong. The various members of SET have published over 15 journal publications and 20 conference publications. Van den Brand was invited speaker at JFLA’2006 and SLE’2009. An older publication on the ATerm library turned out to be one of the most cited publications in software engineering over the last 5 years. Van den Brand was invited to write a paper on the effect of the ATerm library and got this paper accepted in a special issue of the journal Information and Software Technology. Van den Brand was also twice guest editor for a special issue of Science of Computer Programming on Experimental Software and Toolkits (EST).

9.a. Key publications


9.b. Numerical overview

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<th>2006</th>
<th>2007</th>
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<td>-</td>
<td>5</td>
<td>2</td>
<td>11</td>
<td>18</td>
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<tr>
<td>b. in refereed proceedings</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>7</td>
<td>6</td>
<td>10</td>
<td>23</td>
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<td>c. book chapters</td>
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<td>d. other</td>
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<td>3</td>
<td>4</td>
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<tr>
<td>Total</td>
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<td>-</td>
<td>12</td>
<td>10</td>
<td>24</td>
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</table>

9.c. List of publications

Academic publications: refereed journals

2006

246 Research Evaluation Computer Science 2009 * Part B: SET


2007

M.G.J. van den Brand, P. Klint (2007). A Terms for manipulation and exchange of structured data: it’s all about sharing. *Information and Software Technology, 49*(1), 55-64.


2008


**Academic publications : refereed conference proceedings**

2006


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Names of authors participating in the research programme SET are printed in boldface.


2007


**Academic publications: other**

**2007**


**2008**


**Monographs**

**2008**


**PhD theses**

**2008**


**Professional publications: Software**


- **Repleo** URL: http://www.repleo.nl/ First release: 2007 Main developers: Jeroen Arnoldus

- **Peach** URL: http://peach.win.tue.nl/3/ First release: Current release: 3 (September 2008) Main developers: Tom Verhoeff

**10. SWOT-analysis**

**Strengths.**

- Expertise on generic language technology in order to develop advanced static analysis tooling. Fruitful cross fertilization with LaQuSo. Enthusiast assistant professors and PhD students working on model-driven software development and static analysis.
Weaknesses.

- The number of PhD students, PostDocs and assistant professors is low.

Opportunities.

- Strong industrial contacts with embedded software industry. Good relationship with research groups within mechanical engineering. Cooperation with other (3-TU) software engineering groups.

Threats.

- The size of the group is too small to acquire large industrial research projects.

Conclusion

The former SoC group was responsible for a large amount of education on the bachelor level. The group members had hardly any time to do research. This resulted in a negative spiral. The former head of the group has established quite a publication record but was not able to activate the other group members to increase their publication output.

The current head of the group has taken a number of actions to change this. First of all, new PhD students on industrial projects were hired. Staff members were offered either other positions, more teaching than research oriented, or actively stimulated to establish a sound research track, with respect to acquisition and publications. A young and ambitious assistant professor was hired.

The SET group has increased the research output, in the form of (conference and journal) publications. A number of PhD students will finish their thesis either in 2009 or 2010. The strategy to meet these objectives will be to further strengthen the focus and to increase the participation in academic and industrial research projects.
Security

Full title	Security

Programme leader	prof.dr. S. Etalle

Starting date	2007

Research area	Security of Embedded and Computer Systems

CR-classification	D.4.6 and K.6.5 Security and Protection

Affiliations and cooperations
Below the formal affiliations and most important cooperations are listed.

research school: IPA
national:

national: Prof. Pieter Hartel (TU Twente)
            Prof. Bart Jacobs (RU Nijmegen)
            Prof. Boudewijn Haverkort (ESI)
            dr. Bruno Crispo (VU)

international: Prof. Fabio Massacci (University of Trento)
               Prof. W. H. Winsborough (University of Texas S. Antonio)
               Prof. Sjouke Mauw (University of Luxembourg)
               Prof. Catuscia Palamidessi (INRIA)
               Stefan Katzenbeisser (TU Darmstadt)
               Pim Tuyls (KU Leuven)
Mission statement

The mission of the SEC group is to develop methods, and tools for securing decentralized and embedded systems. SEC addresses a broad range of the technical challenges posed by embedded systems, such as policy compliance, policy interoperability, side channel attacks, authentication and secure key storage.

1. Leadership

The group is managed by the senior staff (Prof. Etalle). Weekly management meetings with the permanent group members (Hartog, Skoric, Matthijsse) guarantee cohesion and communication across the group. Each non-permanent staff member has a permanent staff member as supervisor. Permanent and semi-permanent (Zannone) staff members are encouraged to develop their own area of expertise and share the responsibility of PhD supervision with the head of the group.

The group cooperates closely with the Coding and Crypto (CC) group of the department of mathematics. Together, SEC and CC form EIPSI, the Eindhoven Institute for the Protection of Systems and Information. EIPSI has frequent informal consultation and a bi-weekly seminar. EIPSI constitutes the largest independent technical security group of the Netherlands.

SEC and EIPSI have a comprehensive up to date web site. In the past eight years, the members of SEC have been successful in acquiring external research funding, and getting papers accepted in high quality conferences and journals.

2. Strategy and policy

2.a. Design in brief, future program development

SEC started actual operation in 2008, and has reached a degree of stability only by the end of 2008. It would make premature to elaborate on the design until now, so we restrict the discussion to future program development.

The context. SEC finds itself in a fortunate position for a security group. There are a number of important resources in and around the TU/e we capitalize on:

1. Within the TU/e, there is an outstanding coding and crypto group.
2. Related to the TU/e, there is ESI, the Embedded Systems Institute, which has overlapping interests and can constitute a strategic partner for SEC.
3. Close to the TU/e, there are a number of companies which have an interest in security. To mention just the most prominent ones: Philips (in particular, Philips medical), NXP semiconductors, and IRDETO (digital content delivery).

Focus and Approach. SEC focuses on standard security properties: confidentiality, privacy, authentication, access control, integrity, non-repudiation, and - to some extent - availability. Privacy could in principle be seen as a combination of confidentiality and access control; however, the differences in the key questions that it raises require it to be seen as a separate research topic.

SEC’s approach is to start from a concrete security problem and solve it by addressing the fundamental issues behind it. SEC’s strength lies precisely in the ability to understand deeply both the user’s concern as well as the theory behind it.

Concrete security problems are a fast moving target. Yesterday’s concrete problems are of little importance today and will be irrelevant tomorrow. On the one hand, SEC focuses mainly on the deeper underlying
problems; on the other hand, we keep a vision of today and tomorrow's concrete problems by maintaining close relationship with our industrial partners.

Areas. SEC research spans two areas vital to the security of decentralized and embedded systems, and has its center of gravity in the intersection of these areas. The two areas are security policy specification & enforcement and security of embedded systems. Figure 6 puts the areas and the associated projects in perspective, and shows how they fit with the research area of the coding and crypto group (CC).

- **Policy Specification and Enforcement.** While the Internet allows for a free exchange of data, the security boundaries needed to guarantee privacy and confidentiality have become the main obstacle to flexible cooperation within and between (virtual) organizations. The classical preventive access control mechanisms cannot cope with heterogeneous distributed systems and they have to be at least partially replaced by more elaborate trust management and compliance control systems. This is where SEC expertise lies: in the specification and implementation of policies for distributed systems. Privacy policies are an excellent example. The projects TAS3 (on a trusted architecture for securely shared services) and POSEIDON (on security of Systems of Systems) are central in this area. Traitor tracing, the identification of the source of unauthorized content redistribution, is a special form of a-posteriori compliance control which is also closely linked to coding and crypto.

- **Security of Embedded Systems.** Securing networked embedded systems is particularly challenging because of their lack of computational and physical resources. In this area, SEC focuses presently on the security of mobile (e.g. smart-card based) systems; for instance in the PinpasJC project we are studying side channel attacks on smart cards. Another key challenge faced by embedded devices is secure key storage. This issue is addressed by SEC's research on Physical Unclonable Functions, a novel approach based on the extraction of randomness from the physical components of the device itself.

These two areas overlap to a great extent and their intersection forms the core of SEC's research: compliance control for distributed and embedded systems. As also shown in Figure 6, both our projects PEARL (on privacy-awareness of RFID systems) and S-mobile (on an innovative contract-based form of user-friendly compliance control system for mobile devices) fall in this intersection.
2.b. Future Programme development

As we mentioned, SEC has just become operative. Thus, concerning the management, the focus is currently on creating stronger links with the industry and particularly with the strategic partners in the area (see also the section "external collaboration"). Concerning research, at present, we have more activity in the upper part of the diagram of Figure 6 than in the lower part (for instance, we do not yet have an externally funded project on "physical unclonable functions"). This is not surprising, as Boris Skoric joined SEC only a few months ago. In the future, our efforts will concentrate on strengthening the topics more closely related to the hardware of embedded systems (lower right corner) by obtaining external funds for PhD students in the area; this will allow SEC to strike a balance between the two areas, which is needed to achieve its mission.

3. Processes in research, internal and external collaboration

All research is done in teams. PhD students are closely supervised by at least one of the permanent staff, often with assistance from one or more of the PostDocs. All papers co-authored by PhD students are always the result of cooperation with at least one of the permanent staff members of the group, who takes responsibility for the quality of the publication. PhD students are expected to publish at least 5 papers in journals or high quality conferences to form the basis of the PhD thesis.

Internal collaboration.

- All members of the academic staff are active in teaching and research. PhD students are less involved in teaching but are expected to help by giving one or more lectures on topics related to their research, or by helping with exercises classes or master students supervision.
- SEC hosts an excellent coffee machine and shares a common space for informal meetings with CC. This stimulates interaction and is conducive to good research.

External collaboration.
• SEC cooperates intensively with industrial partners and particularly with the strategic partners mentioned in section 3. Namely
  – Philips Research. SEC just hired a temporary part-time professor who also works at Philips Research. Every two months we organize a joint seminar with the security group of Philips Research (we alternate locations).
  – Embedded Systems Institute. Presently, we cooperate on the POSEIDON project. Other proposals are in the pipeline.
  – Additional partners in the area: NXP, Irdeto, Civolution (former Philips Content Identification), Intrinsic-ID: we have already submitted a number of project proposals in which they are partners, or are currently writing proposals.

Furthermore, industrial partners of our presently running projects include: Brightsight and ST microelectronics in PINPAS JC, Philips and TNO in PEARL and S-Mobile. SAP, Oracle, Kenteq, Custodix, e.o. in TAS3. Thales, Noldus in POSEIDON

• SEC cooperates intensively with the well-established Coding and Crypto group of the TU/e. We are strategically located close to each other, publish papers together, and our staff members have regular bilateral research meetings.

• SEC PhD students are member of the IPA research school, and the National SPAN network of PhD students in security. This brings the students into contact with their peers in the Netherlands. As part of the standard training we send our PhD students to all relevant international summer schools.

• SEC cooperates with most Dutch Universities (TU Delft, Twente, Tilburg, UvA, VU, Nijmegen), and with a large number of universities abroad. As part of 3TU Federation we participate in the 3TU research institute NIRICT, where our research activities are part of the Strategic Research Agenda Security. In addition, for most of our projects we have installed an external advisory board or user group consisting of companies that have a potential interest in our results.

4. Academic reputation

Prof. dr. Sandro Etalle

• Program Committee: IFIP'TM '07 (chair), S08, '09, '10, PASSAT '09, SELFTRUST '09, CONGRESS '09, EC2ND '08 & '09, SAS '08, BDIM '08 & '09, PEAS '07, WITS '07, '08 (chair) & '09, STM '06 (chair), CSFW '06, iTrust '06, FAST '03, '04 & '10, ICLP '02, '03, '06 (chair), LOPSTR 1999, '01, '04 (chair), PPDP 1999 & '01, CL '00.
• Founding member and vice president of the IFIP working group 11.11 on Trust Management. Since 2006.
• Member of the program committee of SENTINELS, a funding program for security research in the Netherlands under auspices of STW, NWO and EZ, since Oct 2008.
• Member of the Scientific Committee of the International School on Foundations of Security Analysis and Design, since 2007.
• Member of the ERCIM working group on security and Trust Management. Since 2005.
• Member of the Executive Committee of the International Association for Logic Programming. 2003 - 2008.
• Member of the steering committee of LOPSTR "International Symposium On Logic-Based Program Synthesis and Transformation", 2004 - 2009.
• Member of the IFIP WG 1.7 "Theoretical Foundations of Security Analysis and Design", 2003.
• Invited speaker at the kick-off meeting of the ERCIM working group on security and trust management.

Dr. Jerry den Hartog

• Guest editor: JAR-CS09
• Program Committee: IASTED CNIS07, FCS-ARSPA-WITS08 (co-chair), ARSPA-WITS09, FCS09.

Dr. Nicola Zannone
5. Internal evaluation

See Part A.8

6. External validation

6.a. Societal relevance

Nowadays, the impact of IT security on society is enormous. We all make use of mobile devices, internet banking, e-commerce. Our critical infrastructure is regulated by (badly protected) interconnected embedded systems. In the future, this impact will only increase, as innovations such as electronic health records, smart electricity meters, smart homes etc., are put in place. Indeed, security is not only technical; it is a multidisciplinary field that also has deep legal, regulatory and societal aspects. SEC covers the technical aspects of security research, but keeps a close link with non-technical aspects by cooperating with non-technical experts in multidisciplinary projects (e.g., Tas3, Poseidon). SEC delivers courses in the Kerckhoff master in computer security, in cooperation with the U Twente and the RU Nijmegen. This master course is partially coordinated by SEC.

6b. Industrial contacts

Thales NL (Poseidon project), Noldus Technology (Poseidon project), Philips Research (S-mobile project & PEARL project), TNO ICT (S-mobile project & PEARL project), STMicroElectronics (PINPAS JC project), TNO ITSEF (Brightsight) (PINPAS JC project), Sybergetics (TAS3 project), SAP Research (TAS3 project), Eifel asbl (TAS3 project), Intalio Ltd (TAS3 project), Risaris Ltd (TAS3 project), Kenteq (TAS3 project), Oracle (TAS3 project), Custodix nv/sa (TAS3 project).
7. Researchers and other personnel

<table>
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<tr>
<th>Full professor</th>
<th>2002</th>
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<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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</thead>
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8. Resources, funding and facilities

8.a. Laboratory infrastructure

8.b Funding

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<tr>
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<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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<td>Contracts</td>
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Table 27: Funding of SEC.

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<th>Funding sources %</th>
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<th>2008</th>
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<td>Other</td>
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<td>0%</td>
</tr>
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</table>

Table 28: Funding of postdocs/PhD’s.
8.c. List of external funds

Below the external funds are listed with for each project the researchers that are (partially) funded from the project.

<table>
<thead>
<tr>
<th>period</th>
<th>external funding (2002–2008): research grant</th>
<th>budget (k€)</th>
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<tbody>
<tr>
<td>2008–2013</td>
<td>STW -Sentinels : Pearl – Privacy Enhanced security Architecture for RFID Labels (Bruso, Chatzikokolakis)</td>
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<table>
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<tr>
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<tr>
<td>2007–2012</td>
<td>BSIK (Embedded system Institute- Research Project) : Poseidon (Etalle, Den Hartog, Trivellato, Spiessens)</td>
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</table>

Overview of the results

9.a. Key publications

SEC is a too young group to have a track record of its own. Therefore, to assess the quality of the scientific staff we need to look at publications of the individual SEC members; these publications may have appeared before they joined SEC.

9.b. Numerical overview

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>total</th>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
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<tr>
<td>b. in refereed proceedings</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23</td>
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<tr>
<td>c. book chapters</td>
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<td>4</td>
<td></td>
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<tr>
<td>d. none</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td></td>
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<tr>
<td>Total</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>35</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td></td>
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<tr>
<td>b. publications</td>
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<td></td>
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</table>

9.c. List of publications

Academic publications : refereed journals

2008


Academic publications : refereed conference proceedings

2008


Academic publications : book chapters

2008


263 Research Evaluation Computer Science 2009 * Part B: SEC
**Academic publications : other**

None

**PhD theses**

None

**Monographs**


**Professional publications and Products**

None

**Patents**

None

### 10. Analysis

SEC is a new group which has just finished hiring its members. It is too early to make an assessment. There are a number of good indicators: members are young, have good publication records, the group has numerous industrial contacts and an excellent project portfolio for such a young group. The focus is now on fostering internal and external cooperation and streamlining processes.
Appendices - Research Evaluation Computer Science 2009
Appendix A: LaQuSo

Our modern society is becoming more and more dependent on complex software systems. Hence, verification and validation of such systems is of paramount importance. The Division of Computer Science has a long tradition in formal methods, which can play a crucial role in this area. In the past, however, we did not have the infrastructure to apply and test our methods on an industrial scale. Therefore we decided in 2003 to start the Laboratory for Quality Software (LaQuSo). LaQuSo serves as an intermediary between industry and the Division: it provides us with a platform for experimental research in the area of verification and validation, it allows us to transfer our knowledge and results to industry, it gives us inspiration for future research, and it increases the interest from industry in our research. Thus LaQuSo helps to bridge the gap between academic research and industry in the area of verification and validation of software systems. LaQuSo is one of three NIRICT research laboratories and given the focus of LaQuSo it is actively involved in CeDICT. Furthermore LaQuSo participates in the promotion of excellence and utilization of knowledge to strengthen technological and societal innovation.

Organizational structure. LaQuSo is embedded within the Division of Computer Science but nowadays has a branch at the Radboud University Nijmegen as well. The Board of LaQuSo consists of a scientific director (until September 2006 prof.dr. K.M. van Hee, and since October 2006 prof.dr. M.G.J. van den Brand), a managerial director (until September 2008 drs. H.P. Schimmel, and since October 2008 ir. H.T.G. Weffers PDEng) and a branch director Nijmegen (prof.dr. M. van Eekelen). Together with three representatives of the research groups they form the management team of LaQuSo. The connection with the research groups is ensured via regular meetings with the chairs of both the RU Nijmegen and TU/e.

LaQuSo is one of the three NIRICT research laboratories and has branches both in Delft and Twente. Prof.dr. A. van Deursen is responsible for LaQuSo Delft and dr. A. Rensink is responsible for LaQuSo Twente. These two laboratories are in a start-up phase. Furthermore, their focus is on the software and tool development within the faculties whereas LaQuSo Eindhoven/Nijmegen focuses on analysis of software for industry, service providers and government.

The linking pin with industry is the Advisory Board, where leading ICT-professionals and -managers from profit and non-profit organizations advise LaQuSo about its strategy.

Research. LaQuSo aims to measure, quantify and predict the quality of software systems, both based on models and code, in order to show their reliability and predictability. LaQuSo does this by performing applied research and case studies in and with industry, service providers and government. In these case studies, LaQuSo uses methods, techniques, and tools developed by the participating research groups and by LaQuSo itself, as well as products from commercial and non-commercial partners. The focus is on quality of the software itself: not the development process is object of study, but only the output of the development process. LaQuSo develops and maintains key competencies in the following areas:

- (Formal) verification methods, techniques and tools;
- (Empirical) validation methods, techniques and tools;
- Software system certification.

LaQuSo has defined four main focus areas, for each of these areas one or two of the chairs from the TU/e and/or RU Nijmegen take scientific responsibility:

- Process mining and analysis; scientifically headed by prof.dr.ir. W.M.P. van der Aalst and prof.dr. K.M. van Hee;
A cross-cutting activity of these focus areas is the development of a certification methodology. The ultimate goal of the mining and analysis activities is to give advice on the quality of the software artifact. If the software fulfills externally defined criteria with respect to quality, the underlying software will be certified. Our certification model is published in the Software Quality Journal of Springer Verlag. Up to now two software products have obtained a LaQuSo certificate.

The output of the laboratory is manyfold:

- Diagnosis of software systems in case studies leading to new research on methods, techniques and tools and to industrial results on a short term;
- Establishing contact with other (research) (inter)national institutes for future cooperation;
- Knowledge dissemination of case studies and widely used or new methodologies for verification and validation of software systems;
- Development of tooling for analysis purposes, e.g., SQUaVisIT;
- Integration of software tools and knowledge dissemination about these (commercial and non-commercial) software tools;
- Quality certificates for industrially designed or developed software.

The research within LaQuSo is driven by real-life problems from industry and is done in close collaboration with the participating research groups of the Division, involving staff from both LaQuSo and the groups. This joint research ensures a solid, scientific approach in LaQuSo's industrial case studies, it helps to transfer research results from the groups to industry, and it initiates new research. Through the industrial cases, LaQuSo provides a means to experiment with new ideas, methodologies and techniques on real-life software systems with a magnitude and complexity many times larger than usual in academic environments.

LaQuSo not only performs applied research in collaboration with the participating research groups of the Division, it also wants to directly address problems from industrial partners by answering their questions, pinpointing problems in their software, etc. Thus every case and each experiment has both scientific and business value.

Industrial contacts. LaQuSo works with large (multi-national) organizations, industrial (e.g. Philips, NXP Semiconductors, APG) and governmental (e.g. Ministry of Justice, ministry of the interior and kingdom relations, ICTRO), as well as with small and medium enterprises (SMEs)(e.g. Cepo, medical Dispensing Systems, Secufone). During its starting phase LaQuSo was mostly presented with short-term questions and cases. Nowadays both long-term research and occasional questions and cases are subject of assignments. Often SMEs have a specific request. In these cases most of the time a short survey will suffice. Some SMEs have long-term research goals and ask LaQuSo for help to get new products or services, or to do research how to implement new methods and techniques in their organization. LaQuSo did projects—ranging from solving a specific problem, to diagnosing a software system or doing a research project—for more than 60 SMEs; with about 30 of them we still have an active relationship and with five SMEs we are working on long-term research projects.

Large organizations tend to try LaQuSo in a short-term project first before establishing a more steady relationship. LaQuSo performed research for 20 large organizations.

Dissemination. Dissemination of the research results to the scientific community is done mostly through publications by the participating research groups. The total number of publications LaQuSo employees participated in is 57 publications in journals, conferences and workshop. 37 of these publications are written with members of the expertise groups both of Eindhoven and Nijmegen.

Dissemination to industry is done by LaQuSo itself. Each year LaQuSo organizes the symposium on Verification and Validation of Software Systems that brings together industry and academia. These symposia have been quite successful, with up to 300 participants. Moreover, at many important industrial conferences LaQuSo gave presentations and/or published papers. Finally, in-company presentations and presence in industrial press intensified the contacts with industry.
Resources. As a start-up fee the University Board granted LaQuSo €500 per year from 2004 until 2007. This fee is used to start the laboratory and for infrastructure, public relations and the salaries of LaQuSo staff. Moreover, LaQuSo obtained a €200 grant through NWO (Hefboom 600.641.000—dr. Usenko) for the period 2004–2007. The research, case studies and other assignments LaQuSo performs for external organizations is another source of funding. The growing external funding should make LaQuSo more or less self-supporting from 2008. Currently, LaQuSo employs the following personnel.

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<tr>
<th>Position</th>
<th>Name</th>
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<td>Managerial director</td>
<td>Woeffers PDEng, ir. H.T.G.</td>
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<td>Scientific director</td>
<td>Brand, prof.dr. M.G.J. van den</td>
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<tr>
<td>Researcher</td>
<td>Roubtsov, dr. S.</td>
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<tr>
<td>Researcher</td>
<td>Barosan, dr. ir. I.</td>
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<tr>
<td>Consultant</td>
<td>Gabriels, ir. J.</td>
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<tr>
<td>Consultant</td>
<td>Klabbers, ir. M</td>
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<tr>
<td>Developer</td>
<td>Post, drs. R.D.J.</td>
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<tr>
<td>Other personnel</td>
<td>Some 15 student-assistants (five at a time), internships etc.</td>
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Appendix B: PhD candidates

The table lists the names and projects of the PhD candidates participating in the research programs on January 1, 2009.

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Type A = Standard-PhD-candidate (with employee status)
Type B = Contract-PhD-candidate (without employee status)
Type C = External-PhD-candidate (without employee status)
Appendix C: Statistics

Not everything that can be counted counts, and not everything that counts can be counted.
–Albert Einstein (1879–1955), attributed

In this appendix we give some statistics regarding the publications of our department. We want to stress that we do not feel that simple counting schemes alone are adequate to characterize the publication records of the various researchers and groups. Indeed, the data on which the counting schemes are based is not always accurate, and different counting schemes can lead to different results. Nevertheless, the statistics presented in this appendix may give some useful insights.

C.1 Input-output

We start by giving an overview of the input (in terms of fte's) as well as output (in terms publications) of the various groups, as already reported in the specific chapter of each group.

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275 Research Evaluation Computer Science 2009 * Appendix
Next we give some numbers on the relative productivity of the groups, by relating input to output and by computing the contribution of the group output with respect to the overall output of the division. It should be noted that one can do the computations in various ways, each having its own pros and cons. For example, if one computes output per fte, then the output of researchers with a part-time appointment counts heavily and it is very advantageous to have part-time researchers who do research at their main affiliation as well. Also, if one divides the output by the total number of fte’s, then having more postdocs, for example, can be bad for the group productivity; one can argue that it is perhaps more important to count how much output is “generated” by the permanent staff, either by doing the research themselves, or by attracting external funding for hiring postdocs and PhD students who then do the research. Thus we have decided to give several different quotients.

### Input group relative to division

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### Output relative to input (in terms of fte’s)

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### B.2 Citations

Finally, we look at the citation records of some of the individual researchers. We restrict ourselves to staff members whose main academic affiliation is at the TU/e.

Hirsch\(^1\) has proposed the $h$-index as a measure to quantify the output of a researchers. It is defined as the maximum number $h$ such that the researcher has published $h$ papers that are each cited at least $h$ times. Based on this definition and the Google Scholar database, Publish or Perish\(^2\) can compute the $h$-index, as well as various other statistics of individual authors. Below we list the $h$-index of all researchers in the division with an $h$-index of at least 10 (June 2009). Since Publish or Perish queries Google Scholar, it is not always completely accurate. We have removed duplicates and other error as much as possible from the results, usually lowering the $h$-index a little. We also list the $g$-index, which is defined as the largest number $g$ such that the topmost $g$ articles together receive at least $g^2$ citations (thus giving more weight to highly cited publications). Finally, we list the number of papers according to the DBLP database.\(^3\) See the paper by Meyer et al.\(^4\) for a discussion of the use of such statistics in assessing computer-science research.
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http://www.harzing.com/resources.html#pop.htm


http://www.informatik.uni-trier.de/ley/db/