Computer Science

Research Evaluation

2001–2005

Department of Computer Science
Fredrik Bajers Vej 7E ▪ DK 9220 Aalborg Ø ▪ Denmark

Aalborg University

Computer Science, Aalborg University—Research Evaluation 2001–2005

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Preface

It is the policy of the Faculty of Engineering and Science at Aalborg University that its research units are to be evaluated every five years. Following that policy, the present report documents the fourth research evaluation of the Department of Computer Science and covers the period 2001–2005.

According to the Faculty's guidelines, the objectives of the evaluation are threefold. The first is to assess whether there is a satisfactory agreement between allocated internal and external research resources and the research accomplished. The second is to determine whether the Department's actual research efforts are consistent with its goals and plans for the period, as they are expressed in the long-term research plans of the Faculty of Engineering and Science. As the third objective, the evaluation is intended to aid the Department in planning its future research efforts.

Realizing that a research evaluation itself is a learning experience that provides an opportunity to rise above the daily routine and reflect upon research, we agreed upon an additional objective. Within the Department, the evaluation—the process as well as the final report—should constructively aid the staff members in evaluating and improving their effectiveness as researchers, as group leaders, and as administrators of research at the departmental level. In particular, the evaluation presents an opportunity to assess the effectiveness of departmental policy in promoting high quality research.

The research evaluation process that has led to the production of this document began in Early 2005, when the Department's research leaders (professors Christian S. Jensen, Finn V. Jensen, and Kim G. Larsen and associate professor Jan Stage) and the head of department (Peter A. Nielsen) initiated discussions on the structure of the process. Among the early, important tasks, a five-member evaluation committee was appointed. Professor Christian S. Jensen accepted to be the local member of the committee (being local, he would be without a vote).

The Department was delighted when Professor Stefan Arnborg (KTH, Sweden), Director Keith Jeffery (Rutherford Appleton Laboratory, UK), Professor Thomas Sinkjær (Center for Sensory-Motoer Interaction, AAU, Denmark), and Professor Ian Sommerville (Lancaster University, UK) agreed to be on the committee. We felt that this committee of recognized and experienced senior scientists and research leaders would be able to cover all the rather diverse research areas in the Department and provide an insightful and wide-ranging evaluation. (Short curricula vitae of the members of the evaluation committee may be found in Chapter 2.)

Next, the general structure of the evaluation process and of this report were agreed upon. The structure of the evaluation report was based on that of its predecessor, the main novelty being that the printed report does not include all the background material provided to the committee by the research groups.

The contributions by the Department's research groups to the evaluation report

went through discussions within the department. This process was useful, as it invariably raised questions about the research approaches, results, and organization of the research groups that were not addressed at first. The contributions that resulted from this process were then collected in a preliminary evaluation report. I was given the responsibility of steering the process, coordinating with Christian S. Jensen when appropriate, and of editing the report. Each research group appointed an editor responsible for providing the group's contribution. By early December 2005, a 347-page preliminary report (on which Part II of this report is based) was completed and sent to the evaluation committee members.

In January 2006, a two-day research evaluation seminar was held at a conference facility. All research staff, including Ph.D. students, long-term visitors, and technical and administrative staff from the Department were invited. On the first day, the Department's research groups gave oral presentations of their research, allowing the committee and other attendees to ask questions on both the presentations and the preliminary report. During the afternoon of the first day, and part of the morning of the second, the evaluation committee worked separately (apart from a discussion with the research group leaders during which the overall organization of the Department was clarified to the committee), and the attendees took part in various activities related to the general theme of research evaluation. At the end of the seminar, the committee presented its evaluation to the Department and answered questions.

Following the seminar, the evaluation committee finalized its written evaluation, which forms Chapter 3 of this document. In parallel, the research units produced final versions of their contributions. It is those slightly updated descriptions that, possibly subjected to some minor editing, appear in Part II of this report.

Part I of this report contains the actual evaluation of the Department's research. It provides a brief description of the formal context of the evaluation, short curricula vitae of the members of the committee, and then presents the committee's evaluation.

Part II has a chapter for the Department in general and one for each research group. It covers the background and organizational context of the Department and the overall organization of the Department's research. Finally, it evaluates the overall administration and organization of research and presents a plan for the period 2006–2010. In their chapter, each research group provides an overview of its profile, summarizes the research goals, and present the activities and results for the period. Finally, a self-evaluation and plans for the next period are given. Detailed descriptions of activities and results and descriptions of organization and staff, Ph.D. projects, research collaborations, service and other research-related activities, and a bibliography then follow in an appendix. Part III provides a brief summary in Danish of the report.

Designing the research evaluation and producing this report was intrinsically a consensual and collective effort involving to varying degrees all the researchers in the Department. I thank them all for their assistance and support. However, the editor for each group: Linas Bukauskas, Hans Hüttel, Manfred Jaeger, and Jesper

Kjeldskov deserve special thanks for their work as editors of the contributions by the research groups.

Luca Aceto, who edited the previous evaluation report, made my editorial work much easier by providing the LaTeX files used for the previous report. The cover page of the report was designed by Jens Lindberg.

Any infelicity in this report is solely the editor's responsibility.

Aalborg, Denmark JOSVA KLEIST
March, 2006

Contents

Part I

The Evaluation and its Framework

1 Evaluation Guidelines

The guidelines from the Faculty of Engineering and Science that constitute the formal context for the research evaluation are paraphrased below.

1. The evaluation is conducted for each research unit separately and covers the research unit's work since the previous evaluation.

2. The evaluation of each research unit is conducted every five years. The specific time is set by the unit's institute.

3. The evaluation is conducted by an evaluation panel of normally three persons, with at most one from the research unit and not less than one from outside the university. Normally, at least one member must be employed by an international institution. A panel member from the unit has no vote on the panel. The panel is appointed by the Faculty following the recommendation of the research unit.

4. The evaluation includes the following:

   (a) Published research results; (b) other research results, such as results yet to be published and results that are unpublished in a traditional sense, but which are disseminated to industry, public institutions and organizations, etc. through curricula or otherwise; (c) research activities in progress; (d) other research activities, including international research collaboration, participation in scientific congresses, conferences, and symposia, editorship, refereeing, and evaluation of theses and applicants for academic positions; and (e) research collaboration.

5. The evaluation has these objectives.

   First it aims at assessing whether there is a satisfactory agreement between allocated internal and external research resources and the research accomplished. Second, it must determine whether the research unit's actual research efforts are consistent with the unit's goals and plans for the period as they are expressed in the long-term research plans of the Faculty of Engineering and Science. Third, the evaluation is intended to aid the research unit in planing its future research efforts and its organization of research.

6. The evaluation panel prepares a preliminary evaluation that is made available to and is discussed with the unit's staff. On this basis, the final report is

prepared and submitted to the Faculty with comments from the research unit and the Institute.

The evaluation report may be written in English or Danish. If it is written in English, a summary in Danish must be included. Conversely, if it is written in Danish, a summary in English must be included.

7. The research unit organizes and conducts its research evaluation while adhering to the above general guidelines, so that the evaluation fits best with the wishes and activities of the unit.

Realizing that a research evaluation is a learning experience that provides a welcome opportunity to rise above the daily routine and reflect upon research, the Department of Computer Science agreed upon an additional objective: Within the Department, the evaluation—the process as well as the final report—should constructively aid the staff members in evaluating and improving their effectiveness as researchers, group leaders, and administrators of research at the departmental level. In particular, the evaluation presents an opportunity to evaluate the effectiveness of departmental policy in promoting high quality research.

The Evaluation Committee | 2

Stefan Arnborg

Stefan Arnborg is professor in Computer Science at KTH since 1982, Director of the Theory group and of the MScE program in computer engineering.

His research interests are: Algorithms and Complexity, Verification, Computer Algebra, Data Engineering and Uncertainty Management, Data Mining, Human Brain Informatics, Command and Control, Esthetics in Engineering Education.

He took the civilingenjör (MScE) exam in Engineering Physics at KTH in 1968, and the Ph.D. in Information Processing at KTH in 1972. Stefan Arnborg also worked as a supercomputer programmer at the Courant Institute (1966), with object-oriented programming systems at the Norwegian Computing Centre (1969-70) and CAP Sweden (1971), as an OR analyst at the Swedish Defence Research Institute FOA (1972-79), and as a distributed systems and computer guru at Philips Financial Terminal Systems (PEAB,1979-82). He spent sabbatical terms at the University of Oregon (1986,1989,1993) and was part-time advisor to the Swedish Institute of Computer Science SICS.

Keith Jeffery

Keith Jeffery is currently Director, IT of CCLRC (Council for the Central Laboratory of the Research Councils), based at Rutherford Appleton Laboratory in UK. His Business and Information Technology Department (15 mill € p.a. turnover, 140 staff) provides services to CCLRC, national services to the UK academic community and undertakes research and development projects funded by the UK Research Councils, government departments, the European Commission and commerce and industry internationally.

Keith has extensive experience in consultancy, project management and product development both within the public sector and the commercial sector. He has been involved actively in EC-funded projects as reviewer, coordinator, system architect and in technical and exploitation roles. He was editor-in-chief and later chairman for the Next Generation GRIDs expert group of DG INFSO F2. He has extensive publications and representation activities. He holds 3 honorary visiting profesorships, is a fellow of both the Geological Society of London and the British Computer Society, is a chartered engineer and chartered IT professional and is an honorary fellow of the Irish Computer Society.

Thomas Sinkjær

Thomas Sinkjær graduated as an M.Sc.E.E. at the Aalborg University, Denmark, in 1983 with specialisation in biomedical engineering. In 1988, he finished his Ph.D. thesis made as a joint-venture project between University of Calgary, Canada, and Aalborg University. He received his doctor of medicine degree in January 1998 from University of Copenhagen. Between 1984 and 1986, he studied as a visiting Ph.D. student at Dept. of Clinical Neurosciences, University of Calgary, Alberta, Canada, and during 1989/90 as a post-doctoral fellow at Department of Physiology, Northwestern University, Chicago, USA.

From 1986 he has been an employee at Department of Medical Informatics and Image Analysis as associate professor, in 1992 as head of the department, and from 1993-1998 as research council professor.

He has headed Center for Sensory-Motor Interaction since its establishment in 1993. In 1997 he became full professor in Motor Control and Rehabilitation at Aalborg University.

His research interests include the application of natural sensors in FES systems, electrophysiology, biomechanics, and motor control (human sensory-motor interaction).

He has written more than 250 scientific papers published in international journals and has received several honours. In 1996 he was awarded with the prestigous Villum Kann Rasmussen's Yearly Grant for outstanding international research and in 2004 the International Steven Hoogendijk Award in Medical Engineering for outstanding international research.

He is currently a member of the Board of the Danish "Højteknologifonden" appointed by the Minister of the Ministry of Science Technology and Innovation and has also been president for the International Functional Electrical Stimulation Society (IFESS), 2002-2004.

Ian Sommerville

Ian Sommerville is Professor of Software Engineering at Lancaster University, UK. He has a BSc in Physics from Strathclyde University, Glasgow and an M.Sc. and Ph.D. in Computer Science from St Andrews University. Prior to joining Lancaster, he held faculty positions in Computer Science at Heriot-Watt University, Edinburgh and Strathclyde University. His current research interests span a range of topics in systems engineering including service-oriented software engineering, requirements engineering, system dependability and social informatics. He is actively involved in national and international research projects including the DIRC inter-disciplinary collaboration in system dependability and SeCSE, a Framework 6 Intergrated Project concerned with service-oriented software. Sommerville has published about 150 papers on software engineering topics and has authored a number of books, notably a widely-used textbook in Software Engineering which was first published in 1982 and is now in its 8th edition. He is a Fellow of the

Institution of Electrical Engineers, the British Computer Society and a Chartered Engineer.

Evaluation Report 3

Stefan Arnborg
KTH

Keith Jeffery
Rutherford Appelton

Thomas Sinkjær
Aalborg University

Ian Sommerville
Lancaster University

3.1 Summary

The overall conclusion of the review panel is that the quality of research in the Department of Computer Science at Aalborg University is universally high and, in some cases, internationally leading. All research groups in the Department have maintained or increased their level of activity since the last review. The Department clearly operates at a standard which is comparable with leading research departments in computer science elsewhere in the world. Changes in demand for computer science courses across Europe mean that growth through increased student numbers can no longer be taken for granted. It is therefore important that the University should be proactive in ensuring that sufficient resources are provided to the Department, to ensure that its leading international position in research can be maintained and improved. In particular, the University should seek to increase the core funding for Ph.D. positions, through internal funding and earmarked regional and national funding.

The panel, however, has some concerns that the organisational structure that has been adopted, based around 4 research groups, is unnecessarily rigid and means that it is difficult to take a strategic, departmental perspective. This could lead to missed opportunities for expansion into new research areas and an inability to take advantage of new sources of research funding. We recommend that the Department should put mechanisms in place to support strategic planning at a departmental and not just at a research group level.

3.2 Introduction

The objectives of the review process as presented to the review panel were:

- To assess whether there is a satisfactory agreement between the allocated research resources and the research accomplished.

- To determine whether the actual research efforts are consistent with the stated goals and plans for the period.
- To debate, and provide advice on the planning of the department's future research efforts and organization.

To make this assessment, the panel were given a detailed report of research activities supplemented by presentations from the Head of Department and Research Leaders, as well as personal discussions with group members. The process was well-organised by the Department.

In this chapter, we comment on the research quality in each of the research groups of the department, discuss issues around growth and expansion of these groups, the organisational structure of the department and the review process. We do not address the above objectives point by point but cover all of them in the following discussions.

Our overall approach was to examine the research quality of each group with respect to international standards. It was outside of our remit to make value judgements of the relative quality of the groups within the Department.

3.3 The Research groups

There are four research groups in the department. We provide a brief overall assessment here followed by a more detailed commentary on each of the groups.

1. The Database component of the Database and Programming Technologies group (DPT) continues to be internationally outstanding and has diversified and developed to one of the world leading groups in this area. The panel were particularly impressed by the innovative work on spatio-temporal theory and applications. The programming component of the DPT Group has a lower profile with limited output at an international level of quality. The group should consider ways in which their work can be more closely integrated with other research within and outside the department.

2. The Distributed Systems and Semantics group (DSS) is internationally outstanding and has expanded and diversified its research over the past 5 years. There is excellent interaction with industry and a good balance between theoretical and practical work. The CISS Initiative is clearly an example of best practice at an international level.

3. The Information Systems group (IS) is made up of two sub-groups. The HCI work is developing well but the group has yet to attain an international reputation. The SD work is highly regarded internationally in their specialism but the group has not yet found a way to extend their work to have a broader impact on system development practice. Overall, the panel felt there was a need for the group to consider how their activities could be more closely

integrated. We also consider it important that a full professor should be appointed as a research leader.

4. The Machine Intelligence group (MI) are more specialised and perform at an international standard in their area of decision support models. Their diversification has begun (games and data mining) but they have yet to make a significant impact in these newer areas.

3.3.1 Database and Programming Technologies

The group consists of two components, database and programming languages. These components were joined some years ago and the synergies are yet to take effect. In particular, staff loss in the programming language area was replaced only in 2002 and the new staff - who have good past track records in research and industrial contexts - have yet to be produce significant research output and new funding income.

The database team is led by Christian S. Jensen and the team (as well as Christian himself) is extremely well-known and respected internationally, having an outstanding publication record. Over the last 5 years the team has increased output and impact. The team has embraced novel ideas specialising particularly in spatio-temporal information management in a mobile context. This initiative has also opened the opportunity for cooperation with other groups in the department, as well as interactions with external groups. The team has interactions with industry through projects and the TimeCenter.

The panel considered the database activity to be of outstanding international standard; this must be maintained and developed further. The future development plans are realistic and achievable. However, the panel felt that these plans might be considered insufficiently ambitious given the enthusiasm, competence and reputation of the team and that there was scope for further international activity and engagement in national and international projects.

The Panel considered the programming language activity over the last 5 years to be only approaching international standard in a very specialised area and the overall output to be less than the norm for a top-class research group. The Programming language team appears to have a heavy teaching load and this has clearly impacted their research output. Staff losses over the last 5 years affected productivity. Nevertheless, the research publications output is relatively low with much of it in a very specialized area. The team has little involvement in externally-funded projects and it does not have recent Ph.D. positions.

Having said this, there is clear potential for the future. The recently appointed associate professors are experienced and have injected direction and energy. The team has produced a proposal for a new direction (P2025 - Programming in 2025) in which all members can participate and this could be a basis for attracting external funding. The panel therefore expects over the next few years to see greatly increased research output and increased external funding being won by this team.

However, while the long-term vision (P2025) is an effective basis for self-integration, the team should consider how it can integrate its activities with other teams in the department to broaden its impact and research opportunities.

3.3.2 Distributed Systems and Semantics

This group was formed during the previous evaluation period by joining two existing groups. During the current evaluation period it has continued developing along lines drawn out in the previous self evaluation.

The group is led by Kim G. Larsen. The group (as well as Kim himself) has a remarkably strong record and is a leading force in fundamental research, applied research and knowledge transfer. The research topics also form a nice progression from fundamental studies to application. Particularly, fundamental decidability results related to priced automata, equational axiomatisation and innovative approaches to computational biology can be mentioned, as can the group's research on verification tools. Overall, this group is internationally leading in all of its core areas of activity.

The CISS center, started during the evaluation period, is particularly promising. The group management characterized the decision to co-locate the group with related activities in the electronic systems department as a high-risk decision, with understandable concerns about the difficulties of inter-disciplinary operation. While there have been efforts made to address the problems of cohesion, it appears, that the groups in control engineering and computer science that make up the CISS are not yet completely integrated. It is recommended that further effort should be devoted to improving communications and collaboration across these groups.

There are problems, though, that must be - and also are - a concern for management, apart from the obvious risk of hubris. Perhaps it is time to think about a strategic renewal in research topics, as well as extending existing theories and software. The research center BRICS will definitely lose its main funding and it is obviously important that the fundamental work supported is continued, although this may have to be reduced in scope. The group has lost two very productive and innovative members. It claims to have had difficulty in recruiting Ph.D. students in the theory area. Perhaps increased visibility in the Masters program of the most visionary researchers can alleviate this problem - if feasible considering the considerable thinning of senior members the group experienced and the considerable demands on senior persons to raise grants. However, the team has an outstanding track record and we are confident that they have the ability to address and overcome these problems.

3.3.3 Information Systems

The information systems group has a long history and established reputation in the 'Scandinavian' tradition of information systems analysis which involves close involvement through 'action research' in the problems of real organisations. How-

ever, as the previous review notes, the visibility of the group was primarily in the information systems community rather than the software engineering community. Since the last review, new directions in research have developed and several of the group members have chosen to divert their energies to research in human-computer interaction (HCI). Organisationally, two professors have left the group over the past 5 years (although Lars Mathiassen retains a part-time position) and have not been replaced in this area. Peter Axel has been head of department and this additional management load clearly impacts the time available for research.

This group therefore specialises in two areas of work - systems development, in which the group adopts a socio-technical rather than an exclusively technical perspective, and HCI, in which their areas of work are in the methods for the usability evaluation of mobile devices and the design of interfaces for mobile systems.

In the area of systems development, the principal sub-areas of work where members of the group have published are in software process improvement (SPI), networked IT, E-government, information systems development and project management. The plans of the sub-group are to focus effort in the areas of software process improvement, the development of mobile information services and e-governance.

Publications in the areas of SPI and information systems development are very good and there have been good publications in networked IT. Project management is a weak area and it is not the intention of the group to continue in this area. E-government is an area of work that has recently emerged and it is to be expected that the publication profile in this area will improve significantly. Although there has clearly been some progress in communicating results to the software engineering community with publications in e.g. IEEE Software, the comments of the previous evaluation are still valid. The group has a higher visibility and reputation in information systems than in core computer science.

The HCI sub-group was established by existing group members moving into a new area and hence it is inevitable that they will take time to find an appropriate niche where they can contribute and to establish a reputation for their work. The areas of work of the group are usability and interaction design, mobile and context-aware systems and (an emerging area) systems for the domestic domain.

The recent development of the work in HCI is reflected in the publications of the group which are mainly in conferences rather than in journals which tend to publish more established research. While there are a number of very high-quality publications in highly regarded conferences, the majority of publications are in workshops and conferences which tend to publish less mature work. Having said this, there is a clear trend towards journal publication and publication in higher-quality outlets - this reflects the ambition and the improving trajectory of the group. The recent awards of substantial external funding reflect the energy and ambition of the group and is an encouraging sign of progress towards international recognition.

The overall conclusions of the panel are that the information systems group is performing well, there remains scope for better communication of the systems development work to the software engineering community and for continuing im-

provements in HCI research. We are concerned, however, that there is a leadership void in this group and feel that there is a need to appoint a full professor who will serve as a research leader and who will be able to integrate the areas of work of the group. Furthermore, the HCI work clearly needed time to develop independently, we feel that it is now sufficiently mature that it can be integrated both with the work on systems development and, more broadly, with work in other groups on mobile information systems. The group should therefore consider how the currently divergent plans of each sub-group might be brought together.

3.3.4 Machine Intelligence

This is apparently the smallest group of the department. The MI team is led by Finn Jensen and the team is well-known and respected internationally, with an excellent publication record. It is recognized as having defined a particular statistical model family that has become very popular in non-traditional statistical modeling areas. The change of name of this group was accompanied by a widening of scope to several areas in decision support systems besides Bayesian networks. The new name of the group is much broader and can accommodate an even wider scope of topics than the group actually has declared it will address.

The added topics are labelled machine learning and data mining, and autonomous agents. The main focus of the group seems however still to be development of the BN/ID paradigm – where the group made pioneering work in the past - to the exclusion of other graphical and non-graphical models like MRFs, RVMs and neural networks.

The textbook on Bayesian Networks produced by the research leader is highly regarded and cited. The group has during the evaluation period produced enough high quality work on Bayesian Network theory, extension and application, to be counted as a leading authority in this area. Work in the new areas, while promising, still has to obtain headway and consolidation.

In the previous evaluation report, the group aimed to study decision making as a game problem, whereas today it has dropped this ambition and wants to study approaches (cheap, easy, realistic?) for bounded rationality or approximate decision analysis. Whereas this approach seems to be applicable in the groups chosen application area, entertainment, one can ask if not real world decision problems could be just as important as artificial ones, and for such problems one might want at least a connection to the 'gold standard' of Nash/Harsanyi type game theory.

Both the report and the research leaders presentation emphasises the waste of time sometimes involved in current ways of obtaining funding. While the panel has considerable understanding of this attitude and notes that the current generous Ministry support of research makes it possible for senior researchers in Denmark today, it is unlikely to be a useful role model for Ph.D. students, if they want to survive in academia. The standard of limiting interaction to two unfunded meetings seems somewhat inflexible and one could well decide this on a case by case basis, taking a subjective judgement of the prospect into the decision process. In order to

prosper after the upcoming generation shift the panel suggests that the group could already now take up a more aggressive strategy in raising external funding, and widen its scope somewhat within the Machine Intelligence area.

3.4 Growth and expansion

The primary mechanism for growth is through increased teaching but changes in the demand for computer science courses mean that long term growth through this mechanism cannot be assumed.

1. The tight coupling of teaching to groups makes it difficult to reallocate resources strategically and does not stimulate groups to think innovatively about alternative funding sources. The panel recommends that teaching allocations should be a departmental rather than a group responsibility so that, by rebalancing the load, research resource can be distributed strategically. We note that this recommendation re-iterates a suggestion made by the previous review panel.

2. The panel encourages all teams, but particularly those who do not have significant external support, to give priority to obtaining funding from external sources; in particular all teams should prepare to apply for the expected increased funding in strategically significant area of IT and computer science from the Danish Ministry of Science.

3. In some areas of work there is an imbalance between the number of permanent staff and Ph.D. students. The performance of all groups in the department could be improved further by the presence of more Ph.D. students and PostDocs. Ideally, this should be attained through core funding rather than uncertain external funding and we recommend that the University should consider how it can direct funding to Ph.D. positions to maintain the high research quality in the Department.

4. While some groups have been very successful in attracting external funding, this is not the case for all groups in the Department. An active approach to securing external funding by all groups would make an important contribution to maintaining and improving the quality of the research base.

5. The Department should consider how it can target priority areas for development within the department through the strategic allocation of Ph.D. positions.

6. The department has lost 2 professors. The panel recommends strongly that each group should have at least one professor as research leader and recruitment strategies should be adopted to achieve this.

7. While recognising the difficulties of recruitment of high-quality staff, the panel recommends that the Department should be proactive in seeking to attract well-qualified external applicants to vacant positions at all levels. The Panel felt it was important that the Department should try to broaden its base of assistant and associate professors to increase the number of staff who are not 'Aalborg insiders'.

3.5 Organisational structure

The department culture has a strong focus on four independent research groups with extensive delegation of decision making to these groups. This has important benefits in that it allows groups to adapt dynamically, in different ways, to changing circumstances and avoids some problems of competition for resources. However, the panel supports the conclusion of the previous review panel that there is a need for more research management and planning at a departmental level.

The rigid group structure appears to lead to a number of problems.

1. It is difficult to formulate an overall research strategy that could unify different areas of work,

2. there is limited cross-group activity and communication,

3. different groups may be working on closely related areas without shared goals or knowledge of complementary activities;

4. career development for young researchers may be limited by the rigid group structure and the different approaches to research in the different groups.

Irrespective of whatever changes in organisation might be adopted, the review panel recommends that explicit measures should be put in place and resources made available to encourage cooperation and communication between different areas of research, especially at the Ph.D. student level. It is important that such mechanisms should be led by the Ph.D. students and Assistant Professors rather than imposed by senior staff.

The panel also recommends that a strategic research planning group should be established which includes all research leaders in the Department.

3.6 The review process

Overall, the panel was impressed by the open and constructive nature of the review process. Extensive documentation about the research achievements over the past 5 years was made available. All groups were candid about their work and the difficulties that they faced. However, the panel recommends that for future reviews:

1. All groups should adopt a consistent format for presenting their work. While there has clearly been some guidance on presentation, there were considerable differences in the information provided by each group which made it difficult for the panel to make comparisons across groups. We note that such consistent presentation would also make it easier for research managers to assess progress and draw up strategic plans.

2. The panel would have welcomed more emphasis on future planning and how these plans might be achieved rather than simply a retrospective report of progress. This would have made it easier for the panel to offer constructive suggestions for the future.

3.7 Conclusions

The overall conclusion of the review panel is that the quality of research in the Department of Computer Science at Aalborg University is universally high and, in some cases, internationally leading. All research groups in the Department have maintained or increased their level of activity since the last review. The Department clearly operates at a standard which is comparable with leading research departments in computer science elsewhere in the world.

Changes in demand for computer science courses across Europe mean that growth through increased student numbers can no longer be taken for granted. It is therefore important that the University should be proactive in ensuring that sufficient resources are provided to the Department, to ensure that its leading international position in research can be maintained and improved. In particular, the University should seek to increase the core funding for Ph.D. positions, through internal funding and earmarked regional and national funding.

The panel, however, has some concerns that the organisational structure that has been adopted, based around 4 research groups, is unnecessarily rigid and means that it is difficult to take a strategic, departmental perspective. This could lead to missed opportunities for expansion into new research areas and an inability to take advantage of new sources of research funding. We recommend that the Department should put mechanisms in place to support strategic planning at a departmental and not just at a research group level.

Part II

The Department's Research Report

4 The Department of Computer Science

In this chapter we provide a general introduction of the Department of Computer Science with a particular focus on research. We provide some background and a brief history, an overview of the organisation, the research topics covered by the department's research groups, and the resources. Furthermore, we evaluate the department's research plan for the period 2001-2005 and the previous evaluation committee's suggestions.

4.1 Introduction

The department's research has software, use and performance of software, as well as information and data as its subject. In particular there is research in use of software in organisations, software engineering, management of software engineering, human-computer interaction, programming and languages, data management, data analysis and data mining, techniques for decision support, machine learning, autonomous agents, networks and protocols, techniques and models for distributed and parallel software, and tests.

The research approach is fundamentally constructive and embraces the analytical mathematical research, the experimental research with algorithms, systems, techniques and methodologies, as well as the analytical empirical research.

Computer science is connected to mathematics, engineering, and to the human and social sciences.

4.2 Background, Conditions, and Funding

We first describe the local organisational context of the department then its history and finally the resources.

4.2.1 Computer Science at Aalborg University

Aalborg University was established in 1974 and is the newest university in Denmark. It consists of three faculties:

- The Faculty of the Humanities
- The Faculty of Social Sciences
- The Faculty of Engineering and Science

The Department of Computer Science is part of the Faculty of Engineering and Science, which presently is divided into 13 departments. The head of department and four group leaders form the executive management. The head of department is elected among peers for a three-year period. The group leaders are appointed. As of 2006 also the head of department will be appointed.

The Faculty of Engineering and Science decides the budget for the department, based on the budget it gets from the university. A budget model taking produced teaching as a primary parameter determines the department's internal funding including number of scientific staff and funding for support staff, laboratories, offices and research. The department influences the internal funding by deciding to teach more or less than expected in the budget model. The department is responsible for managing and conducting research and for supplying teaching to the study boards. The department also is responsible for administrating the internal funding. The Danish research councils, the European Union, various foundations, and IT companies provide external funding for research projects.

Study boards govern education and degree programmes. The department's scientific staff performs the teaching requested by the study boards. The department provides teaching to the Natural Science Study Board, the Electrical Engineering Study Board, and the Basic Education Study Board.

4.2.2 A Brief History of the Department

The history of the department goes back to 1976, when a minor degree (i.e., in practice a bachelor degree) in computer science was established in combination with a graduate degree (called cand. scient.) in mathematics. In the early eighties, major degrees in computer science (cand. scient.) and computer engineering (cand. polyt.) were established with associated undergraduate studies in mathematics and electronics engineering, respectively. From this early beginning and until 1990, the number of awarded graduate degrees grew from less than 5 per year to approximately 40, and the number of scientific staff (full, associate, and assistant professors) grew from 4 to 8. The first full professor was appointed in 1987.

From the mid-eighties to 1993, the Ministry of Research and Education reserved special budgets for computer science and engineering at all Danish universities. This meant that computer science was able to initiate a relatively high volume of Ph.D. studies (3-4 per year), and that the Faculty granted positions as assistant professor and associate professor to follow up on this. By the end of 2000 the scientific staffs consisted of 38 full, associate, and assistant professors.

Computer Science was previously together with mathematics in the Department of Mathematics and Computer Science that again was part of the Department of Electronic Systems. The department was first separated from mathematics in 1995, and then in 1999 it became an independent department at the same organisational level as Mathematics and Electronic Systems.

4.2.3 Research Funding

The internal research funding depends directly on the amount of teaching produced by the department. On top of this comes a significant amount of external funding for research projects in the department.

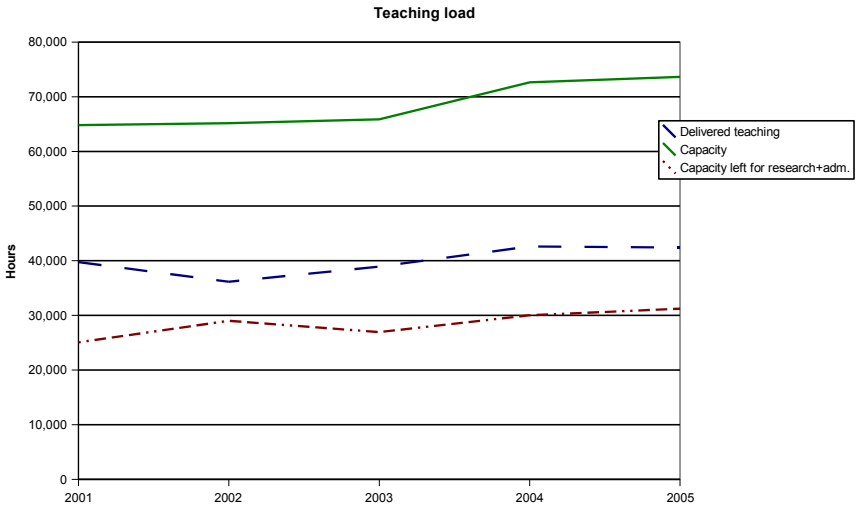


Figure 4.1: The department's delivered teaching

The department has increased its delivered teaching. The capacity is a measure of how many hours the scientific staff can nominally spend on teaching, research and administration. Figure 4.1 shows that the increase in capacity of less than the increase in delivered teaching. The difference between the two is left for research and administration.

The overload is calculated as the delivered teaching above 50% capacity. The overload is less than 20% and decreasing.

The increase in graduate degrees is significant and a result of a new recruitment strategy implemented more than five years ago.

The development of funding shows two patterns. The internal funding from the Faculty increases gradually during 2001-2005. During the whole period there has been a significant increase of the external funding for research projects established within the department (external funding in 2005 is estimated in October 2005).

The development in staffing is shown in Figure 4.5. Professors and associate professors are tenured while assistant professors and temporary associate professors are on three-year contracts. Ph.D. students are employed for three years, during which they are expected to complete their study. Support staffs are full-time systems administrators and secretaries. This show a stable period during 2001-2005 except for assistant professors where the decrease is significant.

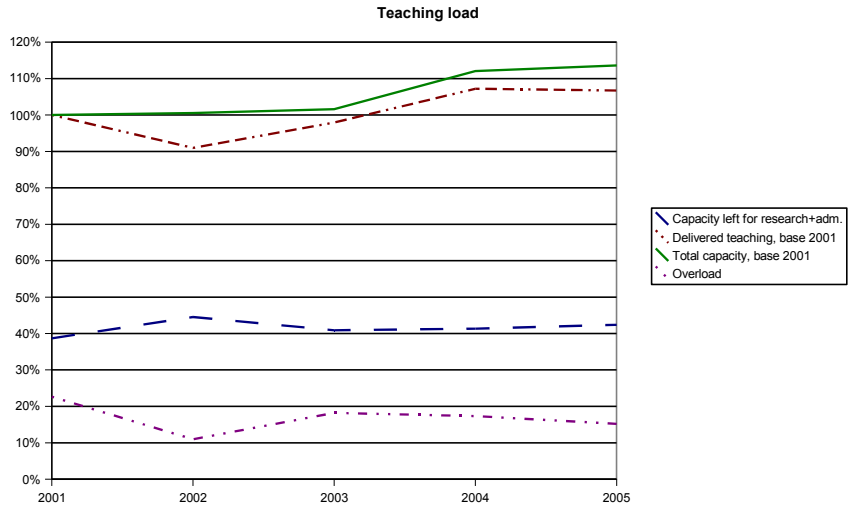


Figure 4.2: Development in teaching load and overload

4.3 The Department's Organisation

The department's organisation is described in terms of the research groups, education, Ph.D. studies, and collaboration with the IT industry.

4.3.1 Research Groups

Until 1998 the department had been organised in six research groups. In early 1999, the scientific staff divided itself into four research groups (Database and Programming Technologies, Machine Intelligence, Distributed Systems and Semantics, and Information Systems). The main purposes were to make the department visible through its research profile and also to de-centralise the responsibility for research, planning, and teaching. The research groups form the basic social environment for the individual researcher.

Database and Programming Technologies covering data management and techniques and tools for data access, in addition to the design, implementation and application of programming languages, their environments, and tools.

Machine Intelligence covering probabilistic graphical models, data mining, autonomous agents.

Distributed Systems and Semantics covering real-time and distributed systems, networks, formalisms for the description and analysis of computer systems, tools for verification and validation.

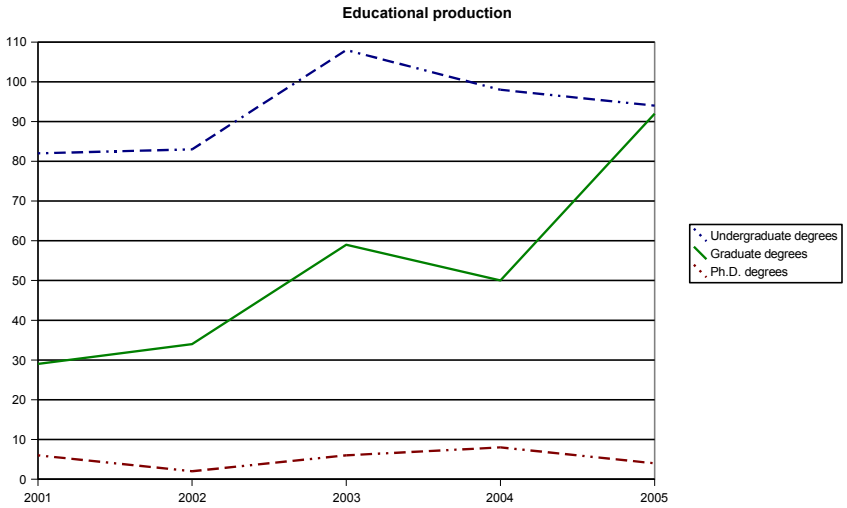


Figure 4.3: Development in produced degrees

Information Systems covering in particular the development and application of computerised systems in organisations.

4.3.2 Research-Based Education

Research and teaching are intimately connected. The teaching duties of the staff in computer science are mainly directed towards the following areas:

1. The basic education year at the Faculty of Engineering and Science that initiates all the students of the faculty to scientific studies, and in particular to the problem-oriented and project-organised studies used at Aalborg University.

2. Computer science, Informatics, and Software Engineering at the undergraduate level.

3. Computer science, Informatics, and Software Engineering at the graduate level.

4. Ph.D. supervision and courses within the Computer Science and Engineering Programme.

Aalborg University employs project-organised problem-oriented studies. Every term has a particular problem theme. The students divide themselves into project groups of 5-8, and each group is assigned a full-time working room. Approximately half of the time, the students work in the groups on topics within the chosen problem theme. It is the group and its supervisor that agree on the particular topic. The other half of the time, the students take courses of a more traditional

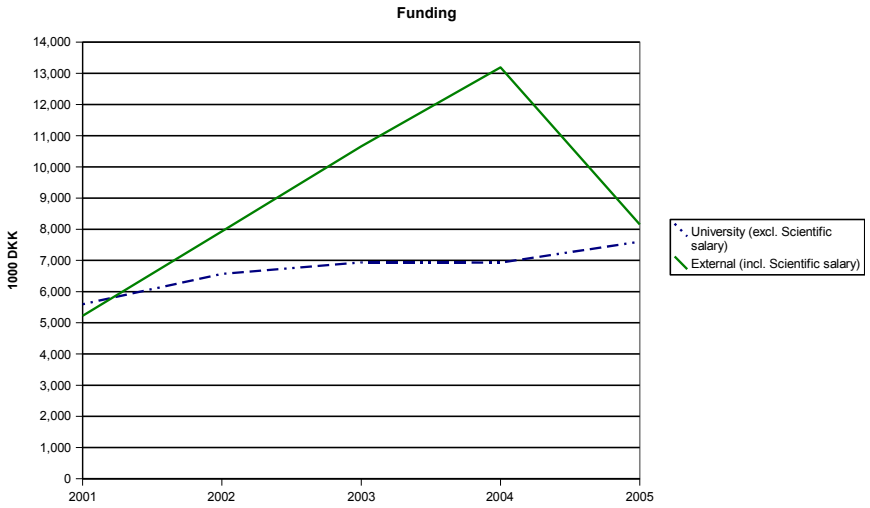


Figure 4.4: Development in the department's funding

form. About half of the courses are directly relevant to the projects, and the other half form part of the general discipline. Each project group is assigned one or more scientific staff as supervisors for the project. Scientific staffs serve both as project supervisors and as lecturers on courses.

The main part of produced degrees consists of five-year graduate studies in computer science, software engineering or informatics. Towards the end of the fourth year, the students choose an area of specialisation for the final year with one research group. The final project work is conducted in close collaboration with the research groups to ensure a close relationship between research and teaching.

In 2001 a new graduate degree in software engineering was established.

4.3.3 Ph.D. studies

The Faculty's Ph.D. studies are organised by its Research School that offers three-year degree programmes. The research school governs the Ph.D. study in computer science and engineering, while all activities and courses are carried out in the department.

The department offers every year 1-2 Ph.D. positions for full-time research in three years. Many additional Ph.D. positions are offered by externally funded research projects. A few Ph.D. positions are devoted to collaboration with an IT company. Few Ph.D. students are without a Ph.D. position.

Ph.D. students devote the full three-year period to a particular research project that is within the interests of one of the research groups. This work is supplemented by Ph.D. courses and most likely also by a six-month visit at a university abroad.

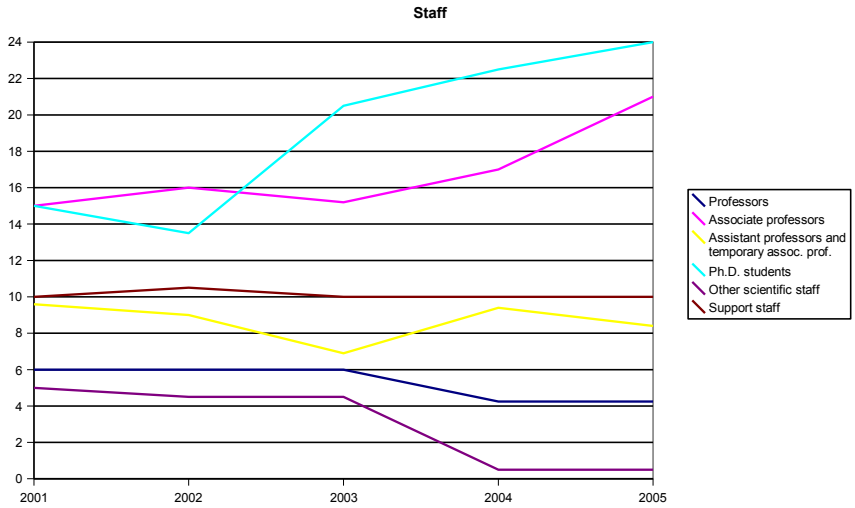


Figure 4.5: Development in staffing

4.3.4 Collaboration with IT Industry: Nouhauz

Collaboration with the IT industry has always played a role for many of the research groups' activities. Many externally funded research projects are co-financed by IT companies.

During 2000 the department has set up an organisation for structuring this collaboration and for providing support for an expansion in this area. The organisation is called Nouhauz (i.e. "No House" and "Know Hows"), and its purposes are to structure further education for IT practitioners, courses, networks where IT researchers and practitioners meet, students' projects conducted in companies, IT practitioners as teachers in our courses and projects, and research collaboration.

4.4 Own Evaluation of the Department

Each of the research groups are evaluated in each their section. The department is part of creating the environment in which the research groups operate. It is the department as a creator of environment for research that is evaluated.

In the previous research evaluation the department's plan was to develop an explicit strategy for the department as a whole. The previous committee's evaluation of the departmental strategy addressed four issues:

- The committee argued that the department should become able to *manage growth*. The committee felt that the strong organisation into four research groups might impose an overly rigid structure and prevent growth.
- The committee sensed reluctance by the senior staff members to engage in

management and leadership and argued that the department would loose its direction and become unable to prioritize its resources and focus its attention.

- The department should take effective measures to ensure its growth by not relaxing its high standards in *hiring*.

- The committee urged the department to set goals for *cooperation with industry* to focus attention and extend relationships with relevant companies rather than simply assuming that more collaboration is better.

The department has addresses these challenges set forth in 2001 plan and by the committee. The self-evaluation falls in three parts: strategy, new leadership, and new activities.

4.4.1 Strategy

The department's strategy has been discussed by the management and at departmental seminar at a regular basis. The strategy has been revised every year, but is so general that it has changed little during 2001-2005. The current strategy is:

The long-term goal of the department is gradually to become a top-level department in software technology through cohesive research, education, dissemination and technology application performed by recognized research groups together with a few research groups with international impact. The department's strategy is to transcend the traditional research-oriented university department and become an innovative department that also seeks to:

- Proactively adapt to changed needs and demands from outside.
- Several career paths.
- Multiple activities that entend beyond research and education into coorperation with external partners, dissemination, and technology application.
- Leadership at all levels.

Establishing NouHauz is part of the movement into new activity areas. NouHauz must be stabalized and integrated into the research groups.
The leadership and management structure has been re-organised. It must be implemented at all levels in the near future.

More specifically, the implementation of the strategy is formulated as shown in Table 4.1 and also communicated to the Faculty of Science and Technology and there integrated into its strategy:

	Near future (0-2 years)	Medium visions (3-5 years)
Research	Gradually extend existing research groups. MI to extend with data mining	Gradually extend existing research grups. Awareness of new and improved strongholds
Competences	DSS: embedded software, networks, semantics IS: systems development, human-computer interaction MI: probabilistic graphical models, autonomous agents, extend data mining DPT: programming environments, web technology, databases including mobile data and data mining	DSS: embedded software, networks, semantics IS: systems development, human-computer interaction, mobile software MI: probabilistic graphical models, autonomous agents, extend data mining DPT: programming environments, web technology, databases including mobile data and data mining
Laboratories	Establish network lab Establish ERP lab	
Research evaluation	The fourth research evaluation 2005	The fifth research evaluation, 2010
Ordinary educations	Strengthen the Informatics education Establish the Software Engineering education, semester 6-10.	Re-open Open Education
Further education	Establish partnership with IT-Vest and own elements in the Software Construction education	Maintain partnership with IT-Vest and own elements in the Software Construction education
Dissemination	Strengthen NouHauz. Main actor in the technology transfer network Mobile Systems.	
Leadership	Diffusion of leadership culture	

Table 4.1: Implementation of the department's strategy

The strategy has at all times been supplemented with a Growth Agreement between the four research groups. The agreement states roughly that the limits to growth in the research groups are:

- DSS: 10
- DPT: 10
- IS: 10
- MI: 7

The agreement has been revised in 2005.

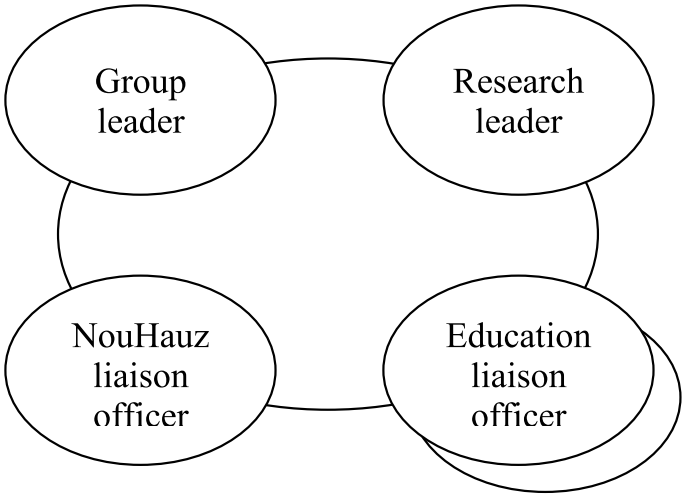
The strategy and its implementations are discussed in the light of the resources that the department gets in terms of funding and positions.

The explication of the strategy has supported the department's management in working with the strategy and in its discussion and decisions on growth.

4.4.2 New Leadership

The department agreed with the previous evaluation committee that leadership practice in the department was traditional, determined by the history of events and needed a rethinking. The rethinking of leadership was discussed during 2004 and ended in late 2004 by four leadership and management roles being defined.

Leadership and management in each of the four research groups were defined through:



Each group should have a *group leader* that manages the group, is responsible for the group's administration, and is part of the executive management group together with the head of department. The executive management group meets every week.

The *research leader* of each is responsible for research and research strategies. The typical tasks for the research leader are: motivating researchers, organising networking and collaboration, creating a sound research environment, creating research projects, supervising application for external funding, and taking responsibility for the research evaluation. The research leaders meet regularly with the head of department.

The group's *NouHauz liaison officer* is responsible for organising the group's involvement in NouHauz. The liaison officers meet regularly with the NouHauz director.

The group's *education liaison officers* are responsible for the department's educations: computer science, informatics, software engineering, and international masters. A group will typically have 2-3 education liaison officers. Each of the education groups meet regularly.

The new leadership roles have been defined with the purposes of clarifying to all staff the different roles and responsibilities and of distributing responsibilities to the groups. This has had the deliberate effect of decentralising decision-making and involve more scientific staff in taking responsibilities for the department and for the groups.

The department's group leaders and research leaders assess that the new roles have had the effect that it is easier to manage the concern for growth raised by the previous committee and the lacking or uneven leadership performed also raised as a concern.

4.4.3 New Initiatives

In response to the concerns raised by the previous evaluation committee and challenges emerging during 2001-2005 three new initiatives are relevant to mention.

It has long been a concern that hiring needed much more emphasis to maintain a high standard. In 2001 the department formed a hiring committee with the task of streamlining the hiring process and investigate whether a search committee as practiced by many North American university departments would be a feasible solution. The hiring process was easily streamlined and it now follows a rather rigid process to ensure the necessary timeline. The ministry's rules and the university's rules regulating application for scientific positions make it very difficult to actively search for applicants. Additionally, the groups' wishes to recruit differ and searching will be in different research communities. The responsibility for approaching possible applicants thus remains with each research group. As a whole the department has not been sufficiently successful in filling all its vacant positions. Hiring remains a major challenge for the coming years.

Society's demands for *collaboration* between research departments and industry, public sector organisations and society at large have risen during the last five years. A higher proportion of research funding is external and that proportion will become even higher. These changes have already led the department and the groups to focus more attention on external funding and new forms of collaboration.

NouHauz keeps directing attention towards industry collaboration. All the groups have collaboration with industry typically through research projects funded by industry and research councils. By far the largest effort is the Centre for Embedded Software Systems where the DSS group during 2003-2005 has become involved with a large number of industrial partners. The technology transfer network Mobile Systems is a new form of collaboration with industry where the DSS, DPT and IS groups are involved. The department has a whole responded well to these changing demands for collaboration and have found its way into different forms of collaboration. It is however evident that it remains a challenge for the coming years to become efficient and effective in these new forms.

During the last years an increasing push from the ministry has put students' entrepreneurship on the agenda. As a response to this the department now teach computer science students entrepreneurship and facilitate their work on creating their own companies during the fifth study year. In addition, the department hosts an incubator environment for its graduates under the name of *GreenHouse*. In GreenHouse a few graduates can after application stay in offices in the department next to the research group where they did their thesis work. The graduates are supported financially in a small way and are offered instant access to the research knowledge and the researchers.

Database and Programming Technologies 5

5.1 Excecutive Summary

With a steady-state level of scientific staff of about two dozen, where about one third are permanent staff and half pursue the Ph.D. degree, the database and programming technologies group is responsible for the department's teaching in core areas of computer science. The group's research activities range from ones that aim to obtain results with short-term industrial applicability to activities that aim for applicability only indirectly and in the longer term. With respect to database research, the group specializes in temporal and spatio-temporal data management, in business intelligence, and in the data management foundations for mobile services. The focus of the programming research is on next-generation programming language concepts.

The evaluation period was seen as an experiment that would reveal whether the newly formed group consisting of database and programming researchers was viable. This experiment has had a positive outcome, and the group's joint research theme on mobile Internet services has been effective in fostering collaboration within the group. During the evaluation period, the group has engaged in 19 funded projects, it has collaborated widely with industrial partners, including local companies, and scientific colleagues across the globe, and its publication and services records are considered to be quite extensive. The group's performance with respect to citation counts, publication outlets, awards, prestigious scientific service responsibilities, and funding suggest that the group performs quite well in a number of respects.

5.2 Profile of the Group

We consider first the scientific profile of the group, then offer an overview of the staffing of the group throughout the evaluation period.

5.2.1 Research Profile

Due in part to the continued advances in hardware technologies, the diffusion of the Internet, and the increasing complexity of software systems, the areas of database management and programming languages and environments are faced with abundant research challenges. Today's software systems manage large amounts of traditional and non-traditional data, including temporal, spatial, spatio-temporal, di-

mensional, multimedia, and semi-structured data. The group's research objective is to develop technologies that meet programming and data management needs posed by software systems in general and by data-intensive applications, in particular.

The areas covered include general-purpose programming languages as well as special-purpose languages, e.g., for the management of different types of data, and it covers also languages that aim to integrate program logic and data management. Programming paradigms and specific language facilities and concepts are covered. Also studied are environments that offer integrated tool support for application and program development, covering the activities of design, implementation, documentation, test, and maintenance/operation.

In the area of databases, the research relates to data warehousing and to temporal, spatial, and spatio-temporal databases, including conceptual modeling and database design, data models, query processing, indexing, and applications. Research related to mobile services and the world-wide-web covers semi-structured data management, location-based and context-dependent mobile services, application development, and XML-related programming.

The group's research approach has a technological focus and is primarily constructive in its outset, but also integrates experimental and analytical elements. Constructive activities include the design of concepts and frameworks, as well as the design and implementation of algorithms, data structures, languages, tools, and systems. Experimental activities cover the testing of constructed artifacts, including prototype-based studies and simulation-based performance studies. Analytical activities include complexity analysis and language evaluation. The emphasis is on the development of theoretically sound results that solve actual real-world problems.

5.2.2 Staff

At the beginning of the period, the group had the following staff (where D and P indicate the specializations of the staff members):

Permanent staff Lars Bendix (associate professor, P), Michael H. Böhlen (associate professor, D), Christian S. Jensen (professor, D), Kurt Nørmark (associate professor, P), Torben Bach Pedersen (associate professor, D), Nectaria Tryfona (associate professor, D)

Assistant professors Erik Ernst (P), Heidi Gregersen (D), Dieter Pfoser (D)

Ph.D. students Michael O. O. Akinde (D), Linas Bukauskas (D), Anders Friis-Christensen (D, formally employed by the National Cadastre and Survey), Ole Guttorm (D), Simonas Šaltenis (D), Janne Skyt (D), Giedrius Slivinskas (D), Thomas Vestdam (P)

The programming technologies staffing has changed substantially during the

period. Erik Ernst joined Århus University in February 2002, and Lars Bendix joined Lund University in August 2003. Lone Leth Thomsen and Bent Thomsen joined the group as associate professors in April 2002. They both came from ICL/Fujitsu Research in the UK. Having defended his thesis, Thomas Vestdam became an assistant professor in August 2003. Per Madsen joined the group as a Ph.D. student in August 2001 and is currently an amenuensis (in US terms, a lecturer), still working towards the Ph.D. degree.

Considering next the database technologies staffing, there has also been substantial changes. Having accepted positions at the Computer Technology Institute in Athens, Greece, Nectaria Tryfona and Dieter Pfoser left their positions at Aalborg University in December 2002. Michael H. Böhlen left the group when he became a professor and dean at Free University of Bozen/Bolzano, in July 2003 (he still maintain an affiliation with the department and runs an EU project via the department). Heidi Gregersen left the group in September 2003 and then joined the staff of Aarhus School of Business. All Ph.D. students active at the start of the period have graduated.

Kristian Torp joined as an assistant professor in January 2003 and became an associate professor in September 2003. Simonas Šaltenis became an assistant professor in August 2001 and then an associate professor in August 2004. Janne Skyt became an assistant professor in August 2001. Having had two maternity leaves and a leave due to an employment on a project, she remains an assistant professor. Ole Guttorm became an assistant professor and left this position in August 2004. Albrecht Schmidt joined the group as an assistant professor in January 2003. Linas Bukauskas became an assistant professor in August 2004.

A new generation of Ph.D. students and research assistants have also joined the group, including Agnė Brilingaitė, Győző Gidófalvi (formally employed by Geomatic, Inc.), Xuegang Huang, Stardas Pakalnis, Magdalena Maria Ruxanda, Laurynas Speičys (currently completing his Ph.D. as an amenuensis), Christian Thomsen, Dalia Tiešytė, Nerius Tradišauskas, and Xuepeng Yin. In addition, a number of individuals have been employed temporarily as research assistants during the evaluation period.

The staffing at the end of the period is thus as follows:

Permanent staff Christian S. Jensen (professor, D), Kurt Nørmark (associate professor, P), Torben Bach Pedersen (associate professor, D), Simonas Šaltenis (associate professor, D), Bent Thomsen (associate professor, P), Lone Leth Thomsen (associate professor, P), Kristian Torp (associate professor, D)

Assistant professors Linas Bukauskas (D), Albrecht Schmidt (D), Janne Skyt (D), Thomas Vestdam (P)

Ph.D. students, research assistants, etc. Agnė Brilingaitė (D), Győző Gidófalvi (formally employed by Geomatic, Inc., D), Xuegang Huang (D), Per Madsen (P), Stardas Pakalnis (D), Magdalena Maria Ruxanda (D), Laurynas Speičys

(D), Christian Thomsen (D), Dalia Tiešytė (D), Nerius Tradišauskas (D), and Xuepeng Yin (D).

5.3 Research Goals 2001–05

We proceed to summarize the research goals for the evaluation period. The detailed plan may be found in the report on the previous evaluation period.

As the group was created towards the end of the previous evaluation period, it was identified as an important theme to manage the diversity imposed by the merger of two previously separate groups and the emerging diversity caused by factors such as the increased size of the group and its members' needs for individual identities.

It was considered important to ensure that the members who represented different approaches interacted in a manner that leads to cross-fertilization. It was also considered desirable to preserve the diversity in the group. Diversity is a strength in itself and is also important in relation to the group's broad area of teaching.

The members of the group considered the evaluation period an experiment that would reveal whether or not it was a good idea to have database and programming researchers in the same group.

A joint research theme, *mobile Internet services*, was identified, the idea being that all staff members could, and should, conduct some of their research within this theme, in addition to possibly conducting other research. Four specific challenges were pointed out within mobile Internet services: data mining for continuously changing data, indexing of continuous movement, Internet programming, and precomputation and distributed querying in data warehousing. Five additional areas were identified: configuration management; Elucidative Programming and LAML technology; gbeta; temporal, spatial and spatio-temporal databases; and 3D visual data mining.

The group did not aim to increase the quantity of its collaboration with industry, but chose instead to focus on improving the quality. By prioritizing longer-term and substantial collaborations, and the group aimed to seek out industrial partners that would be able to use the group's research results in their products.

The research theme, an area prioritized by the university, was chosen in part in an attempt at establishing more collaboration with local industry in the "mobile information management" area. The majority of the group's funding was expected to continue to come from traditional research projects, but it was decided to try to attract some funding directly from industry.

The group anticipated a level of research for the evaluation period that was similar to that of the previous period. The productivity per staff member was also expected to remain at the same level as in the previous period. The group chose to continue to strive to publish in the prominent journals in its area; the group also

aimed to publish some parts of its research in prestigious, general conferences, while publishing other parts in pertinent, specialized conferences and workshops.

The group also had as goals to establish laboratories for mobile information management and for business intelligence, and possibly for programming and program documentation.

The group anticipated that it would be difficult to attract staff. The drain of staff from the previous programming systems group was considered a cause for concern. The group elected to pursue the hiring of additional staff members with profiles within all the areas spanned by database and programming technologies, including new areas as well as those covered by the current staff.

Finally, the group considered it essential to establish a first-class research environment. Therefore, it was considered important to put focus on consolidating and further improving the existing research environment. The group expressed concern about the consistent teaching overload.

5.4 Activities and Results

We cover in turn activities and results within the common research theme; the additional, planned research areas; and new and unanticipated areas. Additional descriptions of Ph.D. projects and, primarily, funded projects are available in the appendix.

5.4.1 Mobile Internet Services

We cover activities results related to the four specific challenges within mobile Internet services as described in the previous section, and we cover additional results.

Overview: Some 12 of the 19 externally funded projects that have been active during the evaluation period relate to this theme. These involve quite a few external participants, from industry as well as academia. The projects range from being short-term, application-oriented projects to being projects with long-term objectives. In addition, collaborations with researchers at National University of Singapore and Vilnius University without separate external funding have been undertaken.

About 15 journal papers and 50 conference papers relate to this theme.

Data mining for continuously changing data: In the area of data mining and business intelligence for continuously changing data, Ph.D. student Igor Timko and others worked on data modeling, query processing, and pre-aggregation for location-based services within the LBS project and in collaboration with the Danish LBS vendor, Euman. In 2004, Industrial Ph.D. student Győző Gidófalvi, employed by Geomatic, a Danish spatial data mining company, started his work on spatio-temporal data mining for location-based services.

Indexing of continuous movement: A number of indexing techniques have been proposed, some in collaboration with colleagues at National University of Singapore and Vilnius University. The R^{EXP}-tree and B^x-tree are indexes for the current and predicted future positions of continuously moving objects. The former provides efficient support for expiration times, and the latter can be implemented on top of the existing commercial database management systems. The BB^x-tree, an extension of the B^x-tree, and the R^{PPF}-tree support the indexing of the the past, present, and future positions of moving objects. Techniques for the indexing of network constrained moving objects were also proposed. Techniques for bottom-up update of R-trees have been proposed, the objective being to support highly dynamic workloads. The box on spatio-temporal indexing offers additional information.

Internet programming: Two M.Sc. projects have compared the development of mobile Internet services in Java (J2ME/J2EE) and .Net (.Net/C#). End-to-end solutions were developed in collaboration with companies, DEIF, and Wirtek. The projects have established objective and subjective criteria for comparison. The results have been presented widely to local industrial audiences and have helped the companies make important technology choices. The activities related to LAML, covered below, also relate to Internet programming.

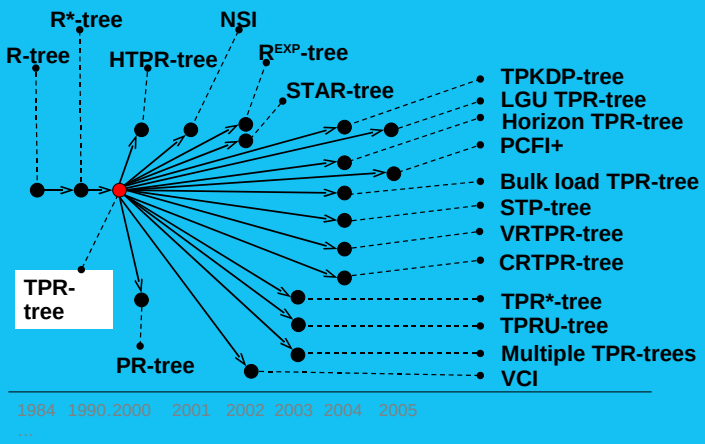
Pre-computation and distributed querying in data warehousing: The work on integrated querying of OLAP and object data was continued from the last evaluation period. In addition, the integrated querying of OLAP and XML data was investigated, in part in a number of M.Sc. projects, and in collaboration with the Danish OLAP vendor, TARGIT. The OLAP-XML integration work resulted in a number of papers. The collaboration with TARGIT and the work on OLAP-XML integration was continued in the BIPC project from 2003, see Section 5.4.3.

Concerning pre-computation, the work on modeling complex multidimensional data was continued from the last evaluation period. The work on pre-aggregation for complex multidimensional data was also continued, resulting in a paper and a patent; a startup, TreeScape, was founded to commercialize the results.

Additional activities and results: During the evaluation period, three Ph.D. studies have been initiated that related to mobile Internet services. One Ph.D. project (Agnė Brilingaitė, funded by the ContextIT project) is devoted to the study of routes as context in mobile services, one concerns tracking (Stardas Pakalnis, funded by the TRAX project), and one concerns query processing for moving objects (Xuegang Huang, funded by the department). In addition, Dalia Tiešytė and Nerius Tradišauskas have embarked on activities in this area.

Spatio-Temporal Indexing

The group's spatio-temporal indexing research, initiated during the last evaluation period and continued during the present period, has already enjoyed substantial impact within the research community. At the end of the evaluation period, Google Scholar lists 276 citations to the SIGMOD 2000 paper that introduced the TPR-tree, an index for the current and predicted future positions of continuously moving objects. A follow-on ICDE 2002 paper has a citation count of 83. A VLDB 2000 paper on the indexing of the past trajectories of moving objects has a count in the range 129–219 (it has two Google Scholar entries).
The ensuing figure displays some of the extensions of the TPR-tree, as well as other indexing approaches inspired by the ideas of the TPR-tree. Query processing techniques that build on the TPR-tree and related cost modeling work are not covered. TPR-tree-based research is or has been performed at, among others, Duke, Rutgers, and Purdue Universities, University of Nebraska-Lincoln, University of California at Irvine and Santa Barbara, Nagoya University, Chungbuk National University, and Hong Kong University of Science and Technology.



The documentation of the group's indexing research during the period includes 11 peer-reviewed publications. Together with the two publications from year 2000, these papers have received at least some 600 Google Scholar citations.

5.4.2 Additional, Planned Research Areas

Regarding the area Elucidative Programming and LAML technology and the area temporal, spatial and spatio-temporal databases, substantial results were obtained.

As planned, both Elucidative Programming and LAML were active areas of research the period, and these areas remain active. Thomas Vestdam and Kurt Nørmark have collaborated within Elucidative Programming, most notably during Thomas Vestdam's Ph.D. study, which was finalized in January 2004. This line of research has continued and is being extended in primarily the direction of documentation of program evolution. This has lead to new results that have been

published in appropriate outlets. The work on LAML was done by Kurt Nørmark. Highlights include the invention of techniques for the automatic derivation of a function library that represents a given XML language, for the integrated validation of XML-in-LAML documents, the LAML SchemeDoc system, and the Scheme Elucidator system. During the period, LAML has been consolidated into a mature, XML-based web development package for the Scheme language programming.

The database group is an active partner in and co-directs the international umbrella project TimeCenter with 35 researchers from 20 universities and 3 companies (including Amazon and Microsoft). TimeCenter focuses on temporal database management, an area within which the group has worked on transaction time support; temporal indexing and query processing, including temporal joins and aggregation; the extension of existing conceptual data models with temporal support; and temporal data models and query languages. Most of this work has been done in collaboration with researchers from the other participating universities and companies.

Spatial and spatio-temporal databases have also been active areas of research. Anders Friis-Christensen, Christian S. Jensen, Dieter Pfoser, and Nectaria Tryfona worked on conceptual modeling of spatial and spatio-temporal data. They developed techniques for managing multiply represented geographic entities, for modeling geographic data quality, and for capturing the indeterminacy and uncertainty of spatio-temporal data. As described in the previous section, Xuegang Huang, Christian S. Jensen, Dieter Pfoser, and Simonas Šaltenis investigated different aspects of indexing and advanced query processing for moving objects, including objects constrained to spatial networks. Skyline queries, nearest neighbor queries, as well as density queries were explored.

Nykredit Center for Database Research

Created in January 1998 as a five-year project by an inaugural grant of DKK 5,000,000 from the Nykredit Corporation, the center has served as a setting for a range of more specific database research activities, primarily within temporal databases, mobile services, and business intelligence, within the group. Highlights include the following:

- Ca. 200 scientific publications.
- Three research awards and several very positive evaluations.
- More than 100 invited talks.
- A dozen Ph.D. degrees.
- Memberships of 75 program committees.
- Collaborations with a dozen companies.
- Half a dozen spin-offs.
- External funding in excess of DKK 30,000,000.

The additional areas of configuration management, gbeta, and 3D visual data mining were specific to staff that have now left the group, and the group no longer pursues these. While employed at Aalborg University, Lars Bendix studied the

application of configuration management in contexts such as extreme programming, open source, and software architecture. Collaborations with industry were strengthened by the establishment of networks of excellence in configuration management at both the local and Scandinavian levels. Next, the main result of Erik Ernst's research during his employment at Aalborg University concerns family polymorphism—this work has inspired a number of research groups to further develop and extend the concept of family polymorphism. The work on 3D visual data mining was conducted within an interdisciplinary project with participants from database management, statistics, perceptual psychology, and scientific visualization. The database participants designed and developed a data structure to index the visibilities of objects and a volatile access structure. Both structures enable databases to support incremental, observer-position-relative extraction of visible objects. During the project, the database participants also developed an adaptive probability density function estimator that processes a sample from a database and computes a small, space-partitioning data structure. Its salient features include a minimal space partitioning that guarantees a uniform density estimation error; the data structure adapts to the structures in the database; and the memory complexity of the estimator depends only on the dimensionality of the structures and is independent of the dimensionality of the database. The estimator permits density computations in interactive, visual data mining settings, and it leverages techniques from the areas of statistics, databases, and scientific visualization.

5.4.3 New Research Initiatives

During the period, new activities have also been initiated.

Bent Thomsen worked on programming techniques and technologies for mobile systems, context dependent and location-based systems, and foundations of programming technology in general. Lone Leth Thomsen worked on programming techniques and technologies for business process systems, context dependent mobile systems, and foundations of programming technology in general. Thomas Vestdam and Janne Skyt worked on ways of representing source code using a database management system, and a prototype of a storage system is under development. As part of his Ph.D. project, Per Madsen works on tools and language support for the testing of object oriented software. During 2005, the joint activities of the staff within programming technologies has focused on the design of a new programming language.

The European Internet Accessibility Observatory, which started in 2004, aims to build a European-wide technical infrastructure for monitoring the accessibility of European web pages. Christian Thomsen builds data warehouse, data mining, and data streams functionality that must accommodate huge data volumes and must be based purely on open-source technology. A first prototype has been finished and several papers published.

The Intelligent Sound project aims to build a framework for the next generation of intelligent sound services. The group will provide techniques for the modeling,

query processing, and indexing of both streamed and static sound data. The project started in 2005 and the first Ph.D. student, Maria Magdalena Ruxanda, was hired in September 2005.

The Rethinking Business Intelligence for the Age of Pervasive Computing: Data Streams and Online Data Integration project started in 2003. Xuepeng Yin and others continue the work on the integration of OLAP and XML data. The framework is currently being extended to also accommodate the querying of data streams, the integrated quering of data streams and static data, and the integration of Information Retrieval and OLAP queries.

Work was also done, partly within a number of M.Sc. projects, on the use of business intelligence in industrial settings, on web usage mining, and on techniques for discovering multidimensional schemas from existing relational databases.

5.5 The Group's Own Evaluation

Internal collaboration: This period was seen as "an experiment that would reveal whether or not it was a good idea to have database and programming researchers in the same group." This experiment has had a largely positive outcome. It is clear that the two specializations respect each others' areas and approaches, and respect each other as valuable individuals and researchers. In addition, the two specializations collaborate well with respect to the group's teaching responsibilities.

Two staff members, Janne Skyt and Thomas Vestdam, collaborate on an interdisciplinary project. And while there is little evidence in terms of publications that the joint research theme has been effective in fostering collaboration, both database and programming staff took part in the ContextIT project. The joint theme has also influenced the research activities within each of the two specializations. Further, a range of student projects that concern aspects of mobile systems have been supervised by both database and programming staff.

As an example of cross-fertilization, a number of current M.Sc. projects advised by programming staff focus on programming language support for database management. Three staff members, Kurt Nørmark, Kristian Torp, and Lone Leth Thomsen, jointly collect experiences about programming exams. Their results will be published in a forthcoming book by the Scandinavian Pedagogy of Programming Network.

The group is thus satisfied with the current level of internal collaboration and cross-fertilization among the database and programming staff and expects it to remain or increase slightly during the coming period.

External collaboration: Among the group's research activities, some have potential for leading to results with industrial applications in the relatively near term. The group's research in tracking is but one example. (Other research is longer term, including much of the work on spatio-temporal indexing.)

The group has collaborated with quite a range of industrial partners—either in the contexts of specific, funded projects or as part of networking activities—and it is felt that the group has succeeded in improving the quality of its industrial collaborations. In particular, the group believes that the industrial collaborations have had a positive impact on the relevance of the research problems addressed, in at least two ways. When researchers get their inspiration from the results made available by other researchers, they tend to address small variations of problems that have already been addressed, and the implications for practice are often unclear. In contrast, close interactions with industrial partners often offer new perspectives and often improve on the relevance of the problems addressed. Next, researchers tend to thrive on problems, while practitioners tend to thrive on solutions. Interactions with practitioners help eliminate those problems that are not "real" in practice.

The group has had successful knowledge exchange collaborations and short-term projects with several local companies in the "mobile" area. Such collaborations include Blip Systems, GateHouse, M-tec, N'volve, Sonofon, Siemens Mobile (now BenQ), and Wirtek. However, the group has had little success in establishing long-term, funded research collaborations with local mobile companies.

The group has collaborated with academic colleagues at quite a few universities across the globe. These collaborations have been rather productive—they have led to quite a few joint publications—and they constitute a valuable means of staying in touch with the newest developments in the scientific community.

As part if its scientific collaboration, the group has hosted 7 visiting Ph.D. students for longer stays; and 9 Ph.D. students from the group has visited external institutions for longer stays(see Section 5.10.4).

Scientific output: The publication strategy has been to publish the best research results in the best general journals and conferences. Other results are published in the best specialized journals and conferences. The lowest priority is given to publication in general outlets with little quality control and consequent relatively low quality, e.g., remote regional conferences and workshops.

This publication strategy has been designed to promote quality, not mere numbers of publications. It is designed to ensure impact and to promote a high peer reputation for the group and its staff.

Within databases, rankings of outlets are given below, together with average acceptances rates for the period 2001–05 for some of the conferences. (Journals tend to not advertise their acceptance rates.) In the rankings, a "1" indicates the top tier, and "1a," "1b," etc. indicate rankings within the tier. Only key outlets are listed, and only specialized outlets within the main specializations of the group are listed. Also, very broad journals, such as *ACM Computing Surveys* and *IEEE Computer*, and conferences outside the database area, *ACM Hypertext* and *European Conference on Information Retrieval*, are omitted although the group has published in these outlets.

General Journals 1a. ACM Transactions on Database Systems. 1b. The VLDB Journal, IEEE Transactions on Knowledge and Data Engineering. 2a. Information Systems. 2b. Data and Knowledge Engineering, The Computer Journal. 3. Journal of Intelligent Information Systems, Knowledge and Information Systems, Journal of Database Management, Journal of Data Semantics, Information Sciences, etc.

Specialized Journals 1. Geoinformatica, Transactions in GIS.

General Conferences 1a. VLDB (17%), ACM SIGMOD (16%). 1b. IEEE ICDE (15%), EDBT (16%).
2. DASFAA (22%), CIKM (19%), IDEAS (24%), CAiSE (22%), ADBIS (24%).
3. SAC, ADC, ICEIS, DEXA, OTM, WISE, COMAD, BNCOD, etc.

Specialized Conferences

Spatial 1. SSTD (31%). 2. ACM GIS (33%), MDM.
3. SDH, MobiQuitous, MobiDE, W2GIS, STDM. 4. ScanGIS, ITS.

Conceptual Modeling 1. ER (21%), UML (26%).

Data Warehousing 1. SSDBM. 2. DOLAP, DaWaK.

A few notes are in order: We have attempted to collect rates for the conferences that we rank highly, but have not been successful in all cases. The figures for DASFAA and CIKM cover only the last two years, and the figure for IDEAS covers only the last three years. The figure for ADBIS does not cover 2004. The figure for ACM GIS covers only the last four years.

We observe that the top-tier outlets are the most selective. As these have gained a reputation over the years for being selective and prestigious, they also involve substantial self-refereeing: authors tend to submit only their best works to these outlets. The acceptance rates found for the second tier of conferences are all below 25%. There is a clear trend towards these conferences becoming increasingly selective during the evaluation period. This trend also applies to the specialized conferences for which we have found figures.

The bibliography of the extended version of this document lists 215 publications that relate to the evaluation period and are authored or coauthored by database staff.

The group publishes a significant fraction of its work in highly ranked journals.

Publication in tier 1 general conferences is highly competitive. Papers are typically 12 pages (2-column, 9 or 10 point type), and most accepted papers report on experimental studies that require substantial software development. Publication in the first two specialized tiers of conferences is also very competitive, and is becoming increasingly competitive. Publication in the best conferences carries substantial prestige and is considered very important in the community. The acceptance rates for the two first tiers of general conferences and for some of the specialized conferences are below, in some cases well below, those of the best journals.

The group has 18 publications in tier 1 general conferences (compared to 14 in the previous period), and it has 16 papers in tier 2 general conferences. In the

top two tiers of "spatial" conferences and the top conferences within conceptual modeling and data warehousing, the group has 20 publications. This exceeds the group's own expectations.

We feel that citation counting for the evaluation period is somewhat premature. In spite of this, the box "Spatio-Temporal Indexing" does present a case study that offers insight into the impact of some of our research, which has been in progress since the end of the previous period. We base our counting on Google Scholar. Thomson Scientific's ISI, a definitive resource for citation counting in some areas of science, unfortunately fails to cover many important outlets in our area, and so the results that can be obtained from ISI are not particularly meaningful.

A recent paper, E. Rahm and A. Thor: Citation analysis of database publications, *ACM SIGMOD Record*, 34(4): 48–53, December 2005, sheds light on the group's performance with respect to citations. This paper reports on studies of citation frequencies of papers published in five highly cited and thus important database outlets, namely the conferences ACM SIGMOD and VLDB, as well as the journals ACM TODS, The VLDB Journal, and ACM SIGMOD Record. The 10-year period from 1994 to 2003 is considered. The study uses the resources DBLP (Digital Bibliography and Library Project, http://www.informatik.uni-trier.de/∼ley/db) and Google Scholar. Citations are cleaned to eliminate self-citations.

In one of its studies, the paper considers citation counts by country, and it reports the following top-ten list of countries: USA, Germany, Canada, France, Italy, Israel, Japan, Denmark, Switzerland, and Greece. We know of no publications from Denmark in these outlets during the period covered that do not stem from our group (there are no other database research groups in Denmark).

The programming technologies staff primarily seek to publish their work in proceedings of conferences and workshops that have the best and the most direct fit with the work that has been done. In addition, a practice has been chosen where some work is presented in Nordic workshops, from which best papers are subsequently selected for publication in special issues of the Nordic Journal of Computing. Finally, an effort is made to present the final research results in highly ranked international journals. The group has been effective in pursuing this strategy.

Funding: A total of 19 funded projects, mainly within database technology, have been active during the evaluation period. This is a quite large number of projects. The funding of these projects can be calculated in a number of ways, a quite conservative approach being to count only the external funding given as "real" money to the projects; thus the department's own co-funding (e.g., salaries of staff) and the co-funding of external participants (e.g., salaries of their participating staff) are not counted). This conservative figure adds up to approximately DKK 25M–30M. Counting also the project participants' co-financing, the total may be in the range DKK 40M–50M.

Three projects were funded by the European Commission; three were funded primarily by the Danish Research Councils; three received funding from the Cen-

tre for IT Research; two were funded by the Electronics and Telecommunications Research Institute, South Korea; two were funded primarily by companies and foundations; two were funded primarily by the Danish Ministry of Economic and Business Affairs; two were funded primarily by regional funds; and one was funded by the Nordic Research Board.

The group believes that it has been quite successful in attracting funding. The range of projects—from being quite applied to having longer term goals—has had a positive effect on the quality and relevance of the group's research. A total of 12 projects have been within the joint research theme. On the negative side, the number of projects is so large that it is on the boundary of what can be managed reasonably by the staff. In addition, some projects are quite small, which increases the administrative overhead.

Scientific Service and Recognition: Members of the group have served on approximately 120 program committees for conferences and workshops, including many program committees for prestigious conferences. They have also served on committees for awards, academic positions, Ph.D. degrees, and grants. The group was given the responsibility for the technical aspects of several conferences, including the *31st International Conference on Very Large Databases*, the *Eighth International Conference on Extending Database Technology*, and the *Seventh International Symposium on Spatial and Temporal Databases*. The service record also includes several keynotes at conferences, and members of the group have performed a range of other services for conferences.

The group has also been represented on the editorial boards of *ACM Transactions on Database Systems* and *IEEE Transactions on Knowledge and Data Engineering*.

Next, three quite prestigious awards have been given to the group for its research: 1. The 2001 Ib Henriksen Research Award. Given annually since 1986 for research across all sciences, this was the first time the award was given to software research. 2. The Telenor Nordic Research Prize 2002. The award was given for research in technologies, applications, and services for mobile Internet access. This was the first time the award was given to Denmark. 3. The 2004 ECIU Young Researchers' Prize. Given annually by the European Consortium of Innovative Universities to young researchers, this was the first time the award was given to Denmark.

Also, a project on technology-transferable database technology, funded by the Danish Technical Research Council, was highlighted by the Council as one of eight success stories in Danish technical research in 2001, the only one in information technology.

The group is represented on the EDBT Endowment, the Board of Trustees of the VLDB Endowment, and in the Danish Academy of Technical Sciences.

Furthermore, members of the group are performing services as project and program reviewers for funding agencies, including the EU FET and IST programmes,

The US National Science Foundation ITR programme, the UK Engineering and Physical Sciences Research Council, The Estonian Science Foundation, and the Research Council of Norway.

To summarize, we find that the group has performed very substantial service to the scientific community. The service record suggests that the group is visible and held in high regard in the research community.

Laboratory facilities: A laboratory with the objective of supporting the group's activities within business intelligence and mobile information management was established in 2001 with support from the department. This laboratory, with equipment that is being updated regularly, has proven useful for both research and student projects.

Hiring: The job market has undergone substantial changes during the evaluation period. Although three permanent staff members have left the group during the period, the group has been relatively successful in maintaining critical mass. Indeed, the situation for the programming area has improved in comparison to the situation at the start of the evaluation period.

The salaries for Ph.D. students are competitive at a global scale. The group has had no difficulties in retaining its Ph.D. students, and the group receives many applications, including enough quality applications, for its stipends. The group has adviser capacity for more Ph.D. students than it is able to secure funding for.

Other aspects: During this period, the formally required teaching load has been fixed at a reasonable level, which is very positive. However, all permanent staff continue to have loads that exceed this level, thus accumulating research time. There is thus a need for additional staff, e.g., teaching staff.

The new management structure for the department, with a group leader and a research leader for each group, is considered a very good step in the direction of increasing the autonomy of the groups.

Summary: The group has a positive outlook.

The growth in staff numbers in the programming technologies area has meant that there is now potential for attacking more significant research challenges. With its relatively large concentration of database researchers, the group has a unique profile in Denmark. We believe that there will be an increasing demand for the area covered by the group, and we also believe that the group is well positioned to compete for resources at the national and international levels.

The area of mobile services has established itself as a common subject for inspiration and cross-fertilization between the database and programming specialization. There has been a growing interest from local industry in knowledge exchange and strategic decision support on some of the shorter term issues addressed by the group.

We feel that the group has received substantial recognition by its peers during the evaluation period, and we consider the group's visibility in the database research community to be high. We feel that the group compares favorably to peer research groups with respect to funding, industrial collaboration, scientific output, and service.

5.6 Research Plan 2006–2010

We initially consider general issues, then describe three topic areas within which the bulk of the group's research will occur during the coming period.

5.6.1 General Considerations

Focus on quality: At the previous research evaluation, professor Vardi expressed the view that "the currency of science is reputation." We will use this maxim as a guideline for our activities and will engage in activities that we believe are likely to enhance our reputation.

Overall, we aim for quality and significance in our research. This implies that we aim to make competent use of the apparatus of computer science in our research and that we aim to solve problems that are considered relevant by some community, be it academic or industrial.

Regarding publication, we will retain the current policy as described in Section 5.5. We commit ourselves to publish in outlets that we feel are in accordance with the significance and specialization of our research results.

Organization: The group expects to maintain the current organization of its activities, which works to the general satisfaction of the staff. The group also believes that increased autonomy of the group will have a further vitalizing effect. In particular, the group believes that it is appropriate to implement the reward structures set up by the Faculty of Engineering and Science within the department. The group would benefit from the availability of seed-funding that may be used for, e.g., hiring prospective Ph.D. students as research assistants already when grant proposals are being prepared.

The group aims to maintain critical mass for its existing activities within databases and programming technologies, and the group is open to the hiring of new staff with profiles within the area of "software systems" (e.g., Internet technologies) that differ from those of the existing staff.

The organization of research activities is covered in the next section.

External collaboration: In the new period, we plan to continue the direction for industrial collaboration that was chosen for the previous period. We now distinguish explicitly among joint projects, knowledge exchange activities, and networking activities. Regarding the former, we aim for few and substantial collaborations

rather than many, but insubstantial, collaborations. We will further prioritize lasting collaborations with industrial partners that may be able to use the results of our research in their products and services; and we will avoid collaborations that do not build on our core competencies and that do not contribute to the strengthening of these. We will also pursue the latter two kinds of activities.

The group will encourage collaboration with prominent researchers from other institutions. The funding available for sending Ph.D. students abroad will be used in part with this in mind.

Funding: The group is well positioned to compete for resources at a national and international level, and it will continue to do so. The group will prioritize applications for grants with funding for one or more Ph.D. students on topics that are within the core competencies of the group. This implies a focus on relatively long and substantial projects.

The group's focus areas within mobile services intersects with the university's focus on mobile communications. Within the current period, the university has channeled substantial local funds into activities in this area. The group hopes that future funds in this area will be open to competition.

The group would like to establish a situation where each senior staff member is responsible for, or participates prominently in, at least one externally funded project. The modest research funds given by the department to the group will be utilized to support activities, including these, that may increase the level of research activity in the group.

5.6.2 Focus Areas

There is a need for critical mass and for obtaining synergies within the group. For example, single individuals and small sub-groups may have difficulty in embarking on substantial projects and may have difficulty in gaining visibility in the research and business communities.

However, there is also a need for diversity within the group. For example, this is important in order to ensure that the teaching is research based, in order to be able to take part in new projects, and in order to allow younger faculty to establish individual profiles.

Based on the experiences from the previous period, we aim to manage the balance between these needs during the coming period by defining three focus areas, within which much of the group's research is expected to take part. Based on our past achievements, we believe that we are well positioned to take on the challenges inherent in these areas. We also believe that the areas are timely and well suited for meeting our general goals as outlined in the previous section.

Research related to TimeCenter will be pursued within the contexts of the latter two focus areas below.

The P2025 Project—"How would you like to program in 2025"

Participants: K. Nørmark, T. Vestdam, P. Madsen, L. L. Thomsen, B. Thomsen

Vision: The world is moving towards a ubiquitous computing platform where everything from supercomputers to everyday consumer electronics will be programmable and connected. Today, programming remains tedious, error prone, and costly, and is characterized by the use of many programming technologies with incoherent programming models and incompatible implementation techniques. High-level programming languages are the only reliable way to improve programmer productivity.

Goals: We want to influence the next generation of mainstream programming languages. First and foremost, we want to create a programming language that is so easy to use and learn that the novice programmer will feel comfortable writing code in the language after a few simple instructions and so rich that it can be used by professional programmers.

Approach: The P2025 project is a long-term research project. Innovations in programming technology take on average 18 years to reach industrial mainstream (Proebstings Law); thus, the project is timely wrt. its goal of influencing programming practice in 2025. Through analytical and empirical studies, we want to contribute to the ongoing global effort on creating better programming technology. The project will be constructive through design and implementation of languages, compilers, and experimental systems. We intend to have openness of our approach and open source of our implementations. The project will serve as an integration playground for new language ideas and as an umbrella covering the programming technology research of the group in the coming years, for permanent research staff, M.Sc. students, industrial computer science students, and Ph.D. students.

Plan: Despite its title, the project has a five year time frame. The project will start with an analytical approach to characterizing the state-of-the-art in programming technologies. We plan a number of study-group activities to read and present related work. We also plan to invite leading researchers to present their work. We expect this phase to take one year. In the ensuing constructive phase, new programming constructs are combined and/or known programming constructs are combined in new ways. This will be followed by experimental implementations of compilers and programming tools. We expect this phase to take two years. Then follows a period of experimental application construction, currently envisioned to be in mobile and pervasive computing. Time permitting, we plan to iterate through these phases several times. Wherever possible, we will engage with industrial partners. We also plan to have 2–5 affiliated M.Sc. projects annually that will experiment with new programming technologies, and we anticipate industrial student projects that will experiment with novel applications using innovative programming technologies. We plan to utilize the research funds provided by the department initially. As the project develops, we intend to seek funding from national and international funding agencies. In particular, we plan to seek funding for a number of Ph.D. students. We plan to publish research results in workshops, conferences,

and journals.

Data Management and Programming Foundations for Mobile Services

Participants: C. S. Jensen, L. L. Thomsen, T. B. Pedersen, S. Šaltenis, K. Torp, A. Schmidt, B. Thomsen, L. Bukauskas, A. Brilingaitė, G. Gidófalvi, X. Huang, S. Pakalnis, L. Speičys, D. Tiešytė, N. Tradišauskas.

Vision: Driven in large part by rapid and sustained advances in key computing and communication hardware technologies, an infrastructure is emerging with vast quantities of interconnected computing and sensory devices. This infrastructure has the potential for enabling entirely new applications and services.

Goal: By capturing pertinent aspects of reality in digital form—in semantically rich and appropriately organized structures and with powerful update and retrieval techniques available—an ideal foundation for delivering a wide range of mobile services is obtained.

The goal is to contribute substantially to the invention of new data management and programming foundations for software systems that will enable the delivery of mobile services.

Special focus will be given to geo-location aspects.

Approach: The focus area will serve as a framework for a range of more specific activities, including Ph.D. projects and other funded projects, and it will encompass a plurality of approaches and activities.

Based on the view of research as the making of a series of decisions, most of which are made implicitly, the approaches can be characterized as being *use inspired*. Put differently, research decisions will often be guided by concerns for use in practice or anticipated practice—the research in this area is mostly motivated by perceived practical concerns. In line with this principle, we will try to interact with practitioners on a regular basis, e.g., via participation in advisory boards or boards of directors for technology companies, via collaboration with practitioners in funded research projects, via participation in industry associations, and via lecturing to industrial audiences. This is expected to have a positive effect on relevance and impact.

Second, the activities will aim for insights, concepts, principles, and techniques that have *general applicability*. Thus, the objective is to obtain general results that go beyond a specific application. This implies that the outcomes are more abstract than solutions to specific, practical problems. We consider it the task of industrial collaborators to apply these outcomes to solve concrete problems. This division of labor within the value chain that includes both research and innovation is quite important.

Third, the activities are generally *constructive* and *experimental*. They fundamentally involves the design of artifacts. This research process often, although not always, requires that prototypes be implemented, either as proof of concept or in order to elicit design properties that may guide the continued design process.

Much of the research will concern artifacts that aim to stand out by virtue of their performance, rather than, e.g., functionality or usability, focus will be on empirical studies of performance characteristics.

The activities are thus different from basic research, which is not use inspired, and product development, which aims for specific solutions to specific problems, but not for general insight. Using a concept from the framework articulated by Donald E. Stokes, we aim for Pasteur's Quadrant and Edison's Quadrant.

The general approach will be constructive and iterative: New techniques are designed and subsequently prototyped, either for proof of concept or with the purpose of eliciting design properties, typically performance properties, via empirical studies. The resulting insights are then used for re-design and improvements.

Some of the techniques invented may well be applicable in the near term, while others may be applicable only indirectly and in the longer term. Publication will follow the general publication plan.

Specific Topics: The activities will cover topics such as indexing the positions of moving objects, including past positions and current and near-future positions; tracking; the provisioning of geo-related context to mobile services, including destinations and routes; caching in peer-to-peer networks; clustering of moving objects; efficient service development; and comparison of service development approaches and technologies.

Querying The World

Participants: T. B. Pedersen, C. S. Jensen, M. M. Ruxanda, J. Skyt, S. Šaltenis, A. Schmidt, C. Thomsen, X. Yin.

Vision: The world is fast becoming populated with sensors, e.g., temperature, noise, or RFID sensors, continously emitting enourmous amounts of data. Along with the sensor data, even more data is being accumulated in traditional databases. It is of paramount importance that all this data can be integrated and queried to answer questions about the past, present, and (expected) future state of the world. The vision is that data from sensors (present state), databases (past state), and prediction models and simulations (future state) are available through a unified infrastructure and can be queried seamlessly.

Goals: We want to make it possible to "query the world" in an integrated and effective way. To do so, we aim to develop both a theoretical framework and practical prototype systems that enable this.

Approach: The developed framework should be able to naturally accommodate both streaming data and traditional, static data. Concretely, we aim to develop data models, query languages, query processing/optimization techniques, data integration techniques, and techniques for integrating data and analytical/predictive models of the data. These results will combine to provide the desired functionality. Challenging aspects that occur naturally in this setting include imperfect data, providing data ranging from "raw" to "smoothed," and handling the highly dynamic and sometimes unreliable nature of interconnected sensors and databases.

Several prototype systems will be built to provide proof-of-concept. These will be evaluated both analytically, in laboratory, and/or in real-world settings. The activities will build on the group's proven track record within multidimensional, temporal, spatial, spatio-temporal, and XML data management.

The focus area will serve as an umbrella for a number of specific projects. Existing such projects include Rethinking Business Intelligence for the Age of Pervasive Computing, European Internet Accessibility Observatory, and Intelligent Sound. It is the aim to continue to obtain funded projects from sources such as the European Union, national research councils, and funding agencies for industrial collaboration. We hope to start 2–3 funded projects during the five year period.

The overall working mode of the underlying projects is to iterate through analytical, constructive, and experimental phases. The work will involve a number of Ph.D. students, along with M.Sc. thesis and industrial computer science projects. We aim to have a regular seminar under the umbrella, probably supplemented with workshops in the specific projects.

The research results will be published in accordance with the publication strategy covered in Section 5.5. A few patents for key technologies might be pursued, while other developments will be open source. We plan to actively seek to commercialize the results through partner companies and/or startup companies.

Appendices 5

5.7 Detailed Description of Activities and Results

5.7.1 Funded Projects

BIPC - Rethinking Business Intelligence for the Age of Pervasive Computing: Data Streams and Online Integration (January 2003–December 2006)

Scientist in charge: Torben Bach Pedersen.

Financing: The Danish Technical Research Council, DKK 1,500,000 (external funding to I16), DKK 1,500,000 (total external funding to all partners), DKK 3,270,240 (total budget for all partners)

Participating organizations: Aalborg University, TARGIT A/S.

Description: Traditional Business Intelligence (BI) technologies must be adapted to the Pervasive Computing age where data continuously stream in from millions of sensors and devices. The project aims at making BI on on-line integrated databases and data streams just as efficient and easy-to-use as BI on traditional data warehouses. This enables totally new application areas for BI technology, e.g., for analyzing data from millions of sensors.

COSPA - Consortium for studying, evaluating, and supporting the introduction of Open Source software and Open Data Standards in the Public Administration (January 2004 - December 2005)

Scientist in charge: Michael H. Böhlen.

Funding: European Union Sixth Framework Programme, Proposal/ Contract no.: IST-1-002614.330,000 Euro

Participating organizations: Free University of Bolzano (Coordinator), Aalborg University, MTA Szamitastechnikai es Automatizalasi Kutatointezet, University of Limerick, University of Sheffield, Beaumont Hospital, Consorzio dei Comuni dell'Alto Adige, Hanstholm Kommune, Province of Genoa, Province of Pisa, Soc-ITM, South West Regional Authority, Torokbalint City Council, Conecta (SME), IBM Belgium.

Core Application Technology for Telematics in USN Environment (August 2005–January 2006)

Scientist in charge: Christian S. Jensen.

Funding: USD 78,260 from the Electronics and Telecommunications Research Institute, South Korea

Additional Participants: Pusan National University, South Korea.

Description: With the rapid progress in wireless communication and sensor technologies, it becomes possible to equip vehicles with multiple communication devices and sensors. Even though CDMA remains the most popular communication environment for LBS and telematics, other alternatives, such as MANETs (Mobile Ad-hoc Network) and DMB (Digital Multimedia Broadcasting), are of interest. This project studies the feasibility of MANETs and sensor networks for telematics applications. The project aims to (1) conduct a feasibility study on MANETs and sensor networks for safety control at intersections, and to (2) uncover theoretical foundations of database systems for vehicles in diverse communication environments.

Bluetooth-Based Mobile Services for Conference Delegates (July 2005–November 2006)

Scientist in charge: Christian S. Jensen.

Funding: DKK 300.000 from Blip Systems, Inc., DKK 175.000 from N'volve, Inc., DKK 140.000 from Det Obelske Familiefond, DKK 140.000 from SparNord Fonden, DKK 168.000 from Centre for Embedded Software Systems, Aalborg University, DKK 30.000 from Aalborg Congress & Culture Centre, DKK 10.000 from Aalborg Airport, and DKK 5.000 from each of Helnan Phoenix, Hotel Hvide Hus, Quality Hotel, and SAS Radisson Hotel.

Additional Participants: Apart from the two foundations, all sponsors participate.

Description: In this project, two companies in Aalborg, BLIP Systems and N'volve, and the Database and Programming Technologies Research group in Department of Computer Science at Aalborg University have jointly developed a mobile service system, termed the Bluetooth Conference System. This system has been designed specially for the International Wireless Summit, held in Aalborg Congress and Culture Center from September 18 to 22, 2005. The scientific project within which the system has been developed has involved collaboration with CISS at Aalborg University, that has also offered financial support together with two foundations, Det Obelske Familiefond and Spar Nord Fonden.

The Bluetooth Conference System is based on the network technology (BlipNet components) from BLIP Systems and includes a database-based content management system on the server side. All content and information is transferred via Bluetooth and is free of charge for the users.

Participating delegates have access to an up-to-date information service. The information in this service is being updated automatically and transparently whenever the delegate is within reach of the Bluetooth network. This service is available any time, including when the delegate is off-line, and it provides information such as the conference program, tourist information, information on city activities, weather information, hotel information, and information on public services. Push messages are also be transferred to the participants—e.g., program updates and news. The messages are transferred depending on time, subject and location.

Intelligent Sound—Search and Retrieval in Dynamic Sound Databases (January 2005–December 2008)

Co-scientists in charge, Aalborg University: Christian S. Jensen and Torben Bach Pedersen.

Funding: Statens Teknisk-Videnskabelige Forskningsråd (Danish Technical Research Council), DKK 14,000,000 ; participants' co-financing, DKK 8,621,000

Additional Participants: Department of Informatics and Mathematical Modeling, Technical University of Denmark; Department of Communication Technology, Aalborg University.

Description: The project will build a framework for the next generation of intelligent sound services based on three strong research communities within the fields of signal processing, database management, and machine learning. The central hypothesis is that this combination can open new scientific frontiers in the important field of multimedia search.

European Internet Accessibility Observatory (September 2004–August 2007)

Co-scientists in charge, Aalborg University: Christian S. Jensen and Torben Bach Pedersen.

Funding: EUR 3,200,000 (total), EUR 2,100,000 (total from the European Commission), EUR 180,000 (AaU funding from the European Commission)

Additional Participants: Agder University College, Vista Utredning AS, FTB-Volmarstein, Manchester Metropolitan University, Nettkroken AS, University of Tromsø, FBL s.r.l., Technical University of Warsaw, Intermedium AS.

Description: The goal of the project is to contribute to better e-accessibility for all citizens and to increase the use of standards for online resources. The project will establish the technical basis for a possible European Internet Accessibility Observatory (EIAO) consisting of: A set of web accessibility metrics. An Internet robot for automatically and frequent collecting data on web accessibility and deviations from web standards (the WAI guidelines). A data warehouse providing online access to collected accessibility data.

Spatial Tracking and Event Monitoring for Mobile Services (August 2004–July 2007)

Scientist in charge: Christian S. Jensen.

Funding: DKK 440,000 from Center for ITS and DKK 440,000 from Faculty of Engineering and Science, Aalborg University

Additional Participants: Vilnius University.

Description: During the coming years, an infrastructure of vehicles with computing, communication, and accurate positioning capabilities will emerge. For example, buses in Northern Jutland and Copenhagen are already equipped with PCs, GPS receivers, and wireless communications capabilities. This project is concerned with fundamental techniques underlying the mobile services enabled by this infrastructure.

The main problem considered is how to maintain various kinds of information about a population of vehicles on a central computer, when certain guarantees have to be met while spending as few resources as possible. For example, the project considers the server-side maintenance of the current positions of vehicles with accuracy guarantees. Resource consumption, including network traffic and server-side updates, may be reduced by being able to accurately predict the near-future movement of each vehicle.

Mobile Tourist Information (August 2004–December 2005)

Scientist in charge: Christian S. Jensen, Aalborg University.

Funding: DKK 3,500,000 (total), DKK 1,600,000 (total from the Danish Ministry of Economic and Business Affairs), DKK 490,000 (AaU funding from the Danish Ministry of Economic and Business Affairs)

Additional Participants: Østjyllands Turistudviklingsfond, Tourist Århus, Danmarks Turistråd, Euman A/S, Innovation Lab Katrinebjerg, University of Southern Denmark, Esbjerg Turistbureau, Ribe Turistbureau.

Description: The project aims to demonstrate in practice the utility of the delivery of location-based tourist information services to the mobile phones of tourists. The services involve the delivery of multimedia data, including images, sound, text, and, eventually, video.

The services aim to: (1) Improve the level of service delivered to tourists and to create a new information and marketing channel for the tourist industry. (2) Establish a robust and flexible information infrastructure that supports services at a national scale. (3) Develop and test four specific, new mobile services. (4) Develop a business model for mobile tourist service delivery.

The project builds upon and further develops the database GuideDanmark, to which all local tourist offices in Denmark contribute with local tourist information. The

project extends this infrastructure to become a robust and flexible mobile service delivery system.

Mobile Tourist Information, pre-project (December 2003–July 2004)

Scientist in charge: Christian S. Jensen, Aalborg University.

Funding: DKK 366,000 (total)

Additional Participants: The Danish Ministry of Economic and Business Affairs, Østjyllands Turistudviklingsfond, Tourist Århus, Euman A/S, Innovation Lab Katrinebjerg.

Description: See the previous project description.

Development of Position Tracking Technology in Ubiquitous LBS (June 2003–December 2003)

Scientist in charge: Christian S. Jensen.

Funding: USD 75,000 from Electronics and Telecommunications Research Institute, South Korea

Additional Participants: Pusan National University, South Korea.

Description: This project's focus is on providing basic support for the class of tracking services, where there is a need for continuously monitoring of the current positions of a population of moving objects. Given a certain required accuracy with which the positions of mobile objects need to be known, the problem is how to most efficiently capture on a central server the positions of a large population of mobile objects within that accuracy.

The techniques developed in the project are based on movement prediction, and it is an underlying assumption that exact locations of moving objects are not needed. Rather, we assume that tracking with a certain minimum accuracy is needed. Location-based games may need high accuracy, while a localized weather information service needs only low accuracy. Specifically, the project has designed, prototyped, and evaluated so-called point-based, vector-based, and segment-based tracking techniques that reduce the number of updates.

Further, the project has designed, prototyped, and evaluated techniques that aim to improve the basic segment-based approach: Some of these are based on re-segmentation of the underlying road network. Others use anticipated routes and, possibly, acceleration profiles associated with these routes to obtain more efficient tracking.

ContextIT: Context-Based Everyday IT Services (January 2003–December 2003)

Scientist in charge: Christian S. Jensen, Aalborg University.

Funding: A total of DKK 7,180,000 contributed by the participants

Additional Participants: The Danish National Centre for IT Research, Euman A/S, TDC Innovation Laboratory, Århus University.

Description: The project aims to provide "next generation everyday services" based on an effective pervasive computing platform. This entails multiple services, which are relevant to the individual user in terms of the use context, characterized by time, location, background profile, user tasks or activities etc. We call such services "context-based services."

DBGlobe: A Data Centric Approach to Global Computing (January 2002–December 2004)

Investigator: Christian S. Jensen.

Funding: European Commission Research Directorates General IST, Future and Emerging Technologies, Global Computing Initiative, EUR 932,000

Additional Participants: University of Ioannina, Greece, Computer Technology Institute, Greece, Athens University of Economics and Business, Greece, INRIA, France, Unversity of Cyprus, Cyprus, University of California, Riverside, USA.

Description: The DBGlobe project aims at developing novel data management techniques to deal with the challenge of global computing. Global computing is considered as a database problem: how to design, build, and analyze systems that manage large amounts of data. The traditional approach of storing data of interest in monolithic database management systems becomes obsolete in such environments. In current database research, data are relatively homogeneous, exhibit a small degree of distribution, and are passive in that they remain unchanged unless explicitly updated. These assumptions do not hold in the global-computing world. This creates the need for new theoretical foundations in all aspects of data management: modeling, storage, and querying.

Data Management Support for Location-Based Services (January 2002–December 2005)

Scientist in charge: Christian S. Jensen.

Funding: A total of DKK 8,665,000 contributed by the participants.

Additional Participants: The Danish National Centre for IT Research, Euman A/S, Sonofon A/S, Nykredit Data A/S, Kort-og Matrikelstyrelsen (the Danish mapping agency), Vejdirektoratet (the Danish Road Directorate).

Description: The project is based on a simple yet wide-reaching thesis: by capturing pertinent aspects of reality in the computer—in semantically rich and appropriately organized structures and with powerful update and retrieval techniques available—an ideal foundation for delivering a wide range of location-enabled services is obtained.

The project participants explore data management foundations for location-enabled services with particular focus on data warehousing in relation to location-enabled services, the representation of geo-related content in location-based services, and the efficient update and advanced querying of geo-related content.

Nykredit Center for Database Research (January 1998–December 2002)

Director: Christian S. Jensen.

Funding: DKK 5,000,000 from Nykredit and DKK 3,600,000 from the Danish National Centre for IT Research

Description: Two governmental reports from 1997 conclude that Danish computer science and engineering candidates are only moderately qualified in database technology and that the existing competence in database technology in higher education is divided among few researchers and is sparse and vulnerable in a national perspective. On the other hand, the ability to make effective use of the newest database technologies is essential to ensuring the competitiveness of companies and institutions, thus rendering it of strategic national importance to establish and maintain a solid and up-to-date competence in databases in the nation's higher-education programs in computer science and engineering.

Nykredit Center for Database Research has as its objective to contribute to increasing the competence in database technology in Denmark in the near and longer terms. Specifically, the center is responsible for conducting database research at a high international level; the center is responsible for offering internationally-oriented research training with the longer-term objective of contributing to the establishment of new database research groups at Danish universities; and to meet short-term demands, the center offers courses and collaboration in database technologies.

The center embraces and provides infrastructure to all other database research activities in the unit. Topics covered consequently include temporal and spatio-temporal databases, data warehousing, and world-wide-web data management.

To maintain a high quality and relevance of the research activities, the project supports intensive collaborations among members of the unit and leading international researchers in each of these areas. A visiting faculty program makes it possible to invite guest researchers for short stays. The project also supports its own researchers in visiting other research institutions. Researchers from the center also collaborate with a number of companies and institutions in Denmark. In excess of a dozen Ph.D.s, half a dozen spinn-offs, and 175 publications have resulted.

Remote: Using Floating Car Data for Traffic Monitoring (August 2003-April 2004)

Scientists in charge: Harry Lahrmann and Kristian Torp.

Funding: DKK 400.000, Viking, Tempo Program, Co-Funded by the European Commission: DG TREN

Additional Participants: The Traffic Research Group at Aalborg University, M-Tec A/S, Euman A/S

Description: Establishing and maintaining loop detectors in roads is costly. This project aims at determining whether the GPS technology in clients (or cars) will be able to provide the same information with lower operational and maintenance costs. Through this project it was recognized that the GPS registrations would be able to ”draw a curve” of the traffic flow in a geographical area - if a sufficient number of cars in the area had the equipment installed and in fact did sent data to a central server.

Wireless Information Management (January 2001–December 2005)

Scientist in charge 2001–2003: Christian S. Jensen

Funding: Nordic Academy of Advanced Study, no. 000389, NOK 1,200,000

Additional Participants: Research groups at Agder University College, Norwegian University of Science and Technology, Vilnius University, Vilnius Gediminas Technical University, Uppsala University, University of Jyvaskyla.

Description: Wireless Information Management is a research training network involving researchers from seven universities in Denmark, Finland, Lithuania, Norway, and Sweden. Approximately 30 Ph.D. students and their advisors and colleagues take part.

Wireless Information Management encompasses the management of information obtained from sensors as well as the management of information involving mobile objects, both of which types of information concern continuous change, be it in virtual spaces or physical space. These types of data will gain prominence in step with the increasing deployment of wireless communications and sensor technologies.

The project aims to offer training in this area, in which there are significant industrial strengths and interests in the Nordic region.

3D Visual Data Mining (August 1999–July 2003)

Principal investigator, scientist in charge, database systems: Michael H. Böhlen

Funding: The Danish Research Councils, DKK 6,900,000

Additional Participants: Michael Böhlen (principal investigator), Erik Granum, Steffen L. Lauritzen, and Peer Mylov.

Description: Visual data mining provides methods for accessing, analyzing, and visualizing large amounts of data. The 3DVDM project combines expertise in databases, statistics, visualization, and perceptual psychology with facilities for immersive real-time interactive visualizations. The 3DVDM project develops new

data analysis methods that exploit the human perceptual faculties as far as possible in the search for unknown structures and relationship in large data sets. Database technology selects and provides the desired data subsets from the large database to be subjected to appropriate statistical processing. Using expertise from perceptual psychology, suitable processing methods from computer vision and scientific visualization are applied to create data structures amenable to visualization and adequate for visual perception.

The 3DVDM project exploits the facilities of the VR Center Nord, a cutting-edge research and development center for virtual reality that encompasses a Cave, a Panorama, and an auditorium with a PowerWall. It is part of a center for research, development, and training in interactive multimedia that was established at Aalborg University in January 1998.

Foundations of Technology-Transferable Database Technology (September 1997–December 2001)

Scientist-in-charge: Christian S. Jensen.

Funding: Statens Teknisk-Videnskabelige Forskningsråd (Danish Technical Research Council),
no. 9700780, DKK 2,414,000

Description: Advances in temporal database research obtained by 1997 demonstrated that most database applications would benefit substantially from built-in temporal support in the database management system used. In spite of this, temporal database technology had so far had little impact on practice.

The objective of the project is to contribute to the foundations for developing database technology that is technology-transfer friendly. More specifically, the project aims to develop database concepts and techniques fundamental to the development of temporally enhanced database technology.

Most activities are devoted to the challenges that occur when implementing a temporal SQL (SQL is the query language supported by all significant DBMSs) by means of a layer on top of an existing (SQL-based) DBMS. The main challenges addressed arise because a temporal SQL, unlike regular SQL, timestamps data in the database (according to a certain discipline) and allows the special variable *now* (denoting the changing current time) to be used in the database and in statements. Some of the work aims to achieve a “thin” layer, where all the processing is left to the DBMS. In other work, we are attempting to delegate more processing to the temporal layer.

A second theme is the *indexing of continuous phenomena*, which includes bitemporal and spatio-temporal data. Bitemporal data has regions in the two-dimensional space spanned by transaction time and valid time associated with it. These regions indicate when the data was true in the modeled reality and recorded as current in the database. Because some data is true and current until *now*, these regions may

grow continuously. The continuity in spatio-temporal data occurs when the indexed objects are capable of continuous movement or when valid and transaction time (and thus *now*) are captured. The inherent continuity in these kinds of data renders existing indices ineffective.

A third theme is the *management of aging data*. Because many real-world database applications, including financial and medical applications, are faced with accountability and trace-ability requirements, the usual update-in-place policy is often being replaced with an append-only policy where logical deletions are being implemented as insertions at the physical level. The resulting databases retain all previously current states and are ever-growing. In his recent Turing Award lecture, Jim Gray pointed out that there will be sold as much disk storage the next 18 months as has been sold previously in history. Together, these two phenomena make for very large databases with bulks of aging data.

Web-sikkerhed via mobiltelefon/Web Security Via Mobile Phones (January 2001–October 2001)

Co-applicant: Christian S. Jensen.

Funding: Det Digitale Nordjylland, DKK 400.000; Nykredit A/S, DKK 660.000; Siemens Business Services A/S, DKK 285.000.

Additional Participants: Nykredit Data, Siemens Business Services A/S.

Description: This project initially provided secure identification of remote users, enabling Nykredit employees to use corporate web applications from any publicly available, Internet connected PC. In a second phase the project, the solution was made available to other companies as well.

Socrates Student Exchange (1999–2005)

Funding: European Union, Socrates

Additional Participants: Athens University of Economics and Business, Greece; Vilnius University, Lithuania.

TimeCenter (September 1996–)

Co-director: Christian S. Jensen

Funding: TimeCenter serves as an umbrella for more specific, funded projects.

Description: TimeCenter is an international center for the support of temporal database applications on traditional and emerging DBMS technologies.

Recent advances in temporal query languages and data models clearly demonstrate that database applications that manage time-varying data—and most do—may benefit substantially from built-in temporal support in the database technology used. It is the goal of TimeCenter to contribute substantially to moving research ideas

into practice. Recently developed commercial offerings indicate that this is now happening, with a database management system and associated tools that support valid-time, transaction-time, and bitemporal data.

While others are pursuing valuable organizational solutions to the general problem of effective technology transfer, TimeCenter focuses on technical solutions and aims at developing temporal database technology that is expressly transferable. Such technology allows for the continued operation of legacy code, for the harmonious coexistence of legacy and new application code and for the reuse of programmer expertise and knowledge. It also allows for maximal, effective, and efficient reuse of the functionality already provided by current database management systems. Together, these properties lead to a technology that is attractive to use and is manageable to implement.

5.7.2 Specific Projects

DOPU

The Scheme and Java Elucidators are maintained as part of the Documentation of Program Understanding project (DOPU). Thomas Vestdam is responsible for the Java Elucidator. Both elucidator tools are concerned with representation and presentation of internal program documentation. As part of this work, different aspects of internal program documentation [149] and maintenance of program understanding [38] have been studied. In the last phase of the project the orientation has been shifted towards the understanding of program evolution [153]. In connection to the LAML project, a library interface documentation tool for Scheme called LAML SchemeDoc has been developed [112].

LAML

The early work on LAML is described in the 1996-2000 research evaluation. In summary, LAML enables import of XML languages as function libraries in the functional programming language Scheme. As one of the important achievements in this period, the functions that represent XML elements carry out comprehensive validation relative to the XML document type defintion (DTD) [25]. LAML supports a common XML-in-LAML library that - among many other things - allows for transformation from one XML language to another by simple means [111]. As part of the work on LAML, a more general study of XML markup in relation to programming notation has been carried out [110]. The educational applications of LAML have been continued, primarily in the direction of supplying XML-compliant interfaces to new and existing tools [249, 251]. The LAML software runs on both multiple platforms with different Scheme systems. New versions of LAML are distributed regularly. LAML is open source software, distributed under the GNU general public license.

EU working group APPSEM II

From 01. Jan 2003 to 31. Dec 2005

APPSEM II is a working group in the 5th Framework Programme of the European Union. The objective of APPSEM II is to maintain and further develop an existing European network for research and technology transfer in the field of application-oriented semantics of programming languages. Programming languages are one of the essential ingredients for successful software development. Theoretical results and expertise that are available in the consortium will be used to solve problems relating to programming with proofs, improving specification and verification, type systems, distributed computing, programming with continuous data, programming the web. At the same time and enabled by these practical problems the theoretical toolbox will be further developed, in particular the semantic understanding of sequentiality, distribution, object-orientation and of resource-bounded computation. This will happen through mutual research visits, workshops and one summer school. APPSEM II has academic participants from 20 universities and four industrial partners. The working group covers the following themes: A. Program structuring: object-oriented programming modules B. Proof assistants, functional programming and dependent types C. Program analysis, generation and configuration D. Specification and verification methods E. Types and type inference in programming F. Games, sequentiality and abstract machines G. Semantic methods for distributed computing H. Resource models and web data I. Continuous phenomena in Computer Science

Ravenscar-Real-time-Java Project

From 01 Sep. 2005 to 31. Aug. 2006

The purpose of the project is to

- implement the Ravenscar-Java Profile on the aJ-100 processor
- find out to what extent ” UML Profile for Schedulability, Performance, and Time, Version 1.1” with advantage can be applied when designing embedded real-time systems
- find out through construction of an industrial case how useful this Ravenscar-Java Profile is for construction of industrial embedded systems with real-time requirements
- compare the Ravenscar-Java solution with a C++ solution.

Project Partners: CISS, Aalborg University, FOSS A/S, Hillerød, and Vitus Bering Denmark.

5.8 Organization and Staff

Brief CVs of the group members (including references of 4 key publications from the period).

5.8.0 Lars Bendix

Academic Degrees

1996	*Ph.D. in Computer Science*, Aalborg University
1986	*Cand.scient. (M.Sc.) in Computer Science*, University of Århus

Positions

2003–2004	*On leave* from Aalborg University to Lund Institute of Technology, Sweden
1998–2003	*Associate Professor, Department of Computer Science*, Aalborg University
1997–1998	*Visiting Associate Professor*, Computer Science Department, University of Bologna (7 months)
1995–1998	*Assistant Professor*, Aalborg University, Department of Mathematics and Computer Science
1994–1995	*Teaching Assistant*, Aalborg University, Department of Mathematics and Computer Science
1993	*Visiting Professor*, Siegen University, Department of Computer Science (10 months)
1991–1992	*Lecturer in Information Technology*, European Business School, Parma, Italy
1989–1991	*Ph.D. scholarship*, University of Århus, Department of Computer Science (stationed at University of Pisa, Computer Science Department)
1987–1989	*Consultant*, BIT Consulting, Struer
1986–1987	*Visiting Researcher*, University of Pisa, Computer Science Department (9 months)

5.8.0 Michael H. Böhlen

Academic Degrees

1994	*Ph.D. (Dr.sc.tech)*, ETH Zürich.
1990	*M.Sc. (Dipl. Informatic-Ing. ETH)*, ETH Zürich.

Positions

2003–	*Full professor*, Faculty of Computer Science, Free University of Bolzano, Italy
1998–2003	*Associate Professor*, Aalborg University
1998	Research associate professor, Aalborg University
1995–1998	*Assistant professor*, Aalborg University
1994–1995	*Postdoctoral Researcher* in the TempIS Temporal Database Group headed by Prof. R. Snodgrass, University of Arizona, Department of Computer Science, Tucson, AZ, USA
1990–1994	*Teaching Assistant* in the Knowledge Based Systems Group headed by Prof. R. Marti, Department of Computer Science, ETH Zürich, Switzerland
1990–1994	*Lecturer* at the HTL Engineering School in Grenchen, Switzerland, courses taught on

5.8.0 Linas Bukauskas

Academic Degrees

2004	*Ph.D. in Computer Science*, Department of Computer Science, Aalborg University
1999	*Cand. scient. (M.Sc.) in Computer Science*, Aalborg University
1998	*B.Sc. in Mathematics (Informatics stream)*, Vilnius University, Vilnius, Lithuania

Positions

2004–	*Lecturer*, Aalborg University, Department of Computer Science
2003–2004	*Research Assistant*, Aalborg University
2002	*Visiting Scholar*, Institute of Technology, Georgia, USA
1999–2003	*Ph.D. Student*, Aalborg University
1997	*Assistant programmer*, Central Securities Depository of Lithuania

Key publications

[55, 56, 12]

5.8.0 Erik Ernst

Academic Degrees

1999	*Ph.D. in Computer Science*, University of Århus
1996	*Cand.scient. (M.Sc.) in Computer Science*, University of Århus
1989	*Diploma in classical guitar*, Royal Academy of Music at Århus
1988	*Music Teacher (cls. guitar)*, Royal Academy of Music at Århus

Positions

2003–	*Associate Professor*, Department of Computer Science University of Århus
2002–2003	*On leave* from Aalborg University at Århus University
2000–2002	*Assistant Professor*, Department of Computer Science, Aalborg University
1999	*Research Assistant Professor*, Department of Computer Science, Aalborg University
1999	*Student Intern 2*, Sun Microsystems Laboratories, Inc., Mountain View, CA, USA (7 months)
1998	*Visiting Scholar*, Department of Computer Science, University of Washington, Seattle, USA (3 months)
1995–1999	*Ph.D. scholarship*, Department of Computer Science, University of Århus
1991–1995	*Project Assoc. Programmer*, DEVISE, Department of Computer Science, University of Århus
1988–1989	*System Developer*, TemaData, Kerteminde, Denmark (10 months)

5.8.0 Jevgenij Gagac

Academic Degrees

2002	*International Master (M.Sc.) in GPS Technology*, Aalborg University

Positions

2002–2003	*Research assistant*, Department of Computer Science, Aalborg University (September 2002–December 2003).

5.8.0 Heidi Gregersen

Academic Degrees

1999	*Ph.D. in Computer Science*, Aalborg University
1995	*Cand.Scient (M.Sc.) in Computer Science*, Aalborg University

Positions

2003–	*Assistant Professor*, Department of Accounting, Finance and Logistics Århus School of Business
1999–2003	*Assistant Professor*, Aalborg University, Department of Computer Science
1997-1998	*Visiting Scholar*, College of Computing, Georgia Institute of Technology, USA (9 months)
1996–1999	*Ph.D. Scholarship*, Aalborg University, Department of Computer Science
1995–1996	*Teaching Assistant*, Aalborg University, Department of Mathematics and Computer Science

5.8.0 Christian S. Jensen

Academic Degrees

2000	*Dr.Techn.*, Faculty of Engineering and Science, Aalborg University, Denmark, May 2000
1991	*Ph.D. in Computer Science*, Aalborg University, January 1991 (studies conducted at the University of Maryland under the supervision of Professor Leo Mark)
1988	*M.S. in Computer Science*, Aalborg University, June 1988
1986	*B.S.'s in Computer Science and Mathematics*, Aalborg University, June 1986 and January 1985, respectively

Positions

2001–	*Professor II*, Agder University College, Faculty of Engineering and Science
2001–	*Honorary Professor*, Cardiff University, Department of Computer Science
2000–	*Professor*, Aalborg University, Department of Computer Science
1998–2002	*Nykredit Research Professor*, Aalborg University, Department of Computer Science, and Director, Nykredit Center for Database Research
2002	*Visiting Professorial Fellow*, National University of Singapore, Department of Computer Science
1999	*Visiting Professor*, University of Arizona, Department of Computer Science
1994–2000	*Associate Professor*, Aalborg University, Department of Computer Science (on October 3, 1996, Department of Mathematics and Computer Science was split, effective August 1, 1996)
1994–1995	*Visiting Associate Professor*, University of Arizona, Department of Computer Science
1990–1994	*Assistant Professor*, Aalborg University, Department of Mathematics and Computer Science
1991,1992	*Visiting Scholar*, University of Arizona, Department of Computer Science.
1988-1990	*Ph.D. Stipend*, Aalborg University, Department of Mathematics and Computer Science, stationed at University of Maryland, Department of Computer Science

Key publications

[11, 15, 28, 35]

5.8.0 Mikael Rune Jensen

Academic Degrees

2003	*Cand.Scient (M.Sc.) in Computer Science*, Aalborg University

Positions

2003–2004	*Lecturer*, Department of Computer Science, Aalborg University

Key publications

[92]

5.8.0 Augustas Kligys

Academic Degrees

2002	*Cand.Scient (M.Sc.) in Knowledge and Data Engineering*, Aalborg University

Positions

2004	*Research Assistant*,Department of Computer Science, Aalborg University Science

5.8.0 Per Madsen

Academic Degrees

1998	*Cand. polyt (M.Sc.) in Computer Engineering*, Aalborg University

Positions

2004–	*Lecturer*, Aalborg University, Department of Computer Science
2001–2004	*Ph.D. student*, Aalborg University
1998–2001	*Lyngsø Industri*, Denmark

Key publications

[24, 106, 105, 104]

5.8.0 Kurt Nørmark

Academic Degrees

1987	*Lic scient (Ph.D) in Computer Science*, Aarhus University.
1983	*Cand. Scient. (M.Sc.) in Computer Science*, Aarhus University.

Positions

1991–	*Associate professor in Computer Science*, Aalborg University.
1987–1991	*Assistant professor in Computer Science*, Aalborg University.
1984–1986	*Visiting Scholar at the Computer Science Department*, Stanford University.
1983–1987	*Ph.D. student*, Aarhus University.

Key publications

[25, 38, 153, 109]

5.8.0 Torben Bach Pedersen

Academic Degrees

2000	*Ph.D. in Computer Science*, Aalborg University
1994	*Cand.Scient (M.Sc.) in Computer Science*, Aarhus University

Positions

2000–	*Associate Professor*, Aalborg University, Department of Computer Science
2000	*Lecturer*, Aalborg University, Department of Computer Science (March-June)
1997–2000	*Industrial Ph.D. Fellow*, Kommunedata
1994–1997	*Database Administrator*, Kommunedata

Key publications

[27, 120, 73, 20]

5.8.0 Dieter Pfoser

Academic Degrees

2000	*Ph.D. in Computer Science*, Aalborg University
1996	*Magister (M.Sc.) in Business Informatics*, University of Linz, Austria

Positions

2002–	*Senior Engineer, Researcher*, Computer Technology Institute, Athens Greece
2000–2002	*Assistant Professor*, Aalborg University, Department of Computer Science
1997–2000	*Ph.D. Student*, Aalborg University, Department of Computer Science
1996–1997	*Ph.D. Student*, University of Maine (USA), Department of Spatial Information Science and Engineering

5.8.0 Janne Skyt

Academic Degrees

2001	*Ph.D. in Computer Science*, Aalborg University
1995	*Cand. Scient (M.Sc.) in Computer Science*, Aalborg University

Positions

2001–	*Assistant Professor*, Aalborg University, Department of Computer Science (2005–2006 Maternity Leave) (2002–2003 Maternity Leave) (2001–2002 On Leave for position as SONOFON Assistant Professor)
2001–2002	*SONOFON Assistant Professor*. Employed by Aalborg University, Department of Computer Science
2001	*Research Assistant*, Aalborg University, Department of Computer Science
1998–2001	*Ph.D. Stipend*, Aalborg University, Department of Computer Science
1998	*Research Assistant*, Aalborg University, Department of Computer Science
1995–1998	*Systems Developer*, TR-Partner A/S (now Trapeze Software Europe A/S), Århus, Denmark

Key publications

[34, 33, 139, 161]

5.8.0 Albrecht Schmidt

Academic Degrees

2002	*Ph.D. in Computer Science*, University of Amsterdam
1998	*M. Sc in Computer Science and Linguistics*, Würzburg University

Positions

2003–	*Assistant Professor*, Aalborg University, Department of Computer Science
1999–2002	*Researcher*, University of Amsterdam
1998	*Researcher*, Munich University of Technology

Key publications

[137, 98, 135, 181]

5.8.0 Laurynas Speičys

Academic Degrees

2002	*Cand.Scient. (M.Sc.) in Knowledge and Data Engineering*, Aalborg University

Positions

2005–	*Temporary Lecturer*, Aalborg University, Department of Computer Science
2002–2005	*Ph.D. student*, Aalborg University, Department of Computer Science

Key publications

[89, 88, 73]

5.8.0 Simonas Šaltenis

Academic Degrees

2001	*Ph.D. in Computer Science*, Aalborg University
1998	*Cand.Scient (M.Sc.) in Computer Science*, Aalborg University

Positions

2004–	*Associate Professor*, Aalborg University, Department of Computer Science
2001–2004	*Assistant Professor*, Aalborg University, Department of Computer Science
1998–2001	*Ph.D. student*, Aalborg University

Key publications

[80, 134, 28, 11]

5.8.0 Dalia Tiešytė

Academic Degrees

2005	*Cand. Scient (M.Sc.) in Data and Knowledge Engineering*, Aalborg University
2003	*B.Sc. in Computer Science*, Vilnius University, Lithuania

Positions

2005–	*Research Assistant*, Department of Computer Science, Aalborg University, Denmark

5.8.0 Bent Thomsen

Academic Degrees

1991	*Ph.D. in Computer Science from Imperial College of Science, Technology and Medicine*, London University, England
1991	*Diploma of Imperial College of Science, Technology and Medicine*, London University, England.
1987	*M.Sc. (Cand. Scient.) in Computer Science and Mathematics*, Aalborg University Centre, Denmark.
1985	*B.Sc. in Computer Science*, Aalborg University Centre, Denmark, June 1985.
1984	*B.Sc. in Mathematics*, Aalborg University Centre, Denmark, January 1984.

Positions

2002–	*Associate Professor*, Department of Computer Science, Aalborg University, Denmark
2000–2002	*Principal Researcher* at ICL, e-Innovation/EMEA HQ.
1996–2000	*Principal Researcher* at ICL, Group Technical Directorate and held the position as Principal Research Fellow at IC-Parc, Imperial College, London.
1994–1996	*Senior researcher and Team leader* at ECRC.
1990–1993	*Researcher* at ECRC.
1989–1990	*Research assistant* on the Foundational Models for Software Engineering project (SERC GR-F 72475) within the Department of Computing, Imperial College, London.
1987–1989	*Junior research fellow* at Institute of Mathematics, Aarhus University, Denmark.
1987–1989	*Danish state official* to do research at Imperial College, London.
1987–1987	*Full time teaching assistant* at Aalborg University Centre, Denmark.
1986–1987	*Part time teaching assistant* at Aalborg University Centre, Denmark.

Key publications

[172, 182]

5.8.0 Lone Leth Thomsen

Academic Degrees

1999	*Ph.D. in Computer Science from Imperial College of Science, Technology and Medicine*, London University, England.
1999	*Diploma of Imperial College of Science, Technology and Medicine*, London University, England.
1986	*M.Sc. (Cand. Polyt.) in Engineering*, specializing in Software Engineering and Computing Systems from Aalborg University Centre, Denmark.

Positions

2002–	*Associate Professor*, Department of Computer Science, Aalborg University, Denmark
2000–2002	*Principal Researcher* at ICL, e-Innovation/EMEA HQ.
1996–2000	*Principal Researcher* at ICL, Group Technical Directorate, Research Directorate and held the position as Principal Research Fellow at IC-Parc, Imperial College, London.
1995–1996	*Senior researcher* at ECRC.
1990–1995	*Researcher* at ECRC.
1987–1990	*Junior research fellow* at Institute of Electronic Systems, Aalborg University Centre, Denmark.
1987–1990	*Danish state official* to do research at Imperial College, London.
1986–1987	*Research/teaching assistant* in the Department of Mathematics and Computer Science, Aalborg University Centre, Denmark.
1985–1986	*Part time industrial programmer* at CR of 1984 A/S, Aalborg, Denmark.

Key publications

[172]

5.8.0 Kristian Torp

Academic Degrees

1998	*Ph.D. in Computer Science*, Aalborg University.
1994	*Cand. Polyt. (M.Sc.) in Computer Science*, Aalborg University.

Positions

2003–	*Associate Professor*, Aalborg University.
2003–2003	*Assistant Professor*, Aalborg University.
2000–2002	*Senior Consultant*, Logimatic Software A/S.
2001–2002	*Nouhauz Researcher*, Aalborg University (part-time).
2001–2002	*External Lecturer*, IT Højskolen, København (part-time).
1998–2000	*Research Assistant*, Aalborg University.
1995–1998	*Ph.D. student*, Aalborg University.

5.8.0 Nerius Tradišauskas

Academic Degrees

2005	*Cand.Scient (M.Sc.) in Computer Science*, Aalborg University
1999	*B.Sc. In Computer Science*, Vilnius University, Lithuania

Positions

2005–	*Research assistant*, Aalborg University, Department of Computer Science

5.8.0 Nectaria Tryfona

Academic Degrees

1995	*Ph.D. in Computer Engineering and Informatics*, University of Patras
1991	*Dipl.eng. in Computer Engineering and and Informatics*, University of Patras

Positions

2001–	*Engineer of Research and Development*, Research Academic Computer Technology Institute, Hellas, Greece
2000–2001	*Associate Professor*, Aalborg University, Department of Computer Science
1997–2000	*Assistant Professor*, Aalborg University, Department of Computer Science
1995–1997	*Post-doctoral Research Associate*, National Center of Geographic Information and Analysis, Department of Spatial Information Science and Engineering, University of Maine, USA
1991–1995	*Research Engineer*, Computer Technology Institute, Patras
1991–1995	*Ph.D. Scholarship*, Computer Technology Institute, Patras

5.8.0 Thomas Vestdam

Academic Degrees

2004	Ph.D. in Computer Science, Aalborg University
1999	M.Sc. in Computer Science, Aalborg University

Positions

2003–	*Assistant Professor*, Aalborg University, Department of Computer Science
1999–2002	*Ph.D. student*, Aalborg University, Department of Computer Science
1999–2000	*Teaching Assistant*, Aalborg University, Department of Computer Science

Key publications

[38, 37, 153, 148]

5.9 Ph.D. Projects

5.9.1 Project Descriptions

Complex and Distributed On-line Analytical Processing

Name: Michael O. Akinde

Education: Cand. polyt. (M.Sc.) in Computer Science, 1998

Duration: August 1998–February 2003

Status: Degree awarded April 2003

Funding: Grant from Nykredit Center of Database Research

Advisor: Prof. Michael H. Böhlen

This Ph.D. thesis presents a general algebraic operator for the expression and evaluation of complex aggregate queries and considers two relevant research questions within the field of complex OLAP (i.e., aggregation queries that require expressions more complex than simple summary-table views): the evaluation of subquery predicates in the presence of complex aggregation, and the distributed evaluation of complex OLAP queries.

The thesis formalizes the generalized multi-dimensional join (GMD-join), an algebraic operator for complex OLAP and presents a set of algebraic transformation rules demonstrating how the operator interacts with the other operators of a multi-set algebra. It also presents a general algorithm that allow subquery predicates to be expressed as GMD-joins expressions thereby enabling them to be evaluated efficiently.

Many of the new applications for complex OLAP involve huge amounts of highly distributed data. In order for such data to be queried we need to develop and maintain a distributed data warehouse. This thesis develops a framework and describes a prototype for the distributed processing of complex OLAP queries. A general strategy for the distributed evaluation of complex OLAP queries expressed using GMD-joins is presented, and optimization strategies that exploit distribution knowledge, if known, as well as strategies that do not assume such knowledge, are developed. A series of experiments are presented to evaluate the performance of these strategies and validate the distributed processing algorithm. Finally, the architecture and algorithms of Skalla, a prototype system for the distributed evaluation of complex OLAP queries implemented during the Ph.D. project is documented.

Location-Related Context in Mobile Services

Name: Agnė Brilingaitė

Education: Cand. scient. (M.Sc.) in Computer Science, 2003

Duration: August 2003–July 2006

Status: In progress

Funding: ContextIT

Advisor: Prof. Christian S. Jensen

The objective of this Ph.D. project is to develop techniques that establish foundations for the design of components of systems that provide context-aware, location-based mobile services.

We currently experience rapid advances in wireless communication technologies. There exists a variety of mobile devices with improving technical characteristics. The prices of mobile devices are reasonable for consumers, and a number of mobile users is growing. Thus, a demand for mobile services and new applications in wireless communication is also growing. While using mobile services, people are interested in obtaining relevant information with as little interaction with the device as possible. Context-aware services adapt to the user's preferences. They deliver the right information at the right time.

In this project, the user's location is considered to be the main context. The aim of the project is to create a foundation for the modeling, creation, maintenance, and use of location information in context-aware services. The possible location elements are defined and modeled. One of location context elements is a route. Mobile users frequently follow the same route to a destination as they did previously. Mobile services that know the user's route, rather than, e.g., just the user's current position, have the potential for being intelligent and more convenient to the user. For example, only traffic information relevant to the route can be sent to the user, or nearest cheap gas stations become nearest cheap gas stations along the route.

The provisioning of functionality that enables the creation of location elements is considered in the project. The possible scenarios are going to be analyzed: the creation can be automatic or semi-automatic, involving user interaction. The service also has to consider context-identification data in order to identify the context element that is relevant to a user in a particular situation. The service has to capture usage patterns that include usage time, day, location, etc. The main challenge is to identify the context using location elements, context identification data, and the current user situation (time and location.)

Moving Observer Support for Databases

Name: Linas Bukauskas

Education: Cand. scient. (M.Sc.) in Computer Science, 1999

Duration: September 1999 – August 2002

Status: Degree awarded April 2004

Funding: 3D Visual Data Mining (3DVDM)

Advisor: Prof. Michael H. Böhlen

Interactive visual data explorations impose rigid requirements on database and visualization systems. Systems that visualize huge amounts of data tend to request large amounts of memory resources and heavily use the CPU to process and visualize data. Current systems employ a loosely coupled architecture to exchange data between database and visualization. Thus, the interaction of the visualizer and the database is kept to the minimum, which most often leads to superfluous data being passed from database to visualizer.

This Ph.D. thesis presents a novel tight coupling of database and visualizer. The thesis discusses the VR-tree, an extension of the R-tree that enables *observer relative data extraction*. To support *incremental observer position relative data extraction* the thesis proposes the Volatile Access Structure (VAST). VAST is a main memory structure that caches nodes of the VR-tree. VAST together with the VR-tree enables the fast extraction of appearing and disappearing objects from the observer's view as he navigates through the data space. Usage of VAST structure significantly reduces the number of objects to be extracted from the VR-tree and VAST enables a fast interaction of database and visualization systems.

The thesis describes other techniques that extend the functionality of an observer aware database to support the extraction of the *N most visible objects*. This functionality is particularly useful if the number of newly visible objects is still too large. The thesis investigates how to optimize a given observer path. We propose *query load balancing* strategies that depend on a step-size and an incremental slice size. The proposed strategies balance a number of queries issued to the database and ensures that none of objects is overstepped along the path. All solutions have been implemented and evaluated empirically. A number of experiments validate the performance, scalability, and effectiveness of the optimizations.

Geodata Modeling

Name: Anders Friis-Christensen

Education: M.Sc. Computer Science and Geography, 2000

Duration: June 2000–June 2003

Status: Degree awarded October, 2003

Funding: Grant provided to the Danish national Survey and Cadastre

Advisor: Nectaria Tryfona and Christian S. Jensen

Geographic data are increasingly being used in various applications, ranging from location-based services to administrative, public services on the web. To satisfy increased demands for the sharing and exchange of geographic data, a National Spatial Data Infrastructure (NSDI) is needed that supports the utilization of geographic data.

The focus of this thesis is on conceptual modeling approaches and notations that satisfy the special requirements posed by geographic data. Thus, the thesis contributes to an infrastructure for geographic data. First, a requirements analysis is presented that identifies and clarifies several potential research issues. Among the issues investigated in the thesis are the management of geographic entities that are represented multiple times in the same or different databases and modeling of the quality of geographic data, which is of high importance to users.

In the thesis is presented a novel concept for modeling multiple represented entities and their consistent representations. A Multiple Representation Management System (MRMS), which maintains consistency among legacy databases, is outlined. A Multiple Representation Schema Language (MRSL), which is based on an extension to the Unified Modeling Language (UML) and on UML's accompanying Object Constraint Language, is described in detail. The MRSL is used to specify a Multiple Representation Schema (MRSchema) that configures the MRMS. A prototype provides a proof-of-concept.

Finally, the thesis espouses a systematic and integrated approach to the modeling of geographic data and its quality. The approach integrates quality information into the basic model constructs, resulting in what may be considered a quality-enabled model. More specifically, it extends UML with new modeling constructs–based on standard classes, attributes, and associations–that include quality information. This model enables designers and users to specify quality requirements in a geographic data model. In addition, a quality-enabled model supports a more application specific distribution of geographic data, e.g., one that uses web services. A case study illustrates the utility of the model.

Spatio-temporal Data Mining for Location-based Services

Name: Gyözö Gidófalvi

Education: Cand. scient. (M.Sc.) in Computer Science, 2002

Duration: August 2004–July 2007

Status: In progress

Funding: Ministry of Science Technology and Innovation, Grant No. 61480

Advisor: Assoc. Professor Torben Bach Pedersen

Recent advances in communication and information technology, such as the increasing accuracy of GPS technology and the miniaturization of wireless communication devices pave the road for Location-Based Services (LBS). To achieve high quality for such services, data mining techniques are suggested for the analysis of the huge amount of data collected from location-aware mobile devices. Since the two most important attributes of the data collected is time and location, the objective of this study is to develop spatio-temporal data mining techniques to extract interesting knowledge for LBS. More specifically, spatio-temporal association rule mining-, spatio-temporal sequential pattern mining-, spatio-temporal clustering- and spatio-temporal classification methods are considered. The company GEOMATIC—employer of the candidate—presently works with advanced data mining techniques on geo-statistical data, and foresees highly promising business opportunities in LBS.

Personalization in Enterprise Information Systems

Name: Anders Henriksen

Education: M.Sc. in Computer Science, 2004

Duration: February 2005 – March 2009

Status: In progress

Funding: Department of Technology, Agder University College

Advisor: Prof. Christian S. Jensen and Prof. Per Egil Petersen (Agder University College)

The objective of this project is to explain how personalization affects the acceptance and use of enterprise information systems.

Organizations implement several information systems supporting both their core business processes and supporting processes. It is important for the organizations that their employees adopt and use these systems. Resent technologies have made it possible to personalize these systems, making them more adaptable to the users' needs.

Research on personalization in the information systems domain has mainly focused on Internet websites. Most research concerns technology studies, but some adoption studies have also been conducted. In acceptance research, personalization has received little attention. Thus, it is important to determine whether users are using personalization features, why they are using them, and which specific features are important for adopting these features.

Users are increasingly familiar with personalized applications on the Internet, including portals, banking services, and online stores. By bringing the personalization features found in such applications into enterprise information systems, it is likely that users are more familiar with the features, which are then more likely to be adopted.

The project will address following research question: How will personalization of enterprise information systems in the workplace affect the acceptance of enterprise systems?

Query Processing in Relation to Moving Objects

Name: Xuegang Huang

Education: Cand. scient. (M.Sc.) in Computational Mathematics, 2003

Duration: August 2003 – July 2006

Status: In progress

Funding: Department of Computer Science Aalborg University

Advisor: Prof. Christian S. Jensen

This project focuses on the demands for new query processing techniques posed by emerging mobile location-based services (LBSs). Particular attention is given to data management techniques (covering querying and update) that relate to the changing positions of mobile users.

Depending on the assumed degree of freedom with which the mobile users can move, the project distinguishes among three scenarios for LBSs. The first occurs when the users are capable of moving unconstrained in the relevant physical space. The second occurs when the movement is partially constrained due to obstacles. For instance, the movement of a participant in an orienteering race is constrained by a lake. The third scenario occurs when the movement is restricted to a spatial network-type structure, the prototypical example being users in cars moving in a road network. The project focuses on the latter two scenarios and considers topics such as data modeling, query processing algorithms, and optimization techniques.

At this time, the following steps have been completed in the project. First, a conceptual framework for defining queries in LBSs hs been provided. Second, motivated by the observation that few mobile users move about aimlessly, but rather travel towards a known destination along a known route, the project has provided query processing techniques for mobile users moving along known routes. Third, the project has provided a technique that enables flexible management of the trade-off between update and query costs for spatial query processing in road networks.

Currently, the project is considering several topics, including techniques for processing bulks of queries in the context of road networks, the management of in-route moving objects, and the query processing for mobile users under partially constrained movement.

The contribution of the project will be of help in future applications of mobile location-based services.

Multi-Dimensional Conditional Schema Evolution in Relational Databases

Name: Ole Guttorm Jensen

Education: Cand. polyt. (M.Sc.) in Computer Science, 1998

Duration: August 1998–February 2003

Status: Degree awarded in September 2004

Funding: Department of Computer Science, Aalborg University

Advisor: Prof. Michael H. Böhlen

Change is a fundamental but sometimes neglected aspect of database systems. In particular, changes in the real world often result in modifications to the database structure by evolving the schema. As database systems and other information systems become progressively more interdependent, changes to the database schema is no longer a problem local to the database but can necessitate changes in all systems interacting with the database. The management of change and the ability of the database system to deal with change is an essential component in developing and maintaining truly useful systems. This Ph.D. thesis develops a formal foundation for conditional schema evolution in relational databases. Conditional schema changes change the schema of the tuples in a relation that satisfy the change condition. This class of schema changes is more general than traditional (unconditional) schema changes and temporal schema changes investigated by existing work. We develop the multi-dimensional conditionally evolving schema as a conceptual model for conditionally evolving schemas. The multi-dimensional conditionally evolving schema is the basis for practical data structures and algorithms developed in the thesis.

Changing the schema of a populated database leads to mismatches between the intended schema of a tuple and the schema used to record the tuple in the first place. The traditional approach of resolving the mismatch by migrating the (non-fitting) tuples to the new schema is lossy. The thesis proposes to keep track of the mismatches at the level of individual tuples, and develops the mismatch extended completed schema to this purpose. A salient feature of this model is that schema changes can be dealt with as standard tuple updates.

The thesis proposes a parametric approach to resolve the mismatches between the intended and recorded schemas of tuples at query time. This allows mismatches to be resolved according to the needs of the application through the specification of a policy. Algorithms for mismatch resolution of relations based on the mismatch extended completed schema are developed in the thesis. As the schema evolves the database system is required to handle legacy tuples. Such tuples are already stored in the database if tuples are not migrated to fit the new schema, and also come from

legacy applications, which continue to issue queries and assertions after a schema change has been committed. The thesis develop efficient algorithms for the classification of tuples. These algorithms along with the default policies for mismatch resolution allows for transparent schema evolution, so users and applications need not be aware that the database is evolving.

In temporal schema versioning schema changes are related to different time dimensions. The thesis specializes conditional schema evolution to conditions over time recording attributes. This leads to optimizations in the space complexity of the multi-dimensional conditionally evolving schema, and facilitates a comparison between conditional schema evolution and temporal schema versioning. For transaction-time the two approaches are equivalent. In valid-time schema versioning, a schema change is applied to a single schema version specified by the user irrespective of the validity of the change and the version. In conditional schema evolution a schema change changes the schema of all segments with a validity that overlaps the validity of the change.

Automated Testing using Design by Contract and Equivalence Partitioning

Name: Per Madsen

Education: Cand. polyt (M.Sc.) in Computer Engineering

Duration: August 2001–2004

Status: In progress

Funding: Department of Computer Science Aalborg University

Advisor: Assoc. Professor Kurt Nørmark(2/3) and Professor Kim Guldstrand Larsen(1/3)

In modern software development a huge amount of time is spent on testing of the software. Still a lot of software is released containing a large number of bugs, which causes a lot of problems for the end-users of the software. Even though the activity of testing is as old as the activity of programming itself, it seems that the testing effort is not yet efficient enough.

This Ph.D. project takes two well-known ideas as a starting point: unit testing as done in Extreme Programming (Kent Beck) and in Design by Contract as done in the programming language Eiffel (Bertrand Meyer).

The basic idea of this project is to combine the use of JUnit and Design by Contract. JUnit provides us with a framework for automatic execution and to some degree automatic evaluation of test cases. If we combine JUnit with Design by Contract we can reuse the assertions written as pre- and postcondition and class-invariants in the test cases. This gives us a testing approach with automatic execution and evaluation of test cases.

If we can come up with an automatic way to generate and setup test cases, use JUnit to execute the test case, and use Design by Contract to evaluate the test, then

we are heading towards a fully automated testing approach. We will refer to this approach as Testing by Contract.

The main research topic for this project is to investigate how we can generate and setup appropriate test cases for Testing by Contract. One approach that seems attractive is to integrate the ideas of Equivalence Partitions and Design by Contract. This is done by describing Equivalence Partitions for each class in a program. (a set of boolean expressions defining a partitioning schema)

A prototype Java-like language with support for Design by Contract enhanced with Equivalence Partitions has been developed. A compiler to regular Java-code as well as a tool for automatic generation of test cases is currently being build. This prototype language/tool will be used to further examine the ideas described above.

The Density Surfaces Method

Name: Artūras Mažeika

Education: Cand. scient. (M.Sc.) in Mathematics, 1999

Duration: April 2001–March 2004

Status: Degree awarded November 12, 2004

Funding: 3DVDM

Advisor: Peer Mylov and Prof. Michael H. Böhlen

VDM methods have to process a large dataset, compute a model of the data, and present the model in some visual form to the analyst. A key property of visual data mining (VDM) is that the analyst takes an active role in the knowledge discovery process. The analyst generates a hypothesis about the data by interactively changing parameters of the model and the visualization. Such a setting puts forward high requirements. The method should permit interactive, analyst controlled data explorations; a methodology should be provided of how to explore the huge search space; a model of the data should visualized to abstract from individual observations and support the interpretation of the data.

This thesis introduces the density surface method: a new and interactive VDM tool to mine data visually. The technique calculates the probability density model of the data and visualizes the model as density surfaces. The APDF tree is developed to interactively compute the probability density model. The estimator defines and uses the shape error, which controls the quality and runtime of the estimation.

The extensive analysis of density surfaces on artificial and click stream data suggested four VDM techniques: animation, conditional analysis, equalization, and windowing. The techniques support the interpretation of data with noise, not equally pronounced relationships, and allow to investigate the data at different granularities.

Density surfaces are implemented as a module of the 3DVDM system. The 3DVDM system allows to analyze data in both virtual reality environments and on regular computer monitors. The 3DVDM system consists of separate modules

that interact with each other via streams and have thin event handlers. The density surface module can visualize density surfaces as triangle, line, and point surfaces.

The last chapter of the thesis focuses on the string domain. The investigation of the density in the string space is complicated due to the high dimensionality of strings and the lack of natural mapping of the metric string space into a vector space. Therefore, we use different techniques to investigate the selectivity. The proposed selectivity technique uses q-grams and inverse strings to estimate the approximate string selectivity queries. The estimator outperforms other selectivity estimators for large databases of short strings (names, addresses).

Advanced Query Processing for Sound Feature Streams

Name: Maria Magdalena Ruxanda

Education: Cand. scient. (M.Sc.) in Computer Science, 2002

Duration: September 2005–August 2008

Status: In progress

Funding: Supported by the Danish Technical Research Council (STVF)

Advisor: Prof. Christian S. Jensen

Following the data as streams paradigm, this project concerns the provisioning of efficient support for specific operation on streaming sound-feature data. More specifically, when processing a query, the first step is to represent the query as a query tree. The leaves of the tree represent data sources, i.e., streams or static databases, and the root and internal nodes represent algebraic operations on the results returned by the child nodes. The query result is thus obtained by carrying out all operations in bottom-up fashion. The performance of query processing is dependent on the system's ability to quickly determine a suitable query-tree representation of a query and by the availability of efficient algorithms for carrying out the individual operations.

This project concerns the design, prototyping, and experimental evaluation of such algorithms for sound-related data and queries.

- Assuming that sound data are represented as some multi-dimensional feature "Streams" vectors, algorithms and indexing techniques will be developed for advanced queries, including variations of range and k-nearest-neighbor queries, and other combinations of queries.

- Indexing is essential when querying large volumes of data because it offers performance that is logarithmic in the size of the data, as opposed to otherwise linear performance. The present project will use some results and insights obtained in during past work, namely:

  – a query processing framework suitable for the processing of queries against ordered, time-varying data where an underlying, proprietary

database system collaborates with a middleware layer to efficiently process queries.

  - a range of indexing techniques, mainly within the R-tree and B-tree family of techniques. These techniques concern one or two temporal dimensions, termed valid and transaction time, and one to six spatial dimensions (six spatial dimensions occur when indexing 3D points given as linear functions of time, as a linear function has three velocity coordinates and three initial-position coordinates).

- The methodology used in the project involves prototyping of designs.
- Empirical performance experiments will be conducted using real sound data.

Integrated Location-Enabled Mobile Services

Name: Stardas Pakalnis

Education: Cand. scient. (M.Sc.) in Computer Science,2003

Duration: August 2004– December 2006

Status: In progress

Funding: Center for Intelligent Transportation Systems (CITS)

Advisor: Prof. Christian S. Jensen

We are witnessing continued improvements in wireless communication and geo-positioning, as well as in the performance/price ratio for consumer electronics. These developments pave the way to a kind of mobile services, namely services that are parts of portfolios of integrated services and that behave differently according to aspects of the individual user's context.

Focus will be on the location aspect of context and on services rely on the tracking of the continuously changing position of each mobile services user among a population of such users. This scenario is characterized by large volumes of updates, for which reason location update technologies become important.

The arguably most promising existing proposal for efficient tracking is the so-called segment-based location representation and update policy. The Ph.D. project will enhance this proposal as well as integrate it with other, simpler proposals, the objective being to obtain a single robust proposal.

An update of the database is made whenever the deviation between the actual location of a moving object and the location as predicted by the database exceeds a given threshold. The segment-based approach uses knowledge of the road network in which the user is moving to represent, and predict, the future positions of the moving object. When the road network is not available, the approach predicts an object's movement in linear manner.

The Ph.D. project will improve on this scenario by modifying the road network that is used for prediction, by using entire routes through the network for prediction, and by using acceleration profiles for the roads in the network. In addition,

the project will propose tracking techniques where thresholds vary across space and where the satisfaction of predicates, e.g., involving metric and topological relationships among objects are being tracked.

All proposed techniques will be implemented, and they will be subjected to empirical studies using real GPS-data and road networks.

Specification-Based Techniques for The Reduction of Temporal and Multidimensional Data

Name: Janne Skyt

Education: Cand. scient. (M.Sc.) in Computer Science, 1995

Duration: June 1998–May 2001

Status: Degree awarded September 2001

Funding: The Faculty of Engineering and Science, Aalborg University

Advisor: Prof. Christian S. Jensen

A wide range of real world database applications, including financial and medical applications, are faced with severe growth problems, problems that are relevant for a wide range of database systems. A main challenge of improving the current way of handling these problems is to create a frame of reference and a reduction strategy that can be applied to the different database contexts and different understandings of *aging* data. The goal of this thesis is to create such frame of reference and strategy to allow reduction of databases by structured and disciplined specifications in different contexts. (*Aging* data is data that is no longer considered useful, i.e., data that is old according to time, content, characteristics or interpretation.)

Many real-world database applications face accountability and trace-ability requirements that lead to the replacement of the usual update-in-place policy by an append-only policy, yielding so-called transaction-time databases. With logical deletions being implemented as insertions at the physical level, these databases retain all previously current states and are ever-growing. Thus meeting the requirements pose severe growth problems. Also in the data warehouse context the append-only databases are prominent: By Inmon's definition, a data warehouse is characterized by all its data exhibiting temporal dimensions. Data is typically time stamped and (bulk) loaded at regular intervals, and is retained in the warehouse for a number of years. Thus the growth problem is highly similar in this context, however the understanding of *aging* data and the requirements, when reducing the data, shows to be different due to the usual focus on business analysis in data warehousing.

To suppress the growth problems many techniques have been proposed, but the support for physical data reduction has received precious little attention despite that it is called for by, e.g., the laws of many countries. A variety of physical storage structures and indexing techniques as well as query languages are proposed

for transaction-time databases, and many precomputation and materialization techniques are proposed for data warehousing, but even if a few cleaning daemons have been proposed non of them have the goal to satisfy legal requirements of data reduction, or the goal to refer to the aging of data.

This thesis suggests a way to specify data reduction in transaction-time databases and data warehousing. It uses the nature and the structure of data in these database systems to apply the same reduction strategy, accepting the different limitations of the systems and achieving the different goals of accountability and traceability as well as maintenance of the business knowledge. The following challenges are addressed in general.

- Definition of the concepts and operators to serve as a solid foundation for data reduction in append-only databases
- Satisfaction of consistency requirements
- Specification of techniques to maintain statistics and aggregate data in the reduced database, since this may remain valuable despite the lack of value for the detail data
- Implementation strategies for the data reduction system in the context of different database systems
- Maintainability of the data reduction specification system
- Handling of queries “faithfully” in the context of a reduced database

The structure of the thesis is as follows. First, the challenges of database reduction in different database contexts are stated. Then, in two larger parts, concepts as well as reduction and aggregation strategies are presented for transaction-time databases and data warehousing, respectively. For transaction-time databases two techniques are presented: *vacuuming* is a technique that offers specification of physical deletion; and *persistent views* are views that are immune to physical deletion and thus they allows retention of specified data while using physical deletion. For data warehouses an approach called *aggregation-based data reduction* is presented and its application is illustrated. Aggregation-based data reduction is a technique that offers gradual aggregation of facts to higher-level granularities in the hierarchical dimensions. Its use is illustrated for a clickstream-analysis case study done in collaboration with Nykredit Data; a case study on analyzing series of clicks on the Nykredit web-site.

A Middleware Approach to Temporal Query Processing

Name: Giedrius Slivinskas

Education: Cand. scient. (M.Sc.) in Computer Science, 1998

Duration: August 1998–July 2001

Status: Degree awarded September, 2001

Funding: Nykredit Center for Database Research

Advisor: Prof. Christian S. Jensen

Most real-world database applications manage time-referenced data. For example, this aspect applies to financial, medical, and travel applications; and being time-variant is one of Inmon's defining properties of a data warehouse. Recent advances in temporal query languages show that such applications may benefit substantially from a DBMS with built-in temporal support. The potential benefits are several: application code is simplified and more easily maintainable, thereby increasing programmer productivity, and more data processing can be left to the DBMS, potentially leading to better performance.

In contrast, the built-in temporal support offered by current database products is limited to predefined, time-related data types, e.g., the Informix TimeSeries DataBlade and the Oracle8 TimeSeries cartridge, and extensibility facilities that enable the user to define new, e.g., temporal, data types. However, temporal support is needed that goes beyond data types and extends the query language itself.

Developing a DBMS with built-in temporal support from scratch is a daunting task that may only be accomplished by major DBMS vendors that already have a DBMS to modify and have large resources available. This has led to the consideration of a layered approach where a layer, implementing temporal support, is interposed between the applications and a conventional DBMS. The layer maps temporal SQL statements to regular SQL statements and passes them to the DBMS, which is not altered. With this approach, it is feasible to support a temporal SQL that strictly extends SQL, thus not affecting legacy applications. However, this approach presents difficulties of its own: for example, some temporal operations, such as temporal aggregation or coalescing, are quite inefficient when evaluated using SQL, but can be evaluated efficiently with application code that uses a cursor to access the underlying data.

This Ph.D. project develops a temporal query representation, optimization, and processing framework needed for introducing temporal support both via a stand-alone temporal DBMS and via a layer on top of a conventional DBMS. The layered approach is generalized by moving some of the query evaluation into the layer, which performs temporal operations itself when it can achieve better results than when passing the job to the underlying DBMS. This approach is termed "temporal middleware."

During the first one and a half years of the project, the foundation for temporal query optimization was developed, including an algebra for temporal query representation, a comprehensive set of transformation rules, and a query plan enumeration algorithm. The algebra enhances existing relational algebras based on multisets by integrating the handling of order and adding temporal support, and the transformation rules are divided into different types according to how they deal with duplicates, order, and time periods. By capturing duplicate removal and reten-

tion as well as order preservation for all queries, as well as coalescing for temporal queries, the foundation formalizes and generalizes existing approaches.

To validate the proposed foundation, a temporal middleware architecture was designed and implemented during the following year. To optimize and process queries, the middleware employs the Volcano extensible query optimizer and the XXL library of query processing algorithms, as well as Oracle as the underlying DBMS. Volcano was significantly extended to include new operators, algorithms, transformation rules, as well as to have support for different types of transformation rules; and the XXL library was augmented by new temporal algorithms. Performance experiments have been conducted, showing that performing some of the query processing in the middleware in some cases improves query performance up to an order of magnitude over performing it all in the DBMS.

Data Representation, Querying, and Indexing for Location Based Services

Name: Laurynas Speičys

Education: Cand. scient. (M.Sc.) in Knowledge and Data Engineering, 2002

Duration: August 2002–January 2006 (expected)

Status: In progress

Funding: The Danish National Center for IT Research

Advisor: Prof. Christian S. Jensen

Various technological advances converge to fuel the proliferation of a new breed of personal services offered through powerful, portable, wirelessly connected, and context aware personal terminals. The services utilize context information to deliver the desired functionality. One of the most important indicator of a user's context is the user's location, which is exploited by location based services (LBSs).

The project aims at solving problems related to data management and to query processing in the context of LBSs offered for road network constrained users. The project presents two road network models. The first model is a short-term solution based on relationally represented data and deployable using state of the art technology. It provides a basis for integrating various road network representations using an additional representation, that is purely internal to the system. The second model is a longer-term solution, presented in a more abstract, mathematical form, aimed at satisfying the essential needs of road network-constrained LBSs. It includes, among other components, a directed graph representation designed to facilitate fast searches in road networks while retaining complex features of real-life road networks. Both solutions include data models. The second solution also shows how to transform spatial network data that is commonly encountered in its geographical Euclidean representation to the more abstract graph representation. Thus it shows how existing repositories of Euclidean network data can be made to use techniques of graph theory.

Additionally, the project presents a general indexing technique of expiration times, which is expected to facilitate querying of rapidly evolving data. This technique such as the changing locations of moving objects. The technique is developed in the context of the B+-tree but is expected to be extendable to other indices.

Indexing Techniques for Continuously Evolving Phenomena

Name: Simonas Šaltenis

Education: Cand. scient. (M.Sc.) in Computer Science, 1998

Duration: August 1998–July 2001

Status: Degree awarded September 2001

Funding: Nykredit Center for Database Research

Advisor: Prof. Christian S. Jensen

With information technology becoming increasingly pervasive, database management systems are required to be able to record and process data related to *continuously evolving* real-world phenomena. Such data changes continuously as a function of time, even in-between the explicit updates of the database. This is in contrast to conventional databases, where data is assumed to be constant unless it is explicitly modified.

This thesis explores the indexing of spatial and spatiotemporal data related to continuously evolving phenomena. The largest part of the thesis is concerned with the indexing of the current positions of continuously moving spatial objects, such as people carrying wireless personal information appliances. An object's near-future movement is modeled as a linear function of time, which offers the ability to extrapolate the object's position into the future. The proposed TPR-tree (Time-Parameterized R-tree) is a novel R*-tree based indexing technique that supports this kind of data by employing so-called time-parameterized bounding rectangles and an insertion algorithm with adapted heuristics. A novel index bulk loading algorithm is provided. Processing of different kind of queries using the TPR-tree is explored, including moving range queries, nearest neighbor, and reverse nearest neighbor queries.

In so-called location-based service scenarios, moving objects that have not reported their positions to a service within a specified duration of time are expected to no longer be interested in, or of interest to, the service. The existence of such "expiring" objects introduces a new kind of implicit updates, which contribute to rendering the database highly dynamic. Building on the ideas of the TPR-tree, the thesis proposes an indexing technique for the current positions of such objects. Among other novel features, the new index employs a lazy technique for purging "expired" entries from the index without scheduling deletions corresponding to expiration events.

The smaller part of the thesis explores the indexing of data where the temporal aspects involve continuous change. A versatile spatiotemporal indexing technique,

termed the R^{ST}-tree, is proposed that indexes discretely changing spatial extents—points or rectangles. The R^{ST}-tree differs from all previously proposed spatiotemporal indices in that it provides support for both transaction time and valid time, termed bitemporal support, and it accommodates general, *now*-relative time intervals.

The thesis reports extensive performance experiments with the implementations of all the indexing techniques and query processing algorithms described in the thesis.

Open Source Business Intelligence Technology for Accessibility Data

Name: Christian Thomsen

Education: Cand. scient. (M.Sc.) in Computer Science and Mathematics, 2004

Duration: August 2004–July 2007

Status: In progress

Funding: EIAO project through grant from EUC no. 004526

Advisor: Assoc. Professor Torben Bach Pedersen

The project is about specifying and developing data warehouse technology for the European Internet Accessibility Observatory (EIAO) project (http://www.-eiao-.net).

The overall objective of the EIAO project is to contribute to better e-accessibility for all citizens and to increase the use of standards for online resources. The EIAO project will develop an Internet robot/crawler called ROBACC. The collected accessibility data should be stored in a data warehouse which provides flexible, reliable, and convenient online access and demonstrates the results in a clear and meaningful way to the users. The data warehouse should be capable of managing a huge amount of web accessibility informations collected by the crawler as the EIAO project evolves.

The purpose of the Ph.D. project is to develop a data warehouse (named ROBACC DW) and business intelligence technology for the EIAO project. This data warehouse should be based on open source technology, particularly the PostgreSQL DBMS. This will require additional work compared to if proprietary solutions were used. On the other hand, it is believed that the developed solution could be applied to other fields than the EIAO project afterwards.

The novel contributions of the project include that PostgreSQL is extended with facilities for data warehousing for the open source community. Also, the application of warehouses and business intelligence to accessibility data is new and will impose many interesting challenges.

Capturing and Querying Complex Location-Based Data

Name: Igor Timko

Education: Cand. scient. (M.Sc.) in Knowledge and Data Engineering, 2002

Duration: August 2002–July 2005

Status: Degree awarded October 3, 2005

Funding: Department of Computer Science, Aalborg University

Advisor: Assoc. Professor Torben Bach Pedersen

Use of location-based services (LBS), e.g., traffic or tourist related services, is increasing. In a typical scenario for LBS moving objects (e.g., people in a city road network with GPS-enabled hand-held devices) send information related to their position (i.e., location, speed, velocity, etc.) to the LBS. The services use this and other information to provide specific functionality.

This project first studies requirements to LBS data modeling and query processing. Specifically, the project considers an example LBS based on active ordered k-nearest neighbor (NN) queries and provides a general framework for NN querying on moving objects in road networks. Next, the project considers the data and queries used in an existing Danish LBS provider's service delivery system. The project concludes that 1) the most important LBS data types were transportation infrastructures (TI) and content (e.g., users' cars, gas stations, speed limits, etc.) positioned within the TI and 2) the LBS queries include spatio-temporal operational (e.g., NN) and analytical (e.g., aggregation) queries.

The project focuses on the analytical queries, which are used in order to optimize and personalize the services. Specifically, the central analysis element is content (e.g., users' cars). A content position, or attachment, is also related to a content description (e.g., to users' characteristics), and to the time when the attachment was observed or recorded. Thus, the LBS data is inherently multidimensional (e.g., content attachments are related to location, user, and time dimensions) and the aggregation-based analysis of this data may be potentially enabled by on-line analytical processing (OLAP) and data warehousing (DW) technology. However, existing technology does not handle well complexities of the LBS data (i.e., partial containment relationships between elements of the TI representations and uncertain content attachments) and the LBS queries (i.e., probabilistic queries that also refer to partial containment).

The project extends the current OLAP and DW technology to support the LBS data and queries. First, the project develops a multidimensional data model that can capture partial containment in dimension hierarchies. The associated algebraic query language allows expressing queries for partial containment dimension hierarchies. Moreover, the project develops a method for enabling pre-aggregation over partial containment dimension hierarchies. Second, the model is further extended to explicitly capture transportation infrastructure representations and content attachments. Third, the project develops a probabilistic version of the mentioned models that can capture uncertain content attachments. The associated algebraic query language allows expressing probabilistic and time-dependent LBS queries.

Fourth, the project generalizes the notion of OLAP measures to probability distributions and presents methods for efficient (pre-)aggregation of the distributions. The project also develops techniques for efficient processing of probabilistic OLAP queries that operate on the probability distributions. Although the project focuses on the LBS domain, all the developed techniques are general enough (or can be easily generalized) to be applied to other similar domains.

Elucidative Programming—Tools, Patterns, and Experiments

Name: Thomas Vestdam

Education: Cand. scient. (M.Sc.) in Computer Science, 1999

Duration: August 2000–January 2004

Status: Degree awarded January 2004

Funding: The Faculty of Engineering and Science, Aalborg University

Advisor: Assoc. Professor Kurt Nørmark

The Ph.D. study was an investigation of the possibilities of Elucidative Programming in order to broaden the applicability of the paradigm. Elucidative Programming is an alternative to Literate Programming. As opposed to Literate Programming, program fragments and explaining text are not interleaved in Elucidative Programming. Instead program and documentation are separated but mutually linked together. The linking mechanism allows explanations to directly address specific parts of a program. Elucidative Programs are presented in an ordinary web-browser where documentation and program are presented side-by-side, and navigation is provided from documentation to source code and from source code to documentation. The thesis deals with the issue, that no matter how well the tool support that we provide is, the programmer is still left with the fundamental problem of figuring out how to write internal documentation. A small pattern language was created in order to capture, maintain, and communicate good practice when writing internal documentation.

The thesis also presents a technique, based on Elucidative Programming techniques, for creating, managing and presenting program tutorials. Program tutorials are instructional documentation that guides a reader through a program in order to give instructions on how to build the given program. Program tutorials are often used to document how to use a framework or a library, or to explain a given concept in an educational context. Program tutorials explain a program piece by piece by interleaving explaining text and program code.

Finally, the thesis deals with how to, as an integrated part of the programming environment, support programmers when they are documenting their programs. The integrated Elucidative Programming support remind programmers of the internal documentation, and provide convenient features that assist programmers in maintaining existing documentation, as well as assist programmers when writing

documentation. The thesis is based on three conference papers and two journal papers.

Data Streams and On-line Data Integration

Name: Xuepeng Yin

Education: Cand. scient. (M.Sc.) in Computer Science and Engineering, 2003

Duration: August 2003–June 2006

Status: In progress

Funding: Danish Technical Research Council under grant no. 26-02-0277

Advisor: Assoc. Professor Torben Bach Pedersen

Business Intelligence (BI) is the process of gaining useful information from data. However, the BI tools today are designed for static data. Pervasive computing refers to the strongly emerging trend towards numerous computing devices embedded in the environment and connected to a ubiquitous network. The data produced continuously by these devices are termed data streams, which have very different characteristics from those of traditional static data. To enable business analysis on these data, new BI systems that are adapted for data streams are strongly desired, due to the limitations of traditional BI systems in coping with pervasive computing. On-line data integration is another issue that is related to stream computing as the data emitted by the small devices is increasingly available on the web. The goal is to develop techniques for BI analyses on on-line integrated databases and data streams. Work has to be done on special data models, query languages, query processing techniques, optimization techniques for on-line data integration, and BI querying on data streams and the combination of the two systems. The final deliverable of this project are a number of techniques and a prototype for on-line integration of data streams. That is, BI queries can be performed on the integration of data streams and data from web services.

5.10 Collaboration

For additional collaborations beyond what is reported below, see the participants listed for the funded projects covered in Section 5.7.1.

5.10.1 Collaborations with Academia

- **Curtis E. Dyreson, Washington State University**. Collaboration on managing complex multidimensional data, e.g., for location-based services, and the querying of semi-structured data. Results include several papers, substantial software systems, and a patent.

- **Lars Kai Hansen and Jan Larsen, Technical University of Denmark**. Collaboration within the project Intelligent Sound. Results have so far been a prototype system and an organized workshop.

- **Kaj Grønbæk and Nils-Olof Bouvin, Århus University**. Collaboration within the project ContextIT. Results include a prototype system and a paper.

- **Algimantas Juozapavičius and Mindaugas Pelanis, Vilnius University**. Collaboration within the WIM project on the indexing of moving objects. The collaboration has resulted in substantial software and a paper accepted for publication in ACM TODS. Christian S. Jensen is on the advisory committe for Mindaugas Pelanis' Ph.D. study.

- **Alminas Čivilis, Vilnius University**. Collaboration within the TRAX and WIM projects. Several papers have resulted.

- **Michael H. Böhlen and Johann Gamper, Free University of Bolzano/Bozen**. Collaboration on TimeCenter-related research and research in temporal databases. Several papers have resulted.

- **Dieter Pfoser and Nectaria Tryfona, Computer Technology Institute, Greece**. Collaboration within the DBGlobe project. Several papers have resulted.

- **Juan Manuel Pérez, Universitat Jaume I, Spain**, visited Torben Bach Pedersen in the period October–December 2004 to work on integration of OLAP and information retrieval techniques.

- **Mikael Snaprud and Nils Ultveit-Moe, Jan P. Nytun, Mike E. Rafoshei-Klev, Agatha Sawicka, and Øyvin Hanssen, Agder University College, Norway**. Participation in the European Internet Accessibility Observatory project, so far resulting in a prototype system and several papers.

  Jan P. Nytun and Vladimir A. Oleshchuk, Agder University College, Norway. Collaboration on UML-based modeling. Several papers have resulted.

  Christian S. Jensen is an adjunct professor at Agder University College.

- **Rosanne Price, Monash University, Australia**. Collaboration on conceptual modeling for spatio-temporal data. Rosanne Price visited Aalborg University for an extended period of time.

- **Dengfeng Gao and Richard T. Snodgrass, University of Arizona**. Collaboration within TimeCenter on, e.g., temporal joins, temporal query optimization, temporal-database modification semantics, and calendar support. Collaboration also within the LBS project on the modeling of transportation infrastructures. Several papers have resulted. Laurynas Speičys has visited University of Arizona as part of his Ph.D. studies.

- **Leo Mark and Edward R. Omiecinski, Georgia Institute of Technology**. Linas Bukauskas and Michael H. Böhlen collaborated with these researchers to investigate indexing of most visible objects and incremental top N most visible object extraction. The collaboration resulted with a conference paper. Leo Mark collaboration within TimeCenter on the vacuuming of temporal databases has resulted with a journal paper. Leo Mark also served as a Ph.D. committee member for Linas Bukauskas Ph.D. defense.

- **Bin Cui, Wynne Hsu, Zhiyong Huang, Mong Li Lee, Dan Lin, Hua Lu, Beng Chin Ooi, Keng Lik Teo, and Rui Zhang, National University of Singapore**. Three Ph.D. students have visited Aalborg University for approximately three months each. Christian S. Jensen was a visiting professorial fellow at National University of Singapore, for a month during June and July 2002. The collaboration concerns query processing technology for moving objects, including indexing techniques and efficient algorithms for density queries, clustering, and skyline queries. Several papers and software prototypes have resulted.

- **Ki-Joune Li, Pusan National University**. Collaboration within two projects, resulting in several publications.

- **Lars Frank, Copenhagen Business School**. Collaboration on data warehousing. One paper has resulted.

- **Prof.Dr.rer.nat. Christian Wagenknecht Hochschule Zittau/Görlitz (FH)** on Scheme-based Internet programming collaborated with Kurt Nørmark.

5.10.2 Collaborations with State Agencies

- **The Danish National Survey and Cadastre (KMS)**—collaboration on advanced location-based services within the LBS project. Advising of one Ph.D. student employed by KMS who has graduated during the evaluation period. The results include knowledge transfer and several papers.

- **The Danish Road Directorate**—collaboration on the modeling of transportation infrastructure for location-based services within the LBS project. Several papers and knowledge transfer have resulted.

- **Arie Shoshani and Junmin Gu, Lawrence Berkeley National Laboratory, CA, USA**. Collaboration on federations of OLAP and object databases, resulting in a prototype system and several papers.

5.10.3 Industry Collaboration

- **David Lomet, Microsoft Research, Redmond**—collaboration on transaction support in temporal database systems. Several papers have resulted.

- **Michael D. Soo, Amazon, Seattle**—collaboration on temporal-join processing. A journal paper has resulted.

- **Sonofon**—collaboration on advanced location-based services, within the LBS project, and on data warehousing, resulting in several papers.

- **AT&T Labs Research**—collaboration on data stream technology, 2005–present, planned to result in a prototype system and one or more papers.

- **Euman**—collaboration on advanced location-based and context-based services, within the LBS and ContextIT projects, resulting in several prototype systems, significant technology transfer, and a number of papers.

- **Geomatic**, collaboration on spatio-temporal data mining and location-based services, 2004–present, resulting in a prototype system and several papers.

- **Mindpass**—collaboration on advanced database and data warehouse technology for web systems, resulting in significant technology transfer.

- **Kort og Matrikelstyrelsen (The Danish Survey and Cadastre)**—collaboration on advanced location-based services, within the LBS project, 2002-present, resulting in technology transfer and several papers.

- **Nykredit**—collaboration on database and data warehouse technology for financial services and advanced location-based services, within the Nykredit Center for Database Research and the LBS project, resulting in technology transfer and a number of papers.

- **TARGIT**—collaboration on integration of web-based XML data and data streams in business intelligence systems, partly within the BIPC project, 2001–present, resulting in several prototype systems and a large number of papers.

- **TDC Innovation Lab**—collaboration on advanced context-based services, within the ContextIT project, 2003, resulting in several prototype systems and technology transfer.

- **BIT - the Nouhauz network in Business Intelligence Technology**—Current network members: BusinessMinds, Department of Business Studies at AAU, Department of Production at AAU, KMD, Nykredit, Platon, Sonofon, Vestas. The network has held 5–6 meetings per year since 2002 and has resulted in significant knowledge transfer to local and national industry and to other departments at AAU.

5.10.4 Visits at Other Institutions

- Linas Bukauskas visited Institute of Technology, Georgia, USA. investigate indexing of most visible objects and incremental top N most visible object extraction (June 2002–December 2002).

- Anders Friis-Christensen visited Distributed Information Systems Group at SINTEF Telecom and Informatics, Oslo, Norway (October 2001–January 2002).

- Xuegang Huang visited Northeastern University, Boston, USA to work on spatial and spatio-temporal query processing (November 2005–January 2006).

- Per Madsen visited Bertrand Meyer, Chair of Software Engineering at ETH Zurich, Switzerland (October 2003–February 2004).

- Artūras Mažeika visited AT&T Labs, New Jersay, USA (January–July 2003).

- Laurynas Speičys visited The University of Arizona, Tucson Arizona, USA to work on modeling of complex transportation data (September 2004–January 2005).

- Igor Timko visited Washington State University, Washington, USA to work on modeling and query processing for complex location-based data (February–December 2004).

- Xuepeng Yin visited AT&T Labs, New Jersey, USA to work on implementation techniques for data streams (August 2005–January 2006).

- Thomas Vestdam visited University of Porto (Faculty of Engineering), Portugal to work on Integrated Documentation Support in Programming Environments (March 2002–June 2002).

5.10.5 Industry Collaboration Through Student Projects

- *Aalborg University Library (AUB)*, collaboration on building a book recommendation system and a loan data warehouse, 2003–2005, resulting in a system currently used at AUB (Torben Bach Pedersen).

- *Acinta*, collaboration on system for automatic discovery/design of multidimensional schemas, 2001–2005, resulting in several papers and a prototype system (Torben Bach Pedersen).

- *Conzentrate (formerly Zenaria)*, collaboration on techniques for analysis of sequences in web logs and their application to e-learning, 2001–present, resulting in a prototype system and several papers (Torben Bach Pedersen).

- *Greater Copenhagen Development Council (Danish: Hovedstadens Udviklingsråd (HUR))*, collaboration on advanced services and data mining for bus traffic, 2003–present, resulting in a prototype system (Torben Bach Pedersen).
- *DEIF*, collaboration in understanding what Java and .Net had to offer in terms of developing remote controls via SmartPhones, Fall 2003 (Bent Thomsen).
- *WirTek*, collaboration goals were to setup a list of comparison factors between two frameworks and apply some of these factors in a comparison between two applications built in either framework. The project was done in collaboration with a local company, Wirtek and one of their clients in logistics, Fall 2004 (Bent Thomsen).
- *Microsoft Research*, collaboration goals were to extend C# with multimethods. Microsoft research was interested in understanding if and how such an extension was feasible, Spring 2005 (Bent Thomsen).
- *Siemens Mobile*, collaboration with Siemens Mobile on positioning technology, respectively performance analysis of various J2ME implementations, Fall 2005 (Bent Thomsen).
- *End2end*, collaboration on building a synthetic data generator for performance evaluation of core database systems, 2003, resulting in an advanced prototype for data generation (Kristian Torp).
- *Logimatic Software A/S*, collaboration on seamless exchanging of documents between relational database systems and XML, 2003-2004, resulting in a single conference publication (Christian Thomsen and Kristian Torp).
- *Mekoprint*, collaboration on building a data warehouse, 2004-2005 resulting in a prototype used as outset for further studies by the company (Kristian Torp).
- *NT Busses*, collaboration on building a data warehouse for track busses, 2005, resulting in two difference data warehouse designs and two proto-type implementations (Kristian Torp).

5.11 Services

This section lists services for events that occurred during the reporting period as well as services performed in full or in part during the evaluation period.

5.11.1 Program Committees

- The list includes committees for events taking place during the evaluation period and committees where the service has been performed during the evaluation period.

- *7th International Conference on Mobile Data Management*, Nara, Japan, May, 2006 (Christian S. Jensen).
- *22nd IEEE International Conference on Data Engineering*, Atlanta, GA, USA, April, 2006 (Christian S. Jensen).
- *21st Annual ACM Symposium on Applied Computing—Advances in Spatial and Image-based Information Systems*, Dijon, France, April 2006 (Christian S. Jensen).
- *The 2006 IASTED International Conference on Databases and Applications*, Innsbruck, Austria, February, 2006 (Christian S. Jensen, Albrecht Schmidt).
- *1st IFIP International Conference on Semantics of a Networked World*, Munich, Germany, March, 2006 (Torben Bach Pedersen).
- *1st Workshop on Query Languages and Query Processing*, Munich, Germany, March, 2006 (Torben Bach Pedersen).
- *11th International Conference on Database Systems for Advanced Applications*, Singapore, April, 2006 (Simonas Šaltenis).
- *4th Biennial International Conference on Advances in Information Systems*, Izmir, Turkey, October, 2006 (Albrecht Schmidt).
- *4th International Workshop on Modelling, Simulation, Verification and Validation of Enterprise Information Systems*, Paphos, Cyprus, May 23-24, 2006 (Lone Leth Thomsen).
- *8th International Workshop on Mobility in Databases and Distributed Systems*, Copenhagen, Denmark, August, 2005 (Simonas Šaltenis).
- *16th International Conference on Database and Expert Systems Applications*, Copenhagen, Denmark, August, 2005 (Simonas Šaltenis).
- *2nd International VLDB Workshop on Data Management for Sensor Networks*, Trondheim, Norway, August, 2005 (Simonas Šaltenis).
- *11th Eleventh International Conference on Management of Data*, Hyderabad, India, December, 2005 (Torben Bach Pedersen).
- *IASTED International Conference on Databases and Applications*, Innsbruck, Austria, February, 2005 (Torben Bach Pedersen and Albrecht Schmidt).
- *4th International Workshop on Web Semantics*, Copenhagen, Denmark, August, 2005 (Torben Bach Pedersen).
- *31st International Conference on Very Large Databases, Core Database Technology Track*, Trondheim, Norway, August/September, 2005 (Torben Bach Pedersen and Albrecht Schmidt).

- *9th East-European Conference on Advances in Databases and Information Systems*, Tallinn, Estonia, September, 2005 (Torben Bach Pedersen).
- *7th International Conference on Data Warehousing and Knowledge Discovery*, Copenhagen, Denmark, August, 2005 (Torben Bach Pedersen).
- *4th International Conference on Ontologies, Databases and Applications of Semantics*, Agia Napa, Cyprus, October/November, 2005 (Torben Bach Pedersen).
- *2nd International Conference on Distributed Computing and Internet Technology*, Bhubaneswar, India, December, 2005 (Torben Bach Pedersen).
- *5th International Workshop on Web and Wireless GIS*, Lausanne, Switzerland, December, 2005 (Christian S. Jensen).
- *13th ACM International Symposium on Advances in Geographic Information Systems*, Bremen, Germany, November, 2005 (Christian S. Jensen).
- *24th International Conference on Conceptual Modeling*, Klagenfurt, Austria, October, 2005 (Christian S. Jensen).
- *2nd International Workshop on Conceptual Modeling for GIS*, Klagenfurt, Austria, October, 2005 (Christian S. Jensen).
- *9th International Symposium on Spatial and Temporal Databases*, Angra, Brazil, August, 2005 (Christian S. Jensen).
- *8th International Workshop on Mobility in Databases and Distributed Systems*, Copenhagen, Denmark, August, 2005 (Christian S. Jensen).
- *15th International Conference on Scientific and Statistical Database Management*, Santa Barbara, California, USA, June, 2005 (Christian S. Jensen).
- *12th International Symposium on Temporal Representation and Reasoning*, Burlington, Vermont, USA, June, 2005 (Christian S. Jensen).
- *2005 ACM SIGMOD International Conference on the Management of Data*, Baltimore, Maryland, USA, June, 2005 (Christian S. Jensen).
- *5th European Congress and Exhibition on Intelligent Transport Systems and Services*, Hannover, Germany, June, 2005 (Christian S. Jensen).
- *6th International Conference on Mobile Data Management*, Larnaca, Cyprus, May, 2005 (Christian S. Jensen).
- *21st IEEE International Conference on Data Engineering*, Tokyo, Japan, April, 2005 (Christian S. Jensen).

- *10th International Conference on Database Systems for Advanced Applications*, Beijing, China, April, 2005 (Christian S. Jensen).
- *ACM Symposium on Applied Computing, Ubiquitous Computing Track*, Socorro, New Mexico, USA, March, 2005 (Christian S. Jensen).
- *3rd international Workshop on Verification and Validation of Enterprise Information Systems*, Miami, FL, USA, May, 2005 (Lone Leth Thomsen).
- *7th International Workshop on Mobility in Databases and Distributed Systems*, Zaragoza, Spain, September, 2004 (Simonas Šaltenis).
- *15th International Conference on Database and Expert Systems Applications*, Zaragoza, Spain, August–September, 2004 (Simonas Šaltenis).
- *IASTED International Conference on Databases and Applications*, Innsbruck, Austria, February, 2004 (Torben Bach Pedersen).
- *3rd International Workshop on Data Integration Over The Web*, Riga, Latvia, June, 2004 (Torben Bach Pedersen).
- *6th International Conference on Scientific and Statistical Database Management*, Santorini Island, Greece, June, 2004 (Torben Bach Pedersen).
- *6th International Conference on Data Warehousing and Knowledge Discovery*, Zaragoza, Spain, September, 2004 (Torben Bach Pedersen).
- *8th East-European Conference on Advances in Databases and Information Systems*, Budapest, Hungary, September, 2004 (Torben Bach Pedersen).
- *3rd Biennial International Conference on Advances in Information Systems*, Izmir, Turkey, October, 2004 (Torben Bach Pedersen).
- *12th ACM International Symposium on Advances in Geographic Information Systems*, Washington DC, USA, November, 2004 (Christian S. Jensen).
- *23rd International Conference on Conceptual Modeling*, Shanghai, China, November, 2004 (Christian S. Jensen).
- *1st International Workshop on Conceptual Modeling for GIS*, Shanghai, China, November, 2004 (Christian S. Jensen).
- *3rd International Conference on Geographic Information Science*, Maryland, USA, October, 2004 (Christian S. Jensen).
- *7th International Workshop on Mobility in Databases and Distributed Systems*, Zaragoza, Spain, September, 2004 (Christian S. Jensen).
- *13th International Conference on Very Large Data Bases*, Toronto, Canada, August–September, 2004 (Christian S. Jensen).

- *2nd International Workshop on Spatio-Temporal Database Management*, Toronto, Canada, August, 2004 (Christian S. Jensen).
- *International Workshop on Data Management for Sensor Networks*, Toronto, Canada, August, 2004 (Christian S. Jensen).
- *11th International Symposium on Temporal Representation and Reasoning*, Caen, France, July, 2004 (Christian S. Jensen).
- *16th Conference on Advanced Information Systems Engineering*, Riga, Latvia, June, 2004 (Christian S. Jensen).
- *ICDE/EDBT Ph.D. Workshop 2004*, Heraklion, Crete, Greece, March 18, 2004 and Boston, Massachusetts, USA, March, 2004 (Christian S. Jensen).
- *20th IEEE International Conference on Data Engineering*, Boston, MA, USA, March–April, 2004 (Christian S. Jensen).
- *ACM Symposium on Applied Computing, Ubiquitous Computing Track*, Nicosia, Cyprus, March, 2004 (Christian S. Jensen).
- *EDBT Workshop on Pervasive Information Management*, Heraklion, Greece, March, 2004 (Christian S. Jensen).
- *9th International Conference on Extending Database Technology*, Heraklion, Greece, March, 2004 (Christian S. Jensen).
- *9th International Conference on Database Systems for Advanced Applications*, Jeju Island, South Korea, February, 2004 (Christian S. Jensen).
- *5th International Conference on Mobile Data Management*, Silicon Valley, CA, USA, January, 2004 (Christian S. Jensen).
- *2nd international Workshop on Verification and Validation of Enterprise Information Systems*, Porto, Portugal, April, 2004 (Lone Leth Thomsen).
- *2nd Australasian Data Mining Workshop*, Canberra, Australia, December, 2003, (Michael H. Böhlen).
- *3rd International Workshop on Visual Data Mining*, Melbourne, Florida, USA, November, 2003 (Michael H. Böhlen).
- *8th International Symposium on Spatial and Temporal Databases*, Santorini island, Greece, July, 2003 (Michael H. Böhlen).
- *6th International Workshop on Mobility in Databases and Distributed Systems*, Prague, Czech Republic, September, 2003 (Simonas Šaltenis).
- *14th International Conference on Database and Expert Systems Applications*, Prague, Czech Republic, September, 2003 (Simonas Šaltenis).

- *5th International Conference on Data Warehousing and Knowledge Discovery*, Prague, Czech Republic, September, 2003 (Torben Bach Pedersen).
- *2003 International Conference on Information Systems and Engineering*, Quebec, Canada, July, 2003 (Torben Bach Pedersen).
- *3rd International Workshop on Web and Wireless GIS*, Rome, Italy, December, 2003 (Christian S. Jensen).
- *11th ACM International Symposium on Advances in Geographic Information Systems*, New Orleans, Louisiana, USA, November, 2003 (Christian S. Jensen).
- *3rd ACM International Workshop on Data Engineering for Wireless and Mobile Access*, San Diego, CA, USA, September, 2003 (Christian S. Jensen).
- *10th East-European Conference on Advances in Databases and Information Systems*, Dresden, Germany, September, 2003 (Christian S. Jensen).
- *Joint 10th International Symposium on Temporal Representation and Reasoning and Fourth International Conference on Temporal Logic*, Cairns, Queensland, Australia, July, 2003 (Christian S. Jensen).
- *8th International Symposium on Spatial and Temporal Databases*, Santorini, Greece, July, 2003 (Christian S. Jensen).
- *15th International Conference on Scientific and Statistical Database Management*, Cambridge, MA, USA, July, 2003 (Christian S. Jensen).
- *2003 ACM SIGMOD International Conference on the Management of Data*, San Diego, CA, USA, June, 2003 (Christian S. Jensen).
- *15th Conference on Advanced Information Systems Engineering*, Velden, Austria, June, 2003 (Christian S. Jensen).
- *Time Aspects of Business Information Systems*, Colorado Springs, CO, USA, June, 2003 (Christian S. Jensen).
- *8th International Conference on Database Systems for Advanced Applications*, Kyoto, Japan, March, 2003 (Christian S. Jensen).
- *19th IEEE International Conference on Data Engineering*, Bangalore, India, March, 2003 (Christian S. Jensen).
- *4th International Conference on Mobile Data Management*, Melbourne, Australia, January, 2003 (Christian S. Jensen).
- *1st international Workshop on Verification and Validation of Enterprise Information Systems*, Angers, France, April, 2003 (Lone Leth Thomsen).

- *3rd International Conference on Web Information Engineering*, Singapore, December, 2002 (Michael H. Böhlen).
- *International Workshop on Visual Data Mining*, August 2002 (Michael H. Böhlen).
- *International Database Engineering and Applications Symposium*, July 2002, (Michael H. Böhlen).
- *5th International Workshop on Mobility in Databases and Distributed Systems*, Aix-en-Provence, France, September, 2002 (Simonas Šaltenis).
- *Workshop on Inheritance*, 2002 (Erik Ernst).
- *Workshop on Aspects, Components, and Patterns for Infrastructure Software*, 2002 (Erik Ernst).
- *Foundations of Object-Oriented Languages*, 2002 (Erik Ernst).
- *Workshop on Aspect Oriented Programming for Distributed Computing Systems*, 2002 (Erik Ernst).
- *8th International Conference on Extending Database Technology*, Prague, Czech Republic, March 2002 (Torben Bach Pedersen).
- *4th International Workshop on Design and Management of Data Warehouses*, Toronto, Ontario, Canada, May 2002 (Torben Bach Pedersen).
- *10th ACM International Symposium on Advances in Geographic Information Systems*, Washington DC, USA, November, 2002 (Christian S. Jensen).
- *2002 IASTED International Conference Information Systems and Databases*, Tokyo, Japan, September, 2002 (Christian S. Jensen).
- *28th International Conference on Very Large Data Bases*, Hong Kong, PRC, August, 2002 (Christian S. Jensen).
- *14th International Conference on Scientific and Statistical Database Management*, Edinburgh, Scotland, UK, July, 2002 (Christian S. Jensen).
- *9th International Symposium on Temporal Representation and Reasoning*, Manchester, UK, July, 2002 (Christian S. Jensen).
- *5th International Workshop on Next Generation Information Technologies and Systems*, Israel, June, 2002 (Christian S. Jensen).
- *2002 ACM SIGMOD International Conference on the Management of Data*, Madison, WI, USA, June, 2002 (Christian S. Jensen).

- *2002 Workshop on XML-Based Data Management*, Prague, Czech Republic, March 24, 2002 (Christian S. Jensen).
- *18th IEEE International Conference on Data Engineering*, San Jose, CA, USA, February/March, 2002 (Christian S. Jensen).
- *3rd International Conference on Mobile Data Management*, Singapore, January, 2002. (Christian S. Jensen).
- *2nd International Conference on Web Information Systems*, 2001 (Michael H. Böhlen).
- *The 9th International Symposium on Temporal Representation and Reasoning*, July 2001 (Michael H. Böhlen).
- *Workshop on Visual Data Mining*, 2001 (Michael H. Böhlen).
- *Workshop on Language Mechanisms for Programming Software Components*, 2001 (Erik Ernst).
- *Workshop on Feature Interaction of Composed Systems*, 2001 (Erik Ernst).
- *20th International Conference on Conceptual Modeling*, Yokohama, Japan, November, 2001 (Christian S. Jensen).
- *9th ACM International Symposium on Advances in Geographic Information Systems*, Atlanta, Georgia, USA, November, 2001 (Christian S. Jensen).
- *2nd International Workshop on Electronic Commerce—Mobility and Electronic Commerce*, Darmstadt, Germany, November, 2001 (Christian S. Jensen).
- *27th International Conference on Very Large Data Bases*, Rome, Italy, September, 2001 (Christian S. Jensen).
- *6th IFCIS International Conference on Cooperative Information Systems*, Trento, Italy, September, 2001 (Christian S. Jensen).
- *TIME 2001 International Symposium on Temporal Representation and Reasoning*, Cividale del Friuli, Italy, June, 2001 (Christian S. Jensen).
- *13th Conference on Advanced Information Systems Engineering*, Interlaken, Switzerland, June, 2001 (Christian S. Jensen).
- *13th International Conference on Software Engineering and Knowledge Engineering*, Buenos Aires, Argentina, June, 2001 (Christian S. Jensen).
- *2001 ACM SIGMOD International Conference on the Management of Data* (tutorial program committee), Santa Barbara, CA, USA, May, 2001 (Christian S. Jensen).

- *2nd ACM International Workshop on Data Engineering for Wireless and Mobile Access*, Santa Barbara, CA, USA, May, 2001 (Christian S. Jensen).

- *Fifth International Conference on Spatial Information Theory* (scientific committee member), Morro Bay, California, USA, September, 2001 (Christian S. Jensen).

- *5th World Conference on Computers* (international scientific committee member), Rethymnon, Crete, Greece, July, 2001 (Christian S. Jensen).

5.11.2 Conference Related Services

Conferences and Workshops—Service Encompassing Leadership

- Steering committee member, *International Symposium on Spatial and Temporal Databases*, July 2001–July 2007 (Christian S. Jensen).

- Panels chair, *2006 ACM SIGMOD International Conference on the Management of Data*, Chicago, Illinois, June 27–29, 2006 (Christian S. Jensen).

- Organizer, *Data Always and Everywhere - Management of Mobile, Ubiquitous, Pervasive, and Sensor Data*, Dagstuhl Seminar Number 05421, Schloss Dagstuhl, Germany, October 16–21, 2005. Co-organizers: Gustavo Alonso, Bernhard Mitschang, and Oddvar Risnes (Christian S. Jensen).

- Technical program chair, *31st International Conference on Very Large Databases*, Trondheim, Norway, August 30–September 2, 2005 (Christian S. Jensen).

- Panels chair, *2004 ACM SIGMOD International Conference on the Management of Data*, Paris, France, June 13–18, 2004 (Christian S. Jensen).

- Advisory committee member, *Second International Workshop on Spatio-Temporal Databases*, Toronto, Canada, August 30, 2004 (Christian S. Jensen).

- Program committee chair, *Eighth International Conference on Extending Database Technology*, Prague, Czech Republic, March 25–27, 2002 (Christian S. Jensen).

- Program committee co-chair, with Bernhard Seeger, *Seventh International Symposium on Spatial and Temporal Databases*, Redondo Beach, CA, USA, July 12–15, 2001 (Christian S. Jensen).

- Program co-chair, *Workshop on Wireless Information Management*, Vilnius, Trakai, June 10–13, 2001 (Christian S. Jensen).

Other Conference and Workshop Related Services

- Panel participant, Database Publication Practices, *Thirtyfirst International Conference on Very Large Databases*, Trondheim, Norway, August 30–September 2, 2005 (Christian S. Jensen).
- Panel participant, The Future of Data Management Research for Sensor Networks, *Second International Workshop on Data Management for Sensor Networks*, Trondheim, Norway, August 29, 2005 (Christian S. Jensen).
- Panel participant, Mobility in Sensor Networks, *6th International Conference on Mobile Data Management*, Ayia Napa, Cyprus, May 9–11, 2005 (Simonas Šaltenis).
- Panel participant, Closing Panel Debate, *It Starts in Primary School—the Conditions of Science and Technology in the Primary School of the Future*, Copenhagen, Denmark, April 22, 2004 (in Danish) (Christian S. Jensen).
- Panel participant, Querying the Past, the Present, and the Future, *20th International Conference on Data Engineering*, Boston, MA, USA, March 31, 2004 (Christian S. Jensen).
- Panel participant, Life of a (young) database faculty!, New Database Faculty Symposium, *2003 ACM SIGMOD International Conference on the Management of Data*, San Diego, CA, USA, June 9, 2003 (Christian S. Jensen).
- Proceedings chair, *International Conference on Extending Database Technology*, Prague, Czech Republic, March 24–28, 2002 (Simonas Šaltenis).
- Member, *2002 ACM SIGMOD Undergraduate Scholarship Program Committee*, Madison, WI, USA, June 2002 (Christian S. Jensen).
- Panel organizer, "Managing location information for billions of gizmos on the move—what's in it for the database folks?," with Ouri Wolfson, *Seventeenth International Conference on Data Engineering*, Heidelberg, Germany, April 2–6, 2001 (Christian S. Jensen).

5.11.3 Invited Talks

The list does not include presentations of tutorials and research papers at conferences and workshops.

Keynotes

- "Data Management for Mobile Services—Location Tracking and Geo-Content Modeling," Sixth ACM/IFIP/USENIX 6th International Middleware Conference, Grenoble, France, November 28–December 2, 2005 (Christian S. Jensen).

- "Towards Knowing, Always and Everywhere, Where Everything Is, Precisely," Danish Map Days, Kolding, Denmark, November 17, 2005, (in Danish) (Christian S. Jensen).
- "Towards Knowing, Always and Everywhere, Where Everything Is, Precisely," Fourth International Workshop on Web and Wireless Geographic Information Systems, Goyang, South Korea, November 26, 2004 (Christian S. Jensen).
- "Data Management for Mobile Services in the Real World," Eighth International Symposium on Spatial and Temporal Databases, Santorini, Greece, July 26, 2003 (Christian S. Jensen).
- "Location-Enabled Services—A Data Management Perspective," The Nordic GIS Conference: GI – Communication and Perspective, Aalborg, Denmark, November 25, 2002 (Christian S. Jensen).
- "Research Challenges in Location-Enabled M-Services," Third International Conference on Mobile Data Management, Singapore, January 8–11, 2002 (Christian S. Jensen).
- "Location-Based Services—A Database Perspective," Eighth Scandinavian Research Conference on Geographical Information Science, Ås, Norway, June 25–27, 2001 (Christian S. Jensen).
- "Mobile E-Services and Their Challenges to Data Warehousing," 9. Fachtagung, Datenbanksysteme in Büro, Technik und Wissenschaft, Oldenburg, Germany, March 6, 2001 (Christian S. Jensen).

Other Talks

- "Research in Mobile Services at Aalborg University," IKT Forum, Aalborg, Denmark, August 25, 2005 (in Danish) (Christian S. Jensen).
- "Geo-Context for Mobile Services—Current-Location Tracking and Routes," Institute of Parallel and Distributed Systems, Faculty of Computer Science, Electrical Engineering, and Information Technology, University of Stuttgart, Stuttgart, Germany, June 23, 2005 (Christian S. Jensen).
- "Data Warehousing and Multidimensional Databases," Workshop on Intelligent Sound, Korsør, Denmark, August 16, 2005 (Torben Bach Pedersen).
- "Fremtidens programmeringssprog," Nouhauz Gå-Hjem Arrangement, May 12, 2005 (Bent Thomsen).
- "Towards Knowing, Always and Everywhere, Where Everything Is, Precisely," Department of Computer Science, University of Arizona, AZ, USA, February 8, 2005 (Christian S. Jensen).

- "Data Expiration – An Algebraic Perspective," CWI Amsterdam, October 2005 (Albrecht Schmidt).
- "Traffic Information of the Future," Danish Broadcasting Corporation, Søborg, Denmark, May 28, 2004 (in Danish) (Christian S. Jensen).
- "Data Modeling for Location-Aware, Mobile Services," Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano/Bozen, Italy, January 16, 2004 (Christian S. Jensen).
- "Capture of Network-Constrained Moving Objects—Towards a Foundation for Mobile Services," Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano/Bozen, Italy, January 2004 (Christian S. Jensen).
- "Generalized Updates in R-Trees," Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano/Bozen, Italy, January 2004 (Christian S. Jensen).
- "A Unit Testing Tool - based on Design by Contract and Equivalence Partitions", SIG-BEER: Presentation, Bern University, Switzerland, January 14, 2004 (Per Madsen).
- "Playing with Rubik's (Hyper)Cube: Managing Complex Multidimensional Data," Department Seminar, Department of Computer Science, Aalborg University, October 29, 2004 (Torben Bach Pedersen).
- "GIS i mobilen giver trafikinfo (GIS in the Mobile Gives Traffic Info)," Kortdage (Annual Danish GIS Users conference), Odense, Denmark, October 26, 2004 (Torben Bach Pedersen).
- "Unit Testing Database Applications," Half day seminar, Åben Uddannelse Aalborg Universitet, August 2004 (Kristian Torp).
- "To .Net or not to .Net," NouHauz Executive Round Table, May 5, 2004 (Bent Thomsen).
- "Life long learning course" on "Java vs. .Net," August 20, 2004 (Bent Thomsen).
- "Data Management for Moving Objects," Second International LBS and Telematics Workshop, KyoYuk MunHwa HoeKwan, Seoul, South Korea, November 20, 2003 (Christian S. Jensen).
- "Capture of Network-Constrained Moving Objects—A Foundation for Mobile Services," Chungbuk National University, Cheongju, South Korea, November 19, 2003 (Christian S. Jensen).

- “Efficient Tracking Techniques in Ubiquitous LBS,” Electronics and Telecommunications Research Institute, Daejeon, South Korea, November 18, 2003 (Christian S. Jensen).
- “Supporting Frequent Updates in R-Trees: A Bottom-Up Approach,” Pusan National University, Busan, South Korea, November 17, 2003 (Christian S. Jensen).
- “Conceptual Modeling of Spatio-Temporal Databases,” Meeting on Technology for a National Geo-Database Infrastructure, Siena, Italy, September 4, 2003 (Christian S. Jensen).
- “Mobile Information Services: Trends and Challenges,” Nouhauz Executive Round Table, Aalborg, Denmark, May 8, 2003 (Christian S. Jensen).
- “Context Data Management For Pervasive Computing,” IT-Vest Conference, Odense, Denmark, February 28, 2003 (Torben Bach Pedersen).
- “Business Intelligence For Pervasive Computing,” Århus-Aalborg Industry Conference, Århus, Denmark, August 25, 2003 (Torben Bach Pedersen).
- “Expiration Times for Data Management,” Free University of Bozen/Bolzano, December 2003 (Albrecht Schmidt).
- “.Net Seminar,” KMD, 04. September, 2003 (Bent Thomsen).
- “Præsentation og evaluering af JUNIT - Værktøj til unit test til Java” (in danish), NouHauz, Netværk i Modellering og Test af Software, September 5, 2002 (Per Madsen).
- “New trends in Business Intelligence Technologies: On-Line Query Processing and Data Streams,” CONFEX Data Warehouse Conference, Copenhagen, Denmark, April 23-24, 2002 (Torben Bach Pedersen).
- “Data Management Support for Location-Based Services: A Private-Public Partnership,” Telenor Research, Fornebu, Oslo, Norway, December 5, 2002 (Christian S. Jensen).
- “Location Data Management Issues in Pervasive Computing,” Telenor Research, Fornebu, Oslo, Norway, December 5, 2002 (Christian S. Jensen).
- “Fremtidens mobile services – eksempel på et samarbejdsprojekt,” Aalborg Universitets Kontaktråd, Aalborg, Denmark, October 8, 2002 (Christian S. Jensen).
- “Towards Virtual Worlds and Augmented Realities: A Research Agenda,” Second International Workshop on Research Directions in Mobile Communications and Services, Grimstad, Norway, September 26, 2002 (Christian S. Jensen).

- "Data Management for Location-Based Services," Department of Computer and Information Science, Norwegian University of Science and Technology, September 10, 2002 (Christian S. Jensen).
- "Data Modeling and Nearest-Neighbor Querying for Network-Constrained Moving Objects," School of Computing, National University of Singapore, July 15, 2002 (Christian S. Jensen).
- "Temporal Data Models and Query Languages," School of Computing, National University of Singapore, July 11 and 12, 2002 (Christian S. Jensen).
- "Indexing the Current and Anticipated Future Positions of Moving Objects," School of Computing, National University of Singapore, July 8, 2002 (Christian S. Jensen).
- "Data Management for Location-Based Services," School of Computing, National University of Singapore, July 1, 2002 (Christian S. Jensen).
- "Data Management for Mobile Services," The 55th Studiemøtet, Sandefjord, Norway, June 13–14, 2002, award acceptance speech (Christian S. Jensen).
- "Database Research at Aalborg University," Seminar on Methods for Software Development and Open Systems, Grimstad, Norway, April 24, 2002 (Christian S. Jensen).
- "Location-Based Services—A Data Management Perspective," Kartdagar 2002, Jönköping, Sweden, April 17–19, 2002 (Christian S. Jensen).
- "Data Representation and Indexing in Location-Enabled M-Services," National Science Foundation Workshop On Context-Aware Mobile Database Management, Brown University, Providence, RI, USA, January 24–25, 2002 (Christian S. Jensen).
- "Integrating External Data In OLAP Databases," Danish Database Workshop 16, Ballerup, Denmark, January 14, 2002 (Torben Bach Pedersen).
- "Data Management for Location-Based Services," Danish Database Workshop 17, Aarhus, Denmark, June 10, 2002 (Torben Bach Pedersen).
- "Data Management Support For Location-Based Services," IT University of Copenhagen, Denmark, December 3, 2002 (Torben Bach Pedersen).
- "Research Issues in Mobile Data Management," Oracle Corporation, Nashua, NH, USA, January 22, 2002 (Christian S. Jensen).
- "Aspects of XML Data Management," Aalborg University, October 2002 (Albrecht Schmidt).

- "Assessing XML Data Management with XMark," EEXTT Workshop, August 2002 (Albrecht Schmidt).
- "Indexing and other Database Management Issues in Location-Based Services," IBM Almaden Data Management Workshop, IBM Almaden Research Center, San Jose, USA, February 25, 2002 (Simonas Šaltenis).
- "PL/SQL Exception Handling," Halvdagsseminar Logimatic Software A/S, 2002 (Kristian Torp).
- "The Internal of a Database API," Halvdagsseminar Logimatic Software A/S, 2002 (Kristian Torp).
- "Designing a Database API," Halvdagsseminar Logimatic Software A/S, 2002 (Kristian Torp).
- "Mobile E-Services," Nykredit Data, December 18, 2001 (Christian S. Jensen).
- "Research Directions in Location-Based Services—a Database Perspective," International Workshop on Research Directions in Mobile Communication and Computing, Grimstad, Norway, October 22, 2001 (Christian S. Jensen).
- "Business Intelligence," Videnskabsbutikken, Aalborg University, Denmark, January 4, 2001 (Torben Bach Pedersen).
- "Mobile e-services," Nouhauz seminar, Aalborg, Denmark, January 31, 2001 (Torben Bach Pedersen).
- "Aspects of Data Modeling and Query Processing for Complex Multidimensional Data," Danish Database Workshop 14, Aarhus, Denmark, January 15, 2001 (Torben Bach Pedersen).
- "Data Warehousing and Business Intelligence," Annual Meeting of The Danish "Datamatiker" Teachers Union, Vejle, Denmark, September 14, 2001 (Torben Bach Pedersen).
- Presenter of a half-day tutorial at the *2nd Meeting of the Norfa Wireless Information Management Network*, Aalborg, Denmark, December 2001 (Christian S. Jensen and Simonas Šaltenis).
- "Business Intelligence Research at Aalborg University," Acinta Business Intelligence Meeting, Copenhagen, August 20, 2001 (Christian S. Jensen).
- "A Database Perspective on Location-Based Services," Agder University College, Grimstad, Norway, August 7, 2001 (Christian S. Jensen).
- "Research Challenges in Wireless Information Management," Workshop on Wireless Information Management, Vilnius, Lithuania, June 10–13, 2001 (Christian S. Jensen).

- "Location-Based Services—A Database Perspective," Workshop on Location-Based Services, Aalborg, Denmark, June 7–8, 2001 (Christian S. Jensen).
- "The XML Benchmark XMark," Microsoft Research, July 2001 (Albrecht Schmidt).
- "Regression Testing," Half day seminar Logimatic Software A/S, 2001 (Kristian Torp).
- "Spatial Information Systems: Methods and Tools," Nordic Summer School on Informatics in the Agricultural Sciences, Oslo July 2001, (Nectaria Tryfona).
- "Oracle Database Tuning," Half day seminar Logimatic Software A/S, 2000 (Kristian Torp).
- "Documenting PL/SQL Code," Half day seminar Logimatic Software A/S, 2000 (Kristian Torp).

5.11.4 Editorial Services

- Associate Editor, *IEEE Data Engineering Bulletin*, December 2001–November 2003 (Christian S. Jensen).
- Associate Editor, *ACM Transactions on Database Systems*, August 2001–July 2007 (Christian S. Jensen).
- Associate Editor, *IEEE Transactions on Knowledge and Data Engineering* (subject area: temporal databases). May 1997–October 2001 (Christian S. Jensen).
- Editorial Board Member, *ACM SIGMOD Digital Review*, May 1999–present (Christian S. Jensen).
- Editorial Board Member, *International Journal of Data Warehousing and Mining*, 2004–present (Torben Bach Pedersen).

5.11.5 Reviews

Journals/Publishers

- *ACM Transactions on Database Systems*, 2005 (Torben Bach Pedersen).
- *Higher-Order and Symbolic Computation*, 2005 (Kurt Nørmark).
- *The Computer Journal*, 2005 (Torben Bach Pedersen and Simonas Šaltenis).
- *IEEE Transactions on Knowledge and Data Engineering*, 2005 (Simonas Šaltenis).

- *Information & Software Technology Journal*, 2005 (Kristian Torp).
- *The VLDB Journal*, 2005 (Christian S. Jensen).
- *The VLDB Journal*, 2004 (Simonas Šaltenis).
- *ACM Transactions on Database Systems*, 2004 (Simonas Šaltenis).
- *ISPRS Journal of Photogrammetry and Remote Sensing*, 2004 (Simonas Šaltenis).
- *Information Processing Letters*, 2004 (Torben Bach Pedersen).
- *Journal ACM Computing Review*, 2001, 2002, 2003 (Kristian Torp).
- *The VLDB Journal*, 2003 (Simonas Šaltenis and Kristian Torp).
- *Knowledge and Information Systems: An International Journal*, 2002 (Torben Bach Pedersen).
- *IEEE Transactions on Knowledge and Data Engineering Journal*, 2002 (Kristian Torp).
- Logics for Emerging Applications of Databases, Springer Verlag, 2003, 2002 (Christian S. Jensen).
- The SIAM Journal on Computing, 2001 (Christian S. Jensen).

External Reviews

- *31st International Conference on Very Large Data Bases*, 2005 (Gyözö Gidófalvi, Laurynas Speičys, Simonas Šaltenis, Christian Thomsen, and Xuepeng Yin).
- *24th International Conference on Conceptual Modeling*, 2005 (Agnė Brilingaitė).
- *21st International Conference on Data Engineering*, 2005 (Agnė Brilingaitė, Linas Bukauskas, Simonas Šaltenis, and Xuegang Huang).
- *16th International Conference on Concurrency Theory*, 2005 (Simonas Šaltenis).
- *13th ACM International Symposium on Advances in Geographic Information Systems*, 2005 (Agnė Brilingaitė, Linas Bukauskas, and Xuegang Huang).
- *10th International Conference on Database Systems for Advanced Applications*, 2005 (Linas Bukauskas and Christian Thomsen).
- *9th International Symposium on Spatial and Temporal Databases*, 2005 (Xuegang Huang).
- *7th East-European Conference on Advances in Databases and Information Systems*, 2005 (Gyözö Gidófalvi and Christian Thomsen).

- *7th International Conference on Data Warehousing and Knowledge Discovery*, 2005 (Gyözö Gidófalvi and Igor Timko).
- *6th International Conference on Mobile Data Management*, 2005 (Stardas Pakalnis and Xuegang Huang).
- *3rd International Conference on Education and Information Systems: Technologies and Applications*, 2005 (Linas Bukauskas).
- *2nd International Conference on Distributed Computing & Internet Technology*, 2005 (Gyözö Gidófalvi).
- *International Database Engineering and Applications Symposium*, 2005 (Linas Bukauskas).
- *Chapters of the book "Processing and Managing Complex Data for Decision Support"*, Idea Group, 2005 (Torben Bach Pedersen).
- *ACM SIGMOD International Conference on Management of Data*, 2005 (Agnė Brilingaitė, Stardas Pakalnis, Torben Bach Pedersen, Laurynas Speičys, Simonas Šaltenis, Igor Timko, Kristian Torp, and Xuegang Huang).
- *The IASTED International Conference on Databases and Applications*, 2005 (Gyözö Gidófalvi and Christian Thomsen).
- *Information Systems*, 2005 (Stardas Pakalnis).
- *30th International Conference on Very Large Data Bases*, 2004 (Stardas Pakalnis, Torben Bach Pedersen, Simonas Šaltenis, and Xuegang Huang).
- *23rd International Conference on Conceptual Modeling for Advanced Application Domains*, 2004 (Linas Bukauskas).
- *20th International Conference on Data Engineering*, 2004 (Stardas Pakalnis, Laurynas Speičys).
- *16th Conference on Advanced Information Systems Engineering* , 2004 (Torben Bach Pedersen).
- *15th International Conference on Database and Expert Systems Applications*, 2004 (Linas Bukauskas).
- *12th ACM International Symposium on Advances in Geographic Information Systems*, 2004 (Stardas Pakalnis and Xuegang Huang).
- *9th International Conference on Extending Database Technology*, 2004 (Agnė Brilingaitė, Linas Bukauskas, Torben Bach Pedersen, Laurynas Speičys, Simonas Šaltenis, and Xuegang Huang).

- *9th International Conference on Database Systems for Advanced Applications*, 2004 (Igor Timko and Janne Skyt).
- *8th International Database Engineering and Applications Symposium*, 2004 (Linas Bukauskas).
- *7th International Workshop on Mobility In Databases and Distributed Systems*, 2004 (Xuegang Huang).
- *5th IEEE International Conference on Mobile Data Management*, 2004 (Agnė Brilingaitė).
- *3rd International Conference on Advances in Information Systems*, 2004 (Kristian Torp).
- *3rd International Conference on Advances in Information Systems*, 2004 (Gyözö Gidófalvi).
- *2nd Workshop on Spatio-Temporal Database Management*, 2004 (Xuegang Huang).
- *Workshop on Conceptual Modeling for Geographic Information Systems*, 2004 (Torben Bach Pedersen).
- *Information Systems*, 2004 (Janne Skyt)
- *Book of Algorithm and Data Structure proposal*, 2004 (Linas Bukauskas).
- *8th International Conference on Database Systems for Advanced Applications*, 2003 (Torben Bach Pedersen).
- *19th International Conference on Data Engineering*, 2003 (Torben Bach Pedersen, Laurynas Speičys, Simonas Šaltenis, and Igor Timko).
- *ACM SIGMOD International Conference on Management of Data*, 2003 (Torben Bach Pedersen, Laurynas Speičys, Simonas Šaltenis, and Igor Timko).
- *15th Conference on Advanced Information Systems Engineering*, 2003 (Torben Bach Pedersen).
- *8th International Symposium on Spatial and Temporal Databases*, 2003 (Simonas Šaltenis).
- *4th International Conference on Mobile Data Management*, 2003 (Simonas Šaltenis).
- *29th International Conference on Very Large Databases*, 2003 (Kristian Torp).
- *11th ACM International Symposium on Advances in Geographic Information Systems*, 2003 (Laurynas Speičys and Igor Timko).

- *3rd International Workshop on Web and Wireless Geographical Information Systems* , 2003 (Laurynas Speičys).
- *15th International Conference on Scientific and Statistical Database Management*, 2002 (Simonas Šaltenis).
- *8th International Symposium on Spatial and Temporal Databases*, July 2002 (Nectaria Tryfona).
- *ACM SIGMOD International Conference on Management of Data*, 2002 (Torben Bach Pedersen and Simonas Šaltenis).
- *14th International Conference on Scientific and Statistical Data Base Management*, 2002 (Torben Bach Pedersen).
- *8th International Conference on Object-Oriented Information Systems*, 2002 (Torben Bach Pedersen).
- *10th ACM International Symposium on Advances in Geographic Information Systems*, 2002 (Simonas Šaltenis).
- *9th International Conference on Cooperative Information Systems*, September 2001 (Michael H. Böhlen and Nectaria Tryfona).
- *20th International Conference on Conceptual Modeling*, November 2001 (Nectaria Tryfona).
- *Foundations of Geographic Information Science, International Conference*, September 2001, (Nectaria Tryfona).
- *7th International Symposium on Spatial and Temporal Databases*, July 2001 (Nectaria Tryfona).
- *International Database Engineering and Applications Symposium*, July 2001, (Nectaria Tryfona).
- *13th Conference on Advanced Information Systems Engineering*, 2001 (Torben Bach Pedersen and Simonas Šaltenis).
- *27th International Conference on Very Large Data Bases*, 2001 (Torben Bach Pedersen and Simonas Šaltenis).
- *20th International Conference on Conceptual Modeling*, 2001 (Torben Bach Pedersen).
- *2nd ACM International Workshop on Data Engineering for Wireless and Mobile Access*, 2001 (Simonas Šaltenis).

5.11.6 Evaluation Committees

Ph.D. and Habilitation Committees

External:

- Member of the graduation committee of Nirvana Meratnia, Department of Computer Science, Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, Netherlands, February 2005 (Christian S. Jensen).

- Member of the Ph.D. jury of Carme Escofet Martín, Department of Software, Technical University of Catalonia, Spain, June 2005 (Michael H. Böhlen, Nieves Rodriguez Brisaboa, Christian S. Jensen, and Felix Sàltor).

- Committee member for Ademar Aguiar Ph.D. defense with a title *A Minimalist Approach to Framework Documentation*, University of Porto, Portugal 2004 (Kurt Nørmark).

- Ph.D. Thesis External Review Committee, ICT Doctorate School of the University of Trento, Italy (Lone Leth Thomsen and Bent Thomsen).

- Member of Ph.D. thesis proposal committee for Klaus Vilstrup Pedersen, Aarhus School of Business, 2003 (Torben Bach Pedersen).

- First opponent for Erlend Tøssebro's Ph.D. defense (advisor: Mads Nygård), Norwegian University of Science and Technology, Department of Computer and Information Science, 2002 (Christian S. Jensen).

- External opponent for Henrik Andre Jönsson's Ph.D. examination (advisor: Nahid Shahmehri), Linköping University, Department of Computer and Information Science, 2002 (Christian S. Jensen).

- Committee member for Erik Berglund's Ph.D. defense with a title *Library Communication Among Programmers Worldwide* Linköping University, Sweden, 2002 (Kurt Nørmark).

- External reviewer of Artem Katasonov's Ph.D. thesis, Faculty of Information Technology, University of Jyväskylä (Simonas Šaltenis).

- External evaluator for Alberto Abello's Ph.D. thesis at the University of Catalunya, Spain, 2002 (Torben Bach Pedersen).

- External evaluator for Thomas Seidl's Habilitation application, Ludwig Maximilians Universität München, Germany, Spring 2001 (Christian S. Jensen)

Internal:

- Head of evaluation committee for Igor Timko's Ph.D. thesis, Aalborg University, 2005 (Simonas Šaltenis).
- Head of evaluation committee for Arturas Mažeika's Ph.D. thesis, Aalborg University, 2004 (Torben Bach. Pedersen).
- Examiner and chair of the PhD Committee for Thomas Vestdam, 2004 (Bent Thomsen).
- Head of evalutation committee for Anders Friis-Christensen's Ph.D. thesis, Aalborg University, 2003 (Torben Bach Pedersen).

Position Evaluation Committees

External:

- Member of an evaluation committee for a professor/associate professor position, May 2005–September 2005 (co-members: Andreas Opdahl and Nahid Shahmehri), University of Bergen, Department of Information Science and media Studies (Christian S. Jensen).
- Member of assessment committee for a number of postdoc positions at the Technical University of Denmark, 2005 (Torben Bach Pedersen).
- Member of an evaluation committee for a professor/associate professor position, May 2005–September 2005, University of Bergen, Department of Information Science and Media Studies (Christian S. Jensen, Andreas Opdahl, and Nahid Shahmehri).
- Member of assessment committee for an associate professor position at Copenhagen Business School, 2002 (Torben Bach Pedersen).
- Member of an evaluation committee in charge of appointing one Assistant or Associate Professor, IT University of Copenhagen, Spring 2001 (Christian S. Jensen).
- Chair of an evaluation committee in charge of appointing one Assistant or Associate Professor (members: Jens Christian Godskesen and Peter Carstensen), IT University of Copenhagen, Fall 2000/Spring 2001 (Christian S. Jensen).
- Member of an evaluation committee in charge of appointing one Assistant or Associate Professor, IT University of Copenhagen, Spring 2001 (Christian S. Jensen).
- Chair of an evaluation committee in charge of appointing one Assistant or Associate Professor, IT University of Copenhagen, Fall 2000/Spring 2001 (Christian S. Jensen).

Internal:

- Member of assessment committee for a number of Ph.D. positions at the Department of Communication Technology, Aalborg University, 2005 (Torben Bach Pedersen).
- Member of assessment committee for a postdoc position at the Department of Communication Technology, Aalborg University, 2005 (Torben Bach Pedersen).
- Member of assessment committee for a number of associate professors positions at Aalborg University, 2005 (Torben Bach Pedersen).
- Head of assessment committee for a research assistant position at Aalborg University, 2005 (Torben Bach Pedersen).
- Member of assessment committee for two research assistant positions at Aalborg University, 2005 (Simonas Šaltenis).
- Member of assessment committee for a research assistant position at Aalborg University, 2005 (Lone Leth Thomsen and Bent Thomsen).
- Head of assessment committee for a number of associate professors positions at Aalborg University, 2004 (Lone Leth Thomsen).
- Head of assessment committee for a number of associate professors positions at Aalborg University, 2004 (Torben Bach Pedersen).
- Head of assessment committee for a research assistant position at Aalborg University, 2003 (Torben Bach Pedersen).
- Member of assessment committee for a research assistant position at Aalborg University, 2003 (Torben Bach Pedersen).
- Head of assessment committee for a number of associate professors positions at Aalborg University, 2003 (Torben Bach Pedersen).
- Head of assessment committee for a number of associate professors positions at Aalborg University, 2003 (Torben Bach Pedersen).

Funding Committees

- Member of the Committee on Industrial Ph.D. Programmes (Erhvervsforskerudvalget) under the Danish Academy of Technical Sciences (Akademiet for de Tekniske Videnskaber), May 1999–May 2004 (Christian S. Jensen).
- Performing Remote evaluation tasks for IST-FET open (Future and Emerging Technologies) (Bent Thomsen).

- An expert in the Sixth Research Framework Programme (Christian S. Jensen, Bent Thomsen, Lone Leth Thomsen).

- Member of the Research Council of Norway's referee panel within physical science and technology, July 2005–June 2008 (Christian S. Jensen).

- Member of the UK Engineering and Physical Sciences Research Council College of peers in the IT and Computer Science Programme area, performing evaluation of up to ten research project proposals per year (Bent Thomsen).

- Performing project proposal evaluation for The Estonian Science Foundation (ETF) (Bent Thomsen).

- Grant proposal reviewer for the Council of Physical Sciences of the Netherlands Organization for Scientific Research, 2005 (Torben Bach Pedersen).

- Member of an evaluation committee in charge of evaluating research centers and institutes within Informatics and Applied Mathematics, under the supervision of the Greek Ministry of Development, General Secretariat of Research and Technology, Supervision of Research Institution Directorate, Greece, July 2005 (Christian S. Jensen).

- Member of the election committee for the Fujitsu Research Studentship in Automated Computing at the Computer Laboratory, Cambridge University, UK, 2004 (Bent Thomsen).

- Reviewer, The Research Grants Council of Hong Kong, 2002, 2003, and 2004 (Christian S. Jensen).

- Reviewer at First review of Global Computing initiative projects (the proactive initiative Co-operation of Autonomous and Mobile Entities in Dynamic Environments, commonly referred to as the Global Computing Initiative). Trento, February 2003 (Lone Leth Tomsen and Bent Thomsen).

- Reviewer, Science & Engineering Research Council, Agency for Science, Technology & Research, Singapore, 2003 (Christian S. Jensen).

- Panel member, ITR Program, National Science Foundation, Arlington, VA, USA, May 2003 (Christian S. Jensen).

- Reviewer, Hong Kong University of Science and Technology, University Grants Committee, 2002 (Christian S. Jensen).

- Reviewer, The Research Council of Norway, 2002 (Christian S. Jensen).

Other Committees

- Censor, Dept. Computer Science, Copenhagen University (DIKU), Christian Stefansen, midway exam/MSc. in 4+4 PhD. studentship (Bent Thomsen).

5.11.7 Consulting

- Independent consultant, GateHouse A/S, March 2005 (Christian S. Jensen).
- Independent consultant, Novo Nordisk, March-April 2005 (Christian S. Jensen, Torben Bach Pedersen).
- Independent consultant, Danish Broadcasting Corporation, May 2004 (Christian S. Jensen).
- Independent consultant, Dralle ApS, August 2002 (Christian S. Jensen).
- Independent consultant, Navigo Systems, July 2002 (Christian S. Jensen, Torben Bach Pedersen).
- Independent consultant, Technologisk Innovation A/S/Technology Innovation A/S, February 2001. (Christian S. Jensen)

5.11.8 Boards of Directors and Advisory Boards and Committees

- Member, Steering Committee, Center for Teleinfrastructure, Aalborg University, January 2004–present (Christian S. Jensen)
- Member, Steering Committee, Center for Intelligent Transport Systems, Aalborg University, January 2004–present (Christian S. Jensen)
- Member, Advisory Board, Mobile Convergence Innovation Network, November 2003–present (Christian S. Jensen)
- Member, Award Committee, Research Award of the Spar Nord Foundation, August 2003–present (Christian S. Jensen)
- Chairman, Board of Directors, ITS NorthDenmark, August 2002–June 2004 (in June 2004, the organization became part of the newly established ITS Denmark) (Christian S. Jensen)
- Member, Board of Advisors, Visanti A/S, May 2002–present (Christian S. Jensen)
- Member, Board of Directors, Acinta ApS, July 2001–June 2003 (Christian S. Jensen)
- Member, Board of Advisors, Mindpass A/S, August 2000–June 2001 (Christian S. Jensen)

- Member, Board of Directors, Euman A/S, June 2000–present (Christian S. Jensen)
- Member, Board of Directors, Netnord A/S, December 2000–July 2002 (Christian S. Jensen)

5.11.9 General

- Organizer, Danish Database Workshop 19, Aalborg, Denmark, April 19–20, 2004 (Torben Bach Pedersen and Kristian Torp).
- Member of the basis group of researchers contributing to the strategic plans of the Danish Technical Research Council for 2003–2007 (Christian S. Jensen).
- Member of the Danish Technical Research Council's Scientific Forum ("Fagligt Forum"), July 2001–July 2003 (Christian S. Jensen).
- Member of the national Danish corps of censors in Computer Science, April 1998–March 2006 (Christian S. Jensen).
- Member of the corps of evaluators, Frodskaparsetur Føroya (Faeroe Islands), 1991–2008 (Christian S. Jensen).
- Member of the Science Education Committee, a committee under the Danish Academy of Technical Sciences' Think Tank, April 2003–April 2004 (Christian S. Jensen).
- Included in the China Scholarship Council Databank of Overseas Supervisors (2002–) (Torben Bach Pedersen).
- Member of the committe in charge of forming a nomination to the ACM Publications Board of the next editor of *ACM Transactions on Database Systems*, Fall 2000/Spring 2001 (Christian S. Jensen).

Professional Organizations

Researchers in the unit are members of various national and international organizations such as ACM,SIGMOD, IEEE, and Computer Society

- Fellow, British Computer Society (BCS) (Lone Leth Thomsen and Bent Thomsen).
- Association for Computing Machinery (ACM):
  - ACM Member (Linas Bukauskas, Christian S. Jensen, Kurt Nørmark, Torben Bach Pedersen, Albrecht Schmidt, Simonas Šaltenis, Lone Leth Thomsen, and Bent Thomsen);

  - ACM Special Interest Group on the Management of Data (SIGMOD) (Linas Bukauskas, Christian S. Jensen, Torben Bach Pedersen, Albrecht Schmidt, and Simonas Šaltenis).
  - ACM Special Interest Group on Knowledge Discovery and Data Mining (SIGKDD) (Christian S. Jensen).

- European Association for Theoretical Computer Science (Lone Leth Thomsen and Bent Thomsen).

- Institute of Electrical and Electronics Engineers (IEEE):

  - IEEE Senior Member (Christian S. Jensen).
  - IEEE Member (Torben Bach Pedersen, Lone Leth Thomsen, and Bent Thomsen).
  - IEEE Computer Society (Christian S. Jensen, Lone Leth Thomsen, and Bent Thomsen).
  - IEEE Technical Committee on Data Engineering (Christian S. Jensen).

- Member of the ZobIS (Zeitorientierte betriebliche Informationssysteme) working group. Part of the German Gesellschaft für Informatik (Christian S. Jensen).

5.12 Bibliography

5.12.1 Coverage

The bibliography aims to document the work conducted and results obtained during the evaluation period. The bibliography includes papers with publication dates during the reporting period and papers accepted for publication. It does, however, not include papers in submission.

As a result, some papers may concern work done only in part during the evaluation period, and other results obtained during the evaluation period are not covered. Also, this practice implies a slight overlap between papers reported for consecutive reporting periods.

Extended versions of some conference publications were later published in journals, which implies some overlap between the two categories of papers. In addition, a substantial portion of the technical reports are extended versions of papers published in conferences and journals.

Finally, it is noted that very substantial program code has been developed that documents the results obtained during the evaluation period. This code is not included in the bibliography.

5.12.2 Refereeing and Acceptance Rates

The bibliography has two categories of refereed publications, where the ACM's definition of *refereed* is used: "A thorough review with emphasis on novelty and soundness. A journal refereeing process seeks to advise the editor whether to reject or provide specific guidance for revisions. A conference refereeing process seeks to advise the editor whether to accept or reject; a strict deadline is enforced. Persons serving as referees are independent of the editors who request their advice." In addition, the last category in this bibliography contains some papers that are only lightly refereed or reviewed.

Rankings of conferences are given below, together with average acceptances rates for the period 2001–05 for some of the conferences. (Journals tend to not advertise their acceptance rates.)

General Conferences 1a. VLDB (17%), ACM SIGMOD (16%). 1b. IEEE ICDE (15%), EDBT (16%).
2. DASFAA (22%), CIKM (19%), IDEAS (24%), CAiSE (22%), ADBIS (24%).
3. SAC, ADC, ICEIS, DEXA, OTM, WISE, COMAD, BNCOD, etc.

Specialized Conferences

Spatial 1. SSTD (31%). 2. ACM GIS (33%), MDM.
3. SDH, MobiQuitous, MobiDE, W2GIS, STDM. 4. ScanGIS, ITS.

Conceptual Modeling 1. ER (21%), UML (26%).

Data Warehousing 1. SSDBM. 2. DOLAP, DaWaK.

A few notes are in order: We have attempted to collect rates for the conferences that we rank highly, but have not been successful in all cases.

The figures for DASFAA and CIKM cover only the last two years, and the figure for IDEAS covers only the last three years. The figure for ADBIS does not cover 2004. The figure for ACM GIS covers only the last four years.

We observe that the top-tier outlets are the most selective. As these have gained a reputation over the years for being selective and prestigious, they also involve substantial self-refereeing: authors tend to submit only their best works to these outlets. The acceptance rates found for the second tier of conferences are all below 25%. There is a clear trend towards these conferences becoming increasingly selective during the evaluation period. This trend also applies to the specialized conferences for which we have found figures.

The explanation seems to be that the database community is growing and that the different outlets. Conferences in the first tier now typically receive between 300 and 600 submissions, with VLDB receiving the most submissions.

5.12.3 Notes Concerning Citations

A recent paper, E. Rahm and A. Thor: Citation analysis of database publications, *ACM SIGMOD Record*, 34(4): 48–53, December 2005, sheds light on the group's

performance with respect to citations. This paper reports on several high-quality studies of citation frequencies of papers published in five highly cited and thus important database outlets.

The outlets include the conferences ACM SIGMOD and VLDB, as well as the journals ACM TODS The VLDB Journal, and ACM SIGMOD Record. The 10-year period from 1994 to 2003 is considered. The study uses the resources DBLP (Digital Bibliography and Library Project, http://www.informatik.uni-trier.de/∼ley/db) and Google Scholar. Citations are cleaned to eliminate self-citations.

In one of its studies, the paper reports on citation counts by country. This study considered only papers that received more than 20 citations (these received more than 91% of all citations). The top-ten list of countries is as follows: USA, Germany, Canada, France, Italy, Israel, Japan, Denmark, Switzerland, and Greece.

We know of no publications from Denmark in these outlets during the period covered that do not stem from our group (there are no other database research groups in Denmark). This study then appears to suggest that the group performs well in comparison to at least the groups in countries that place below Denmark. We also note that if the top-ten list is normalized by population size, only USA and Israel are above Denmark.

5.12.4 Edited Books

[1] Klemens Böhm, C. S. Jensen, Laura M. Haas, Martin L. Kersten, Per-Åke Larson, and Beng Chin Ooi. *Proceedings of the 31st International Conference on Very Large Data Bases*. ACM, Trondheim, Norway, August 30–September2 2005. 1372+xxiv pages.

[2] C. S. Jensen. *Special Issue on the IEEE Data Engineering Bulletin on Indexing of Moving Objects*, volume 25. IEEE Data Engineering Bulletin, June 2002. 64 pages.

[3] C. S. Jensen. *Special Issue of Information Systems With Best Papers from EDBT*, volume 28. Information Systems, March–April 2003. 157 pages.

[4] C. S. Jensen. *Special Issue of the IEEE Data Engineering Bulletin on Infrastructure for Research in Spatio-Temporal Query Processing*, volume 26. IEEE Data Engineering Bulletin, June 2003. 54 pages.

[5] C. S. Jensen, K. Jeffrey, J. Pokorny, S. Saltenis, E. Bertino, K. Böohm, and M. Jarke. *Advances in Database technology - EDBT 2002*. Number 2287 in Lecture notes in computer science. Springer, 2002. 776+xvi pages.

[6] C. S. Jensen, M. Schneider, B. Seeger, and editors V. J. Tsotras. *Advances in Spatial and Temporal Databases—Seventh International Symposium, SSTD 2001*, volume 2121 of *Lecture Notes in Computer Science*. Springer-Verlag, 2001. 543+xi pages.

[7] T. Sellis, M. Koubarakis, A. Frank, S. Grumbach, R.H̃. Güting, C.S̃. Jensen, N. Lorentzos, Y. Manolopoulos, E. Nardelli, B. Pernici, H.-J. Schek, , M. Scholl, B. Theodoulidis, , N. Tryfona, and editors. *Spatio-Temporal Databases : The Chorochronos Approach*, volume 2520. Lecture Notes in Computer Science, 2003. 352+xiv pages.

5.12.5 Refereed Journal Articles

[8] P. K Agarwal, L. J Guibas, H. Edelsbrunner, J. Erickson, M. Isard, S. Har-Peled, J. Hershberger, C. S. Jensen, L. E. Kavraki, P. Koehl, M. Lin, D. Manocha, D. Metaxas, B. Mirtich, D. Mount, S. Muthukrishnan, D. K. Pai, E. Sacks, J. Snoeyink, S. Suri, and O. Wolfson. Algorithmic Issues in Modeling Motion. *ACM Computing Surveys*, 34(4):550–572, December 2002.

[9] M. O. Akinde, M. H. Böhlen, T. Johnson, L. V. S. Lakshmanan, and D. Srivastava. Efficient OLAP query processing in distributed data warehouses. *Information Systems*, 28(1):111–135, February 2003.

[10] Lars Bendix and Görel Hedin. Summary of the subworkshop on extreme programming. *Nordic Journal of Computing*, 9(1):261–266, 2002.

[11] Rimantas Benetis, C. S. Jensen, Gytis Karčiauskas, and Simonas Šaltenis. Nearest Neighbor and Reverse Nearest Neighbor Queries for Moving Objects. *VLDB Journal*, 2006. 22 pages, to appear.

[12] M. H. Böhlen, L. Bukauskas, P. S. Eriksen, S. L. Lauritzen, A. Mažeika, P. Musaeus, and P. Mylov. 3D Visual Data Mining: goals and experiences 3D visual data mining. *Computational Statistics & Data Analysis*, 43(4):445–469, 2003.

[13] M. H. Böhlen, J. Gamper, and C. S. Jensen. An Algebraic Framework for Temporal Attribute Characteristics. *Annals of Mathematics and Artificial Intelligence*, 2006. 28 pages, to appear.

[14] Jan Chomicki, David Toman, and M. H. Böhlen. Querying atsql databases with temporal logic. *ACM Transactions on Database Systems*, 26(2):145–178, 2001.

[15] Alminas Čivilis, C. S. Jensen, and Stardas Pakalnis. Techniques for Efficient Tracking of Road-Network-Based Moving Objects. *IEEE Transactions on Knowledge and Data Engineering*, 17(5):698–712, May 2005.

[16] C. E. Dyreson, M. H. Böhlen, and C. S. Jensen. METAXPath. *JoDI: Journal of Digital Information*, 2(2), 2001. 7 pages.

[17] Erik Ernst. Safe dynamic multiple inheritance. *Nordic Journal of Computing*, 9(3):191–208, Fall 2002.

[18] Anders Friis-Christensen, C. S. Jensen, Jan P. Nytun, and David Skogan. A Conceptual Schema Language for the Management of Multiple Representations of Geographic Entities. *Transactions in GIS*, 9(3):345–380, June 2005.

[19] Dengfeng Gao, C. S. Jensen, Richard T. Snodgrass, and M. D. Soo. Join Operations in Temporal Databases. *VLDB Journal*, 14(1):2–29, March 2005.

[20] C. S. Jensen, Augustas Kligys, T. B. Pedersen, and Igor Timko. Multidimensional Data Modeling For Location-Based Services. *The VLDB Journal*, 13(1):1–21, 2004.

[21] C. S. Jensen and T. B. Pedersen. Mobile E-Services and Their Challenges to Data Warehousing. *Datenbank Rundbrief*, 27:8–16, 2001.

[22] M. R. Jensen, T. H. Møller, and T. B. Pedersen. Specifying OLAP Cubes on XML Data. *Journal of Intelligent Information Systems*, 17(2/3):255–280, 2001. Best papers of SSDBM '01.

[23] M. R. Jensen, T. H. Møller, and T. B. Pedersen. Converting XML DTDs to UML Diagrams For Conceptual Data Integration. *Data and Knowledge Engineering, Kluwer*, 44(3):323–346, 2003.

[24] P. Madsen. Enhancing Design by Contract with Knowledge of Equivalence Partitions. *Journal of Object Technology*, 3(4):5–21, 2004.

[25] K. Nørmark. Web programming in Scheme with LAML. *Journal of Functional Programming*, 15(1):53–65, January 2005.

[26] T. B. Pedersen and C. S. Jensen. Multidimensional Databases Technology. *IEEE Computer: Innovative Technology for Computer Professionals*, 34(12):40–46, 2001.

[27] T. B. Pedersen, C. S. Jensen, and C. E. Dyreson. A Foundation for Capturing and Querying Complex Multidimensional Data. *Information Systems*, 26(5):383–423, 2001.

[28] Mindaugas Pelanis, Simonas Šaltenis, and C. S. Jensen. Indexing the Past, Present and Anticipated Future Positions of Moving Objects. *ACM Transactions on Database Systems*, 2005. 37 pages, to appear.

[29] D. Pfoser and C. S. Jensen. Trajectory Indexing Using Movement Constraints. *Geoinformatica*, 9(2):93–115, 2005.

[30] D. Pfoser and Y. Theodoridis. Generating semantics-based trajectories of moving objects. *International Journal of Computers, Environment and Urban Systems*, 27(3):243–263, 2003.

[31] D. Pfoser, Nectaria Tryfona, and C. S. Jensen. Indeterminacy and Spatiotemporal Data: Basic Definitions and Case Study. *Geoinformatica*, 9(3):211–236, September 2005.

[32] Simonas Šaltenis and C. S. Jensen. Indexing of Now-Relative Spatio-Bitemporal Data. *The VLDB Journal*, 11(1):1–17, 2002.

[33] Janne Skyt and C. S. Jensen. Persistent Views—A Mechanism for Managing Aging Data. *Computer Journal, Oxford Journals*, 45(5):481–493, 2002.

[34] Janne Skyt, C. S. Jensen, and L. Mark. A Foundation for Vacuuming Temporal Databases. *Transactions on Data and Knowledge Engineering*, 44(1):1–29, 2003.

[35] Giedrius Slivinskas, C. S. Jensen, and R. T. Snodgrass. A Foundation for Conventional and Temporal Query Optimization Adressing Duplicates and Ordering. *IEEE Transactions on Knowledge and Data Engineering*, 13(1):21–49, 2001.

[36] Kristian Torp, C. S. Jensen, and R. T. Snodgrass. Modification Semantics in Now-Relative Databases. *Information System*, 29(8):653–683, 2004.

[37] Thomas Vestdam. Elucidative Program Tutorials. *Nordic Journal of Computing*, 9(3):209–230, 2002.

[38] Thomas Vestdam and K. Nørmark. Maintaining Program Understanding - Issues, Tools, and Future Directions. *Nordic Journal of Computing*, 11(3):303–320, Fall 2004.

[39] Xuepeng Yin and Torben Bach Pedersen. Evaluating XML-Extended OLAP Queries Based on a Physical Algebra. *Journal of Database Management*, 17(2):85–114, April-June 2006. to appear.

5.12.6 Refereed Conference Articles

[40] M. Agesen, M. H. Böhlen, L. O. Poulsen, and Kristian Torp. A Split Operator for Now-Relative Bitemporal Databases. In *Proceedings of the 17th International Conference on Data Engineering*, pages 41–50, Heidelberg, Germany, April 2001.

[41] M. O. Akinde and M. H. Böhlen. Generalized MD-joins: Evaluation and reduction to SQL. In *Proceedings of the VLDB 2001 International Workshop on Databases in Telecommunications II*, pages 52–67, Rome, Italy, September 2001.

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Distributed Systems and Semantics | 6

6.1 Executive Summary

The research of the distributed systems and semantics group concerns modelling, analysis and realization of computer programs, with emphasis on distributed and embedded systems. The contributions of the group include work on semantic foundation, algorithms and tools for verification and validation, and design and implementation of networks and operating systems. Thus research activities are both theoretical/ foundational in nature as well as practical/ experimental.

The group takes a leading international position within concurrency theory, verification and validation and embedded systems, and has a high national profile in networks and grid computing. The work on the real-time verification tool UPPAAL and the several emerging branches has been a unifying activity of the group with high international impact. The overall strategic goal of the period has been on focusing the research effort on *embedded systems*. With the opening of Center for Embedded Software Systems, CISS, this direction has been pursued in ways far more successful, than what was hoped for initially, and with significant industrial impact.

During the period the group has been involved in extensive research collaboration. At a national level the continued effort in BRICS (Basic Research in Computer Science), the new responsibilities in DCGC (Danish Center for Grid Computing) and the principle role in the high technological networks Mobile Systems and Pervasive Communication are major activities. Internationally, the group has been engaged in several EU projects including ARTIST2, *the* Network of Excellence within embedded systems under EU's 6th Framework. The international recognition and visibility of the group is also witnessed by the high number of refereed publications in major international conferences and journals, significant research awards to two members of the group, numerous services to the international research community, and the high number of external visitors to the group.

6.2 Profile of the Group

The research of the group concerns modelling, analysis and realization of computer programs, with an emphasis on distributed and embedded systems. This includes the following areas:

- Semantic theories for modelling the behavior of computer programs and systems.

- Design, implementation and models for analysis of distributed systems and networks.
- Algorithms, methods and tools for verification and validation of programs and systems.

In its present form the Distributed Systems and Semantics group was created in 1997 by a fusion of the two previous groups of Computer Systems and Formal Systems. Since 1993 the group has been part of BRICS, the Center for Basic Research in Computer Science (BRICS) together with colleagues at Århus University. In 2001 the Centre for Integrated Software Systems (CISS) was established in collaboration with the Institute for Electronic Systems at Aalborg University. The focus of CISS is to create an industry oriented research centre of excellence with a distinctively visible profile within software construction and embedded systems, making use of and creating new research within areas already existing in the group. Consequently, the research of the group spans a wide range from development of the semantic foundations of computing and concurrency to contributions to the technological state of the art within embedded, real-time and networking systems. To conduct quality research within such a wide spectrum is a challenging task. However, the common emphasis on distributed and concurrent systems focuses the activities within the group.

Each of the three research areas mentioned above constitutes a subject in its own right. Moreover, the areas are interrelated in a number of ways: semantic models offer important guidelines for development of languages and paradigms for distributed systems; semantic models are necessary prerequisites for development of verification algorithms and tools; the development of validation tools provides new insight into the underlying semantic models on one hand, and are applied in environments for the construction and analysis of distributed systems; the evolving nature of distributed systems provide insight to the strengths and weakness of existing semantic models, and serve as inspiration for development of new ones; finally, distributed systems truly expose the limits of given verification algorithms.

The current research of the group includes the following activities:

Concurrency Theory: Semantic theories and meta-theories for concurrent processes and their logical properties. Semantic theories for processes whose communication topology changes dynamically, including security protocols. Study of novel extensions such as hybrid, real-time, and probabilistic processes.

Verification and Validation: Development and implementation of data structures, algorithms and tools for model-checking embedded systems and real-time systems. Applications to communication protocols, control programs, and planning and scheduling.

Embedded Systems Methodology: Methodologies for specification, analysis and testing of embedded systems. Modelling and analysis of industrial case studies. Theoretical foundations of embedded and hybrid systems.

Networks & Operating Systems: Analysis and construction of services and protocols for computer networks, including grid computing and high-performance computing. Real-time and embedded operating systems.

6.3 Research Goals 2001-05

In the previous research evaluation, the research goals for 2001-2005 are stated both in terms of concrete research goals for the existing activities and strategic goals for the group including areas for joint research.

Overall Research Goals

The important overall goal for the group was formulated as *"the creation of a theoretically well-founded discipline for the development of embedded software systems"*. This would involve all research area within the group covering the experimental side, the foundational side and the effort on tool development. This strategy also called for a strengthened involvement in industrial collaborations, as these were seen to be essential for generating external funding, and because they are a strong motivation for students. Finally, a commitment to pursue embedded systems not only in research but also in teaching was formulated.

Concrete Research Goals

The concrete research goals originally stated for 2001-2005 may be summarized as follows:

Process Algebra: Continue work on study of equational logic of mathematic structures arising from process algebras and the classical area of formal languages. Extensions of theories in the direction of hybrid systems. Development of process calculi allowing for both nondeterminism, real-time and stochastic behavior to be modelled. Finally, stronger effort for the community in disseminating the results of the field.

Calculi for Mobility and Objects: Application of the spi-calculus to analysis of security protocols. Construction of a software tool for verification of security properties. Work on relating different models for objects. Development of a new version of the Mobility Workbench.

Verification and Validation: An effort in transferring the results of the group in this area to software engineering practice, in particular in the area of embedded systems. Effort on developing a branch of UPPAAL especially targeted towards (optimal) scheduling and planning. Work on stochastic extensions of UPPAAL allowing for performance analysis. Continued improvement of performance of UPPAAL. Placing our tool efforts in the context of an UML based design methodology. Complementation of work on verification tools with testing. Stimulating work on UPPAAL by UPPAAL workshops.

Real-Time Systems: Pursuing industrial case studies and industrial collaboration. Work on UML based specification methodology – closing the gap between available formalisms and tools in academia and industrial practice. Work on testing for real-time systems. Continued work on design and development of an autonomous plant inspection system.

Networks: Improvements for Internet protocols and in particular on mobility related problems. Research on efficient handling of web traffic, and QoS in heterogeneous networks. Collaboration with local mobile telephone companies on future protocols. Establishment of a substantial laboratory for practical experiments, and also to use the Danish research network for experiments.

Finally a number of joint research directions for exploiting tool and theory development in connection with practice were identified including linking the effort on UPPAAL closer to UML, model-based testing and hybrid systems.

6.4 Activities and Results

6.4.1 Concurrency Theory

Concurrency theory has been a topic in theoretical computer science for the past twenty-five years, and it has by now reached a level of maturity that is comparable to that of the classic theory of automata and formal languages. We have contributed to the study of concurrency theory by solving open problems that are important for the "internal" development of the theory of processes and applying the tools and techniques from concurrency theory to other areas of computer science (e.g. biology, scheduling and security).

Equational Axiomatizations

One of the natural outcomes of the algebraic structure of process calculi is that we can formulate general equivalences between process terms that we expect to hold with respect to the chosen notion of behavioral semantics in terms of equations. Several natural questions immediately arise pertaining to the existence of (finite) collections of laws that allow us to prove by "substituting equals for equals" all of the equalities between process descriptions over fragments of process algebras that hold with respect to some notion of equivalence. A collection of laws with the above property is called a *complete axiomatization* of the algebra under study.

We have made several contributions to the study of complete axiomatizations for various (process) equivalences. Notable amongst these results are the proof of a conjecture of Bergstra and Klop's dating from 1984, and the proof that none of the nested semantics is finitely based over finite synchronization trees.

Decidability and Complexity

Verification techniques for finite-state processes are a successful approach for the validation of reactive programs operating over finite domains. When infinite structures (like infinite data domains, unbounded control structures, real-time features and parameterized reasoning) are introduced, many of the verification problems become in general undecidable. By imposing certain restrictions on the considered models, it is possible to provide algorithmic decision procedures for a variety of properties.

We have contributed to the study of infinite-state systems by obtaining new undecidability results in equivalence checking of PA-processes, Petri nets and pushdown processes, including a complete characterization of the undecidability levels of the respective problems. The complexity issues of bisimilarity checking for simple process algebras were studied. We have shown demonstrated the undecidability of Hhp-Bisimilarity for 1-safe Petri nets. A summary of state-of-the-art was published to give an overview of selected results and techniques.

Basic Research in Computer Science BRICS

Created in 1994 as a large scale research center funded by the Danish National Research Foundation initially for the period 1994-98 with a grant of DKK 6,500,000 per year. Additional funding was given for starting an international Ph.D. school at Århus University. The center has been extended until 2006 with an additional grant of DKK 40,000,000. The original aim of BRICS was to establish important areas of basic research in the mathematical foundations of Computer Science in Denmark, including activities in algorithms, mathematical logic and semantics. In addition to these areas, the center added verification and cryptography to the list of activities in 1996. The activities has been centered around the permanent staff at the two universities, and an average of 15-20 foreign, long term junior and senior associated researchers, 20 Ph.D student and an intensive programme of visiting researchers and scientific events. The activities in Aalborg has accounted for 25% of the total project.

Real-Time and Scheduling

As key activities within two European projects VHS and AMETIST the technology for analyzing timed automata where pursued in the direction of real-time scheduling and planning. In order to address *optimality* of such schedules *priced timed automata* was introduced. During the period a number of optimization problems for this modelling formalism has been considered and shown decidable. The problem of optimal reachability was shown decidable. Later, the problem of optimal *infinite* schedules in terms of optimal long-term cost per time ratio was shown decidable. Optimal reachability in the presence of multiple cost has been considered and shown decidable. Finally, the problem of synthesizing optimal winning strate-

gies for priced timed *games* has been shown decidable under so-called strong cost non-zenoness assumptions. Another activity in the area of real-time systems focused on time extensions of Petri nets and on the relationship of time extended Petri net models with timed automata.

Calculi for Mobility and Security

The family of π-calculi allow us to describe systems whose communication properties change dynamically, including security protocols.

The spi-calculus, due to Abadi and Gordon, extends the π- calculus with encryption and decryption and gives a mathematical theory for reasoning about security protocols. We have described a modal logic characterizing Abadi and Gordon's framed bisimilarity. Later, we have shown that the spi-calculus even with bounded recursion is Turing-powerful but also that framed bisimilarity is decidable for the non-recursive fragment.

We have also studied the expressive power of a recursive process calculus that allows arbitrarily many runs of ping-pong protocols. We show the limited potential of automatic verification even in this setting: Our process calculus is Turing-powerful, and this is even the case without nondeterministic choice. Reachability, though, is decidable for protocols with at most two principals. Moreover, the calculus is powerful enough to describe a strongest Dolev-Yao-style attacker.

We have considered the problem of *access control* for the Calculus of Mobile Resources.We give a type system describing security policies for processes and show that it satisfies the usual requirements of subject reduction and type safety. Moreover, we present a sound type inference algorithm that extracts minimal security policies.

The work on formal models for objects has resulted in a number of results showing how the π-calculus can be used to reason about object-oriented programs.

Computational Biology

During the period 2001–2005, we have applied tools and techniques from the theory of concurrency to the growing field of computational (systems) biology. Most of the work along this line of research has been inspired by a collaboration between Anna Ingólfsdóttir and deCODE Genetics, and by that company's interest in genetic linkage analysis. Perhaps the most notable outcome of this collaboration is the release of Allegro 2, a new version of the company's software tool for genetic linkage analysis based on the technology of Multi Terminal Binary Decision Diagrams, that is far superior to any other existing tool for that purpose.

We have also studied the computational complexity of the problem of checking the consistency of genotype information over pedigrees an important pre-processing step before linkage analysis. The problem is settled to be NP-complete (#P complete).

6.4.2 Verification and Validation

The DSS group is worldwide acknowledged for its research on verification and validation of real-time and embedded software systems as witnessed by the numerous responsibilities entrusted by the community[1]. During the period 2001-2005, the work on the real-time verification tool UPPAAL has continued with undiminished effort involving collaboration with several research research groups outside Denmark.

In connection with our involvement in the two European projects VHS[2] and AMETIST[3] two new very promising directions have emerged, giving rise to the two new branches UPPAAL CORA, targeted towards optimal scheduling, planning and controller synthesis, and UPPAAL TRON, targeted towards testing of real-time systems.

Besides the work on UPPAAL and its branches, main contributions are associated with the commercial verification tool visualSTATE, where a patented, groundbreaking algorithmic verification method has been developed.

Verification

During the period several contributions have been made towards improving the verification engine of UPPAAL. All of these techniques are theoretically firmly based, and have experimentally been shown to yield truly significant improvements of performance both time- and space-wise.

The techniques include development of new data structures for efficient representation of state spaces, algorithmic techniques for user-specified guiding of state space exploration, automatic guiding techniques by application of heuristic search techniques from AI. The contributions also include abstraction techniques resulting in improved performance of an order or magnitude, exploitation of symmetries in models, and acceleration of exploration of loops.

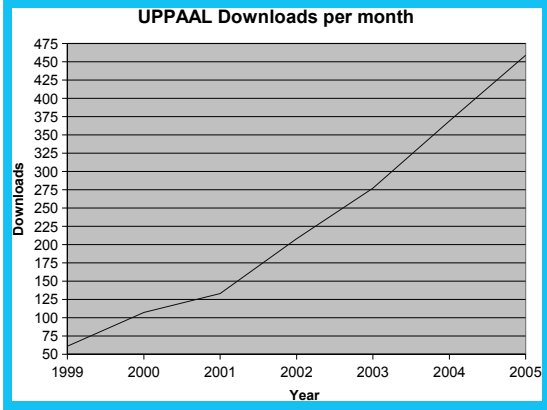
Finally, parallel and distributed implementation of algorithms for UPPAAL has been provided with very encouraging experimental results. Currently work towards allowing for parallel and distributed analysis of properties is going on in the context of the ARTIST2 Network of Excellence. Also, this work is closely connected to the research of the group within high-performance computing and grid computing.

[1] Serving on the steering committees of TACAS and ETAPS; organizing and charing conferences such FORMATS and CAV.

[2] Verification of Hybrid Systems

[3] Advanced MEthods for Timed SysTems

UPPAAL



UPPAAL (`http://www.uppaal.com/`) is a modelling, simulation and verification tool for real-time systems developed since 1995 in collaboration with Uppsala University. Approaching its 10th anniversary, UPPAAL has grown from being a minor research prototype to being *the* de facto tool for verification of real-time systems, to which other tools in the area are compared. The UPPAAL tool has fostered a wide array of research around the world. An indication of its popularity with education and research is that the tool is downloaded between 10 and 25 times a day (over 5600 times within the last year), that courses on UPPAAL or using UPPAAL are given at several international universities – e.g. DTU, IT-U (DK), Chalmers, Linköping, Lund, Chalmers, Mälerdalarn (S), Nijmegen, Twente, CWI (N), UPenn, Northumbria (US), Braunschweig, Oldenborg, Marktoberdorf (D), Tsinghua, Shanghai, IIS, NUS (Asia) – that members of the DSS group have given given invited tutorials at numerous schools – e.g. including Estonian Winterschool (2001), IPA Fall Days (2001), FTRTFT (2002), Third Workshop on Coloured Petri Nets (2002), SFM, Ph.D. school on Formal Methods (2002), MOVEP (2002), DISC Summer School (2003), EFF Summer School (2003), SFM Ph.D. school on Real Time (2004), MOVEP (2004), PRISE (2004), PDMC (2005), ARTIST2 Summerschool (2005), EMSOFT (2005), RTSS (2005), TECS week TCS (2006). Also, there is a great interest by other research groups in contributing to the further development of the tool (e.g. Nijmegen, Cachan, Twente, Nantes, Oldenborg, Friburg, Kent, and Brno) and an enormous number of publications by independent researchers that use UPPAAL. The tool is applied increasingly by companies including Mecel, Jet, Symantec, SRI, Relogic, Realworkd, NASA, Microsoft, ABB, Airbus, PSA, Saab, Siemens and Volvo. Currently UPPAAL are receiving more than 1,500 Google Scholar citations. In comparison commercial tools as Rhapsody and Esterel Technologies has less than 3,500 Google Scholar citations. Finally, the work on UPPAAL has been recognized by two awards: in 1999 Kim G. Larsen became Honorary Doctor at Uppsala University, and Gerd Behrmann received the SPAR Nord Foundation Research Award 2004 for his Ph.D. thesis: “Data Structures and algorithms for the Analysis of Real Time Systems”.

The modeling formalism of UPPAAL has been extended with a number of new features, allowing the use of C data types and C expressions.Also, the specification formalism of UPPAAL has been extended to allow for checking of (time-) bounded liveness properties using so-called test-automata, general liveness properties, and

synthesis for parameterized bounded liveness properties. Several tutorials on UPPAAL (architecture, implementation "secrets" and usage) have been made during the period with being the most recent, and the DBM-library of UPPAAL, i.e. the data structures and algorithms, has been made public.

However, the work on verification is not limited to timed automata. In the beginning of the period significant contributions to symbolic verification of state machines and hierarchical models was made. This work was done in collaboration with the company IAR Systems A/S (and colleagues at Denmark's Technical University) in an attempt to improve the performance of the verification engine of the already commercially successful tool visualSTATE. The results were particularly encouraging: a new CBR-technique was developed allowing for designs with more than 1400 parallel machines (and state spaces with more than 10^{500} states) to be analyzed. By now the method is patented and an integrated part of the distributed version of the visualSTATE tool.

Scheduling, Planning and Controller Synthesis

Within the EU project VHS timed automata technology in general and UPPAAL in particular has been be applied to scheduling and planning problems. It was observed that for several such problems timing constraints play a dominating role and may thus be naturally modelled using timed automata. Early prototype variants of UPPAAL supporting symbolic branch-and-bound exploration and allowing the user to provide guiding heuristics clearly demonstrated the potential of timed automata technology in this new setting of scheduling and planning.

The ability to address general *optimal* planning and scheduling problems, was made possible by the introduction of a PTA, *priced timed automata*. As a modeling formalism PTA extends timed automata with a single real-valued variable *cost* which may increase with different rate in different locations and possibly increase during transitions. In the problem of optimal reachability was shown decidable, and in the efficient *priced zone* data structure was introduced together with the first version of UPPAAL CORA.

The work on applying timed automata technology to scheduling has been the point of focus in the most recent EU project AMETIST. Within AMETIST the performance of cost-optimal reachability has been improved dramatically, by exploiting dualities[4] resulting in a tool which today is competitive with state-of-the-art planning and scheduling techniques: UPPAAL CORA outperforms MILP (Mixed Integer Linear Programming) on a number of benchmarks. UPPAAL CORA has been successfully applied to the most challenging case-study of the AMETIST project: the AXXOM case, in which optimal schedules for production of lacquer was requested. Most recently, a number of papers surveying the use of PTA and UPPAAL CORA in modelling and analyzing optimal scheduling problems (ranging

[4]More precisely by converting linear optimization problems over zones to dual min-cost flow problems for which the more efficient net-simplex algorithm is applicable.

from cost-optimal task-graph scheduling, air-craft landing to energy-optimal dynamic voltage scaling) has been published (often by invitation). Also, recent work by Henning Dierks, Oldenburg, use UPPAAL CORA to provide a planner for the modelling language PDDL-3

Most recently, UPPAAL TIGA – a new branch of UPPAAL – has emerged as the result of a new on-the-fly algorithm for computing (time-optimal) winning strategies for timed games. The performance of UPPAAL TIGA is very encouraging, and effort is currently being made towards full exploitation.

Testing

In many kinds of systems, the occurrence of failures can have a dramatic effect for vendors or for users . Therefore, it is common industrial practice to spend 30-50% of the total development time and costs on testing. This is partly due to the fact that the available methods, tools and techniques until recently have been rather ad hoc — especially at the systems level.

It is generally agreed that the use of *model based testing* has a great potential to improve the above situation. The basic idea is to apply requirements models (e.g. logical formulae, sequence charts or state machines) as the basis for test generation, and to use test generation tools to automatically generate test cases from such models, and later automatically execute these test cases. This often involves using and extending the algorithmic machinery found in model checking tools for traversing specification models. Several research groups have demonstrated the feasibility of the approach for untimed systems, and during the period, the DSS research group has demonstrated that it also can be extended to timed systems in the framework of timed automata using the UPPAAL verification engine.

The notion of *acceptance trees* was extended to a timed setting and a tools was developed for generating timed test cases (using the UPPAAL engine). The idea was further refined to generate test cases based on coverage or various optimality criteria. Also, it has been applied for so-called *connectivity testing* where a failure can be a missing connection between a device and its environment.

Whereas the above contributions are all *off-line* generation of test cases (i.e. ahead of execution), the UPPAAL TRON provides a recent extension supporting *on-line* test generation for real-time systems, having so far been applied to a medium size, industrial case study.

Probabilistic Analysis

The work on the tool RAPTURE was carried out in collaboration with the Formal Methods and Tools Group at Twente University. The ambition was to create a powerful, stochastic extension of UPPAAL allowing for a wide range of performance analyzes to be carried out using model checking.

The tool RAPTURE[5] verifies reachability probability bounds on Markov Deci-

[5] `http://www.irisa.fr/prive/bjeannet/prob/prob.html`

sion Processes (MDPs), also know as Probabilistic Transition Systems. RAPTURE carries out a partitioning/refinement algorithm, computing after each iteration estimates of the reachability probabilities and symbolically representing the blocks of a partition using BDDs (binary decision diagrams). So-called essential state reduction provides further improvements of performance.

RAPTURE has been used in the performance evaluation of a number of case-studies including Philips Bounded Retransmission Protocol and the Binary Exponential Backoff mechanism of the Internet. It has also been shown how Probabilistic Timed Automata may be reduced to Markov Decision Processes and thus analyzed by RAPTURE.

Center for Embedded Software Systems

Created in 2002 as one of four IT-centers under the IT-initiative in Jutland-Fuen. The center is funded for 4 years by the Danish Ministry of Science, Technology and Innovation (DKK 25,500,000), the County of Northern Jutland (DKK 6,000,000) and the city of Aalborg (DKK 6,000,000), and with expected co-financing from AAU (DKK 12,750,000) and IT-companies (DKK 12,750,000). The aim of the project is to strengthen collaboration between research and industry in the area of embedded systems. The center is joint with colleagues at the departments of Control Engineering and Communication Technology. So far, the center has initiated 24 collaborative projects involving 28 companies, 13 industrial Ph.D.'s. The co-financing from industry already at this stage more than 40% above the original budget, and in a recent evaluation performed by the Ministry the industrial impact of the center is rated very high. The center is core partner in ARTIST2, the European Network of Excellence in embedded systems, coordinating the activities in Testing and Verification. Also, the center is principal partner in the two newly started high-technological networks Mobile Systems and Pervasive Communication.

6.4.3 Embedded Systems Methodology

Until recently, most companies developing embedded systems have based their methodology on variants of the V-method. This method follows the linear development life cycle, which is mainly applicable when the system requirements are well defined and when there are no uncertainties wrt. the system architecture.

Modern embedded systems are characterized by complex requirements wrt. functionality and resource management (time, space, energy), and it is generally agreed that the V-method is insufficient to support the development of such systems. What is needed is a method that allows for early analysis of selected complex requirements and postponing the treatment of more trivial ones, and also for reasoning about composite component properties without having detailed knowledge about their implementation.

In order to allow for early requirements analysis, some form of model based development is clearly needed, and the long term vision is to reach a situation

where a T-method (without any programming effort) is possible. In the meantime, more pragmatic approaches are needed, and one solution is to combine state-of-the-art tools supporting model based development with contemporary object oriented methods.

In the period, the DSS group has been involved in a number of industrial collaborations, where an object oriented method has been taught in a concentrated period – followed by a coaching period, where researchers from the group have been introducing the model based approach using the UML notation. Also, the group has contributed to a European roadmap on state-of-the-art wrt. model based development for embedded systems in the EU FP5 project ARTIST.

The collaboration with IAR Systems A/S on the commercial tool visualSTATE has lead to development of a methodology for specialized and optimized code generation for an entire production line from one single master model. The framework is demonstrated by discussing adaptations to realistic design languages and by presenting an example of a product line in a special invited journal version.

Timed automata provides a powerful and expressive formalism for modelling embedded and real-time systems and numerous case-studies having been automatically analyzed using UPPAAL. Despite this success, the phenomena of state-space explosion[6] is ever-present and limits scalability. The Network Calculus[7] provides an inexpensive method for calculating safe estimates on worst case delays and worst case buffer sizes (backlog) in networks of workflow and processing units. The bounds are computed in a compositional manner given bounds (in terms of so-called arrival and service curves) of workflow and processing resources. A method has been developed for applying Network Calculus to real time systems with cyclic dependencies. This method is supported by the tool CyNC[8] which is implemented in MATLAB/SimuLink.

Industrial Case-studies

In order to assure the practical relevance of the work on methods, the results must constantly be validated through academic cases and industrial applications. In the evaluation period, a number of such validations have been performed through industrial collaborations – mainly in the form of projects that have been funded by CISS. The most important observations from the cases can be summarized as follows:[9]

Model Based Development: Two major case-studies have been made with a mobile phone development company (Siemens Mobile) and a ship engine development company (MAN B&W). The study included introduction of model based development to several project groups and subsequent project coaching. The general observation was that the basic idea was appreciated by the staff, but also that there

[6] i.e. the size of the state-space grows exponentially in the number of components of the model

[7] `http://lrcwww.epfl.ch/PS_files/netCal.html`

[8] `http://www.control.aau.dk/~henrik/`

[9] See the Appendix on activities for further details on the individual collaborations

is a need for developing a set of domain specific analysis and design patterns that can be applied as placeholders for the concrete design. Furthermore, it must be possible at an early stage to split the analysis into components for hardware and software.

Testing and verification: Two major studies have been made on testing with a company developing controlling software (Danfoss) and Internet router software (Telebit Ericsson). The studies included requirements modelling and test generation. In both companies, the test cases are currently generated manually, and the software testing forms a major bottleneck. The potential of deriving test cases automatically from models was greatly acknowledged, but it was also pointed out that there is a need for further improvement – especially wrt. the development of adaptor software, which must be derived in a generic way in order to ease the shift to new platforms.

Execution platforms: There has been two feasibility studies on eCos, where the researchers have configured a prototype installation on proprietary hardware. Thereafter, the companies could very easily continue their own work on application specific adaption. In both cases, the prototype work was highly appreciated. The same observation holds in the specific case where the feasibility study was on Linux access rights protection in downloaded binaries.

Hybrid Systems

Hybrid systems is a theory of dynamical systems with a non-trivial interaction of continuous and discrete phenomena. The study of the theory was initiated in the early 1990'ies as an interdisciplinary field between control theory/control engineering and computer science. It has since had increasing impact, in particular within control theory and engineering, because it offers a theory that allows modelling, analysis and synthesis of integrated controllers for complex systems, e.g. whole power trains in engines, robotic agents, and biological systems. It is practically interesting, because embedded computers facilitate hybrid control.

We have been engaged in the development and exploitation from its very beginning. A theoretical result is integration of hybrid theory with action systems. In the period, we have been more engaged in exploitation and dissemination through workshops and talks to companies. The API project has, however, given a nice illustration of a hybrid system in mobile robotics. The interaction with practice is planned to continue through CISS.

6.4.4 Networks and Operating Systems

Network Firewalls

Our main contribution is to use Interval Decision Diagrams, IDD, to represent the network filter of a firewall. Indeed, this representation has two main advantages: the first one is that it turns the filter into a predicate logic formula (soundness) and

the second one is that the complexity of the filtering operation is no more depending of the number of rules in the specification of the filter (efficiency). Moreover, this decision diagram representation of a firewall can be used to model networks and perform some checks on it.

Operating Systems

We have mainly worked on embedded softwares platforms. This work has been done through many collaborations with companies (mainly TDC and Panasonic but with some contacts in Phillips, IBM, Sony). The result of this collaboration has been implemented as an Open Source project called Umbrella.

Umbrella[10] is a security mechanism that implements a combination of Process-Based Access Control (PBAC) and authentication of binaries through Digital Signed Binaries. Umbrella is implemented on top of the Linux Security Modules framework. The PBAC scheme is enforced by a set of restrictions on each process. This policy is distributed with a binary in form of execute restrictions attached in the binary and within the program, where the developer has the opportunity of making a ”restricted fork” setting restrictions for new children.

Grid Computing

Most of the work on grid computing have so far aimed at extending the NorduGrid ARC grid middleware[11] and contributing to NorduGrid, the grid between the Nordic countries.

The research activities within grid computing have focused on gridification of existing programs, monitoring and controlling jobs.

The work on gridification has resulted in the distributed version of UPPAAL being made available on NorduGrid. Also programs such as Gromacs[12], a molecular dynamics package, and Abinit[13], a program for calculating structure, density and charge in systems made of electrons and nuclei, has been adapted to run on NorduGrid.

The work on monitoring and control of jobs has resulted in the development of a Job Manager for NorduGrid ARC. The Job Manager is a framework for managing jobs in the NorduGrid ARC middleware. It introduces a layer between the user and the grid, and acts as a proxy for the user. Jobs are continuously monitored and the system reacts to changes in their status, by invoking plug-ins.

Current activities involves development of a scalable grid information system, developing an adaptive grid firewall, and modifying NorduGrid ARC to support interactive jobs.

[10] `http://umbrella.sourceforge.net2`
[11] `www.nordugrid.org`
[12] `http://www.gromacs.org`
[13] `http://www.abinit.org`

We also run 2 grid enabled production sites accessible for academia: A 52 CPU SMP machine and a 50 CPU cluster. The cluster is at the time of writing the third most utilized grid site connected to NorduGrid, and actively serves 124 users. Finally, we provide access to a smaller 15 node cluster, setup to allow experiments that might disrupt services to be tested on a non-production site.

We participate in the Nordic Grid Neighborhood, which is a network for grid research funded by the Norwegian research council. The purpose of the network is to encourage collaboration on grid in the Nordic and Baltic countries. The network has participants from 7 countries and 20 institutions.

Interdisciplinary collaboration is an important part of the grid activities because: it speeds up dissemination of the research into practical use, it provides the users of grid technology with first hand knowledge, and it provides us with insight into the "real world" problems associated with the use of grid technology. Interdisciplinary collaboration has taken place in the following areas: bioinformatics, material physics, high-energy physics, and nano-technology.

High-Performance Computing

The grid facilities mentioned above also allows us to do work on high performance computing. The work has so far mostly been on creating a parallel and distributed version of UPPAAL.

6.5 The Group's Own Evaluation

In our opinion the research activities carried out by the group during the period 2001-2005 are very satisfactory both in terms of quantity and quality. The number of publications by members of the group has remained very high. The high quality of the publications is evidenced by their appearance in well-respected journals, as invited contributions to special volumes and in the proceedings of competitive conferences. Out of more than 180 refereed publications in the period, 39% of the publications in (refereed) conference proceedings are in the top rank, and 45% of the journal publications are in the top rank, according to the ranking compiled by the group. As was the case for the previous evaluation periods, most publications appear in conference proceedings, following the general trend in our field. However, the proportion of journal publication remains as high as by the end of the previous evaluation period. We consider these figures as clear indicators of the high quality and impact of the group, which are further witnessed by the Danish Citation Laureates Award by Thomson Scientific in 2005 to Professor Kim G. Larsen as the most cited Danish computer scientist in the Period 1990-2004.

Overall Objectives

The overall strategic goal of *embedded systems* methodology as a unifying direction for the group has been pursued in ways far more successful, than what could

have been hoped for at the time when the previous evaluation report was written. Most importantly, in collaboration with two research groups from Institute of Electronic Systems (Distributed Real Time Systems from Department of Process Control and Embedded Systems from Department of Communication) the Center for Embedded Software Systems, CISS, was opened by the Minister of Research in the autumn of 2002 with substantial national and regional funding. The goal of the center is to strengthen research collaboration with industry with a large involvement of industrial oriented Ph.D. candidates. A recent evaluation by the Ministry concludes that the performance of the center is excellent. In terms of initiated Ph.D. studies and industrial co-financing the performance of CISS is some 40% above what was hoped for in the original budget. So far 24 collaborative projects have been conducted with more than 30 companies (including several SME) participating. More details about the contribution to these activities in CISS from the group can be seen in the Appendix, but in bulk figures the group accounts for more than half of the activities within CISS. As participants in CISS, the group has since 2004 been key participant in the two high-technology networks *Mobile Systems* and *Pervasive Communication* pursuing industrial dissemination and collaboration in concerted effort with other Danish research groups. Certainly, the level of industrial collaboration – as called for in the original strategy of the previous evaluation report – has been strengthed substantially during the period.

For several years the basic research center BRICS – in which the group has played an active role since the start of the center in 1993 and throughout the period – has been internationally recognized for its high performance in fundamental research within Computer Science. The significant effort of the group within verification and validation has been one of the core activities of BRICS, and now with the emergence of CISS, the group has successfully established itself as a key player in embedded systems at the European level: the group is core partner and member of the steering committee of *the* European Network of Excellence within embedded systems, ARTIST2, serving as coordinator of the focus area Testing and Verification (one out of seven focus areas of the Network).

The group has been engaged in extensive international collaboration during the period, via participation in various European projects and involving several guests visiting the group for longer or shorter periods of time. As a result, several of the publications of the group have co-authors from outside the group. The international recognition and visibility of the group is also witnessed by the numerous community services including programme committee membership, steering, chairing and organization of main conferences (e.g. CONCUR01 and CAV02), as well as several invited talks by members of the group.

Specific Objectives

Concurrency Theory: During the period the group has further strengthened its international position on the semantic foundation in concurrency theory, covering the areas of process algebra and process calculi for mobility and security. The

main scientific results include contributions to the understanding of existence/non-existence of finite, equational axiomatizations; (un)decidability, complexity and expressiveness results for a number of infinite-state systems, including real-time systems, optimal scheduling and planning, cryptographic protocols, and infinite (data-) structures; transfer of concurrency theory to modelling and understanding of biological systems with both industrial collaboration and participation in starting up international workshops in this new emerging area. Besides these scientific research contributions, the group has also played a leading role in the scientific community of concurrency theory serving as chair of the steering committee of the CONCUR conference series, organizing and chairing CONCUR01, initiating and chairing the newly started IFIP TC1 Working Group 1.8 on Concurrency Theory and serving as editor of the Concurrency Column in The Bulletin of the EATCS.

Verification and Validation: The research of the group in the area of validation and verification has been particularly successful, continuing its development of algorithmic foundation and their implementation in verification and validation tools. The success of the real-time verification tool UPPAAL is undisputed, with numerous downloads of the tool – mainly from academia but also from industry in increasing numbers. The impact of the tool is witnessed by the large number of international research groups taking part in the continuous development of the tool and the several invited tutorials given by members of the group in the period. The directions towards tool support for optimal scheduling and real-time testing has been particular successful with the two branches of UPPAAL, UPPAAL CORA and UPPAAL TRON gaining popularity. The application and development of UPPAAL in general and UPPAAL CORA in particular was a common focus point in the EU project AMETIST (as well as the earlier VHS project) leading to a tool being competitive with tradition algorithmic approaches to scheduling from the Operation Research community. Also, the development of the UPPAAL tool suit has to a large extent been a common effort of the entire group with valuable contributions both from the theoretical side (in terms of basic decidability results and results of expressiveness) and from the experimental side (in terms of efficient distributed versions of the UPPAAL). We see serving as coordinator of the Testing and Verification cluster of ARTIST2 and chairing the main international conference CAV in 2002 as indicators of our international recognition in the area. Also, at a regional level the effort in the area has been acknowledged by awarding the Spar Nord Foundation Award 2004 to Gerd Behrmann for his Ph.D. thesis.

Embedded Systems Methodology: The work on establishing a methodology for embedded systems has been pursued at the regional/national level with extensive industrial collaboration within the context of CISS with the purpose of improving the development process for a number of individual companies. We are happy to see that in collaboration with colleagues at CISS from outside the group, a number of publications are concerned with establishing hybrid methods for modelling and analysis of various aspects of embedded systems by combining techniques from computer science, control theory and hardware. These are important steps towards

creating a theoretically well-founded embedded systems discipline. At an international level we see our contributions to the European roadmap on state-of-the-art embedded design methodology as important milestones. Serving on the steering committees of the NoE ARTIST2 and the conference series HSCC witnesses our international recognition in the area.

Networks and Operating Systems: Within Networks and Operating Systems the research on firewalls and security mechanisms for Linux are theoretically well-founded, experimentally validated and have gained substantial industrial interest. These areas were not foreseen in the original research plan, but were pursued instead of the planned improvements of Internet protocol and efficient handling of web traffic for various reasons (shift in personal interest and lack of industrial interest). Similarly, the substantial effort of the group on high-performance and grid computing was completely unforeseen in the original strategy: besides the successful gridification of our verification tool UPPAAL the work on the Job Manager for monitoring and controlling jobs on the NorduGrid ARC are important contributions in the period. We see the membership of the Danish Center for Grid Computing (DCGC) and the requested involvement in the development of the NorduGrid as clear indications of scientific recognition of the group in this area.

Staffing

Since our last research evaluation, the number of people contributing to the research of the group has remained stable with a change in the profile of the group towards more permanent staff. At the end of the previous evaluation period the group had 1 full professor, 1 research professor, 4 associate professors, 5 assistant professors and 1 teaching assistant. At present the staff of the group consists of 2 full professors, 8 associate professors, 1 assistant professor, 1 teaching assistant. Also in this evaluation period we have experienced several external researchers visiting the group for extensive periods of time. In particular, we have been fortunate in having Professor Zoltan Esik as visiting professor and in associating Professor Ed Brinksma as adjoined professor of the group.

In the last evaluation report, concerns were expressed with respect to difficulties experienced in attracting new Ph.D. students. The industrial orientation taken with CISS has lead to a quite satisfactory situation with respect to both numbers of Ph.D. students and the level of funding. Besides 8 Ph.D. students currently supervised by members of the group, a similar number of other CISS Ph.D. student are being supervised by colleagues from Institute of Electronic Systems. Also, during the period, the group has been visited by several external Ph.D. students, including five that have spent a semester or more at the group.

There is also causes for concern, however. Due to obligations at CISS (director and vice-director respectively), Kim G. Larsen and Arne Skou have reduced teaching obligations (0% and 50% respectively). In addition, Anna Ingólfsdóttir and Luca Aceto have since 2004 been on leave of absence with no or very reduced

teaching obligations. This is a situation of under-staffing, that – if permanent – are bound to effect the future research effort of the group.

A further cause for concern comes from a certain discrepancy between the number of staff members within specific research areas and the number of masters-level students attracted to the corresponding topics. Clearly, the more practical research areas of the group attract quite a few students, and as at the end of the evaluation period we have lost two assistant professors in this area we may well witness under-staffing.

6.6 Research Plan 2006-2010

This section describes the research plans of the group for the next five year period. We begin by presenting overall research goals followed by concrete research plans of the four existing research activities. Next we address our strategy for funding and staffing.

Overall Research Goals

The overall strategic research goals of the group for the next five years include:

- Based on our current key role within the ARTIST2 Network of Excellence as core participant and coordinator, we want to establish ourselves as a leading European research group within Embedded Systems;
- We want to maintain and strengthen our leading position with respect to verification and validation of real-time system models;
- Based on our effort in high-performance and grid computing we aim at becoming a leading national group in GRID computing research and services during the next five year period;
- We want to maintain our current high international visibility and recognition within concurrency theory. Despite the likely loss of two senior and very visible researchers in this area we have already taken steps to compensate for this in various ways (e.g. hiring of a new associate professor in the area, affiliation of guest professors);

Concrete Research Goals

Below we list a number of concrete plans for the existing four research areas. It should be emphasized that – as was seen when comparing the research of this period with the original strategy – that the plans outlined are just “best initial guesses” that most likely will be superseded by the actual events.

Concurrency Theory: the work on decidability results, axiomatizations and results on expressiveness for infinite state processes and logical specification formalisms

will continue. In particular within scheduling there are a number of open problems as to decidability concerning optimal control and controller synthesis under partial observability in the setting of timed automata. For mobile process calculi, work on equational logics for the applied π-calculus and development of type inference rules and comparison of expressive power for process calculi with sites are planned. The work on applying concurrency theory to biological systems will most likely not be pursued by the group as the main researcher (Anna Ingólfsdóttir) is on leave.

Verification and Validation: here the work on UPPAAL will continue. The recent extension of the modelling formalism to allow C-code to appear explicitly in models makes for easy modelling of several data-dependent systems. We see a need (and possibility) for extending current verification technology with techniques from abstract interpretation in order to deal efficiently with future models. Currently UPPAAL supports model-checking with respect to a fragment of CTL. Within the next period we aim at supporting model-checking with full TCTL, even with a distributed algorithm. Also, alternative linear temporal logics are considered. The development of tool support for optimal scheduling and controller synthesis within UPPAAL CORA and UPPAAL TIGA will continue. In particular the development of UPPAAL TIGA to allow for automatic controller synthesis *and* code-generation for given execution platforms is a prime research goal. The work on on-line real-time testing in UPPAAL TRON will be augmented with standard interfaces for test execution on various platforms. Also, extensions towards on-line testing of hybrid systems will be pursued.

Embedded Systems Methodology: More case studies will be conducted with current as well as new industrial partners. This is a key activity for identifying useful methodologies and serves as valuable empirical background for our industrial Ph.D. students. Also, performing case studies is the only way to truly evaluate the performance and relevance of any given variant of UPPAAL. As a necessary supplement to application of our various validation tools, compositional methods for analysis embedded systems design will be pursued. Here ways of combining the light-weight and compositional Net Calculus with the expressive timed automata formalism is a main challenge. Within hybrid systems, the main goal is to create a strong interdisciplinary research environment connecting our group with researchers from control theory. Finally, a fully developed and documented OOA&D methodology for embedded systems based on our collected industrial experience is one of the ambitious goals of the next period.

Networks and Operating Systems: In the next period we will intensify our efforts within grid computing. Focus will be on solutions for data management in grid systems, adaptive firewalls and peer-to-peer information systems. As specific activity – and as part of the ARTIST2 NoE – effort towards realization of a European Verification Grid will be made in collaboration with a number of other European sites researching on distributed model checking. Work towards an embedded systems platform ensuring security in a networked setting will continue with our industrial partners. Our services to the scientific computation community will continue and

one of the ambitious goals of the next period is to host a site of the Danish Center for Scientific Computing (DCSC) at Aalborg.

Funding

Towards the end of 2006 the current funding of both BRICS and CISS terminates. A main challenge of the forthcoming period is to secure new funding of similar size. At a recently performed evaluation by the Ministry of Research of the Jutland-Fuen IT-initiative, CISS has performed extremely well and funding is set aside at the national budget for a continuation of this regional IT-initiative. Also, our involvement within the Danish Center for Grid Computing seems most likely to be also funded in the future.

It is clear that compared with the funding situation five years ago several more strategic instruments are used by the Danish government, and – with the new regional structure in Denmark – increased regional funding for more industry oriented research activities will most likely be available in the near future. We see our effort within CISS and the two high-technology networks *Mobile Systems* and *Pervasive Communication* as being important in qualifying for such future funding. In addition it is vital that the group (and institute) is fully supported by the university in this competition for regional and national funding. As most future funding will most likely be subject to industrial collaboration it is important that means are identified for reserving sufficient portions of the funding for pursuing basic research goals. Hopefully, the identified need for increasing the volume of Ph.D. studies will lead to continued funding of the Ph.D. school of BRICS.

Staffing

The leaves of absence (and likely permanent leaves) and reduced teaching obligations of four senior staff members means that the group is experiencing a situation of under-staffing, that may affect the research effort of the group. This situation should be resolved within the near future, also because the reduced presence at the early levels of education damages the possibilities of recruiting master thesis students and Ph.D. students in the long run.

Appendices | 6

6.7 Detailed Description of Activities and Results

6.7.1 Funded projects

Center for Basic Research in Computer Science, BRICS (September 1993– June 2006)

Scientist in charge: Kim G. Larsen.

Participants: All researchers of the DSS research group.

Funding: The Project is supported by the Danish National Research Foundation.[14] Total funding for Computer Science at Aalborg University in the evaluation period is 6.6 mill. DKK.

Participating organizations: BRICS is a large-scale joint research project between the Computer Science Departments at Aarhus University and Aalborg University. The overall project is directed by Mogens Nielsen, Aarhus University.

Description: The objective of BRICS is to strengthen basic research on logics, semantics and algorithmics in computer science. The center includes a reseach centre and an international Ph.D. school (located at Aarhus University). The original aim of BRICS was to establish important areas of basic research in the mathematical foundations of Computer Science in Denmark, including activities in algorithms, mathematical logic and semantics. In addition to these areas, the center added verification and cryptography to the list of activities in 1996. During the period the funding has been instrumental in the further developoment of the real-time verification tool UPPAAL and its emerging branches. The activities has been centered around the permanent staff at the two universities, and an average of 15-20 foreign, long term junior and senior associated researchers, 20 Ph.D. students and an intensive programme of visiting researchers and scientific events. The activities in Aalborg has accounted for 25% of the total project.

Center for Embedded Software Systems, CISS (September 2002– December 2006)

Scientist in charge: Kim G. Larsen.

Participants: All researchers of the DSS research group.

[14] http://www.brics.dk

Funding: The Project is supported by the Danish Ministry of Science, Technology and Innovation, the County of Northern Juitland and the City of Aalborg. Total funding for Computer Science at Aalborg University in teh evaluation period is 14 mill. DKK.

Participating organizations: CISS is a joint project between the departments of Control Engineering, Communication Technology and Computer Science at Aalborg University.

Description: The aim of the project is to strengthen the research and development cooperation between industry and the regional IT knowledge environment and thus participate in creating an increase in high technology companies and spin-off companies through goal-directed education of business oriented Ph.D. candidates. The activities include R&D projects, feasibility studies, industrial Ph.D's, student projects, open courses, seminars, work-based learning, company networks and internationalisation. The research areas include model based development of embedded software, intelligent sensor networks, platforms for embedded systems, resource optimal scheduling, security, safety critical software systems, embedded systems testing and verification and hardwar/software codesign. So far, the center has initiated 20 collaboration projects and 12 industrial Ph.D's. 20 researchers are directly employed via the grant, and in addition 25 staff members from the three departments are taking part in the work. The DSS research group is responsible for approximately half of the activities.[15]

High Technology Network: Mobile Systems (January 2005– January 2007)

Scientist in charge: Kim G Larsen

Participants: Arne Skou from DSS and Peter A. Nielsen, Christian S. Jensen, Jan Stage from the Institute.

Funding: The project is funded by the Danish Ministry of Science, Technology and Innovation for a 4-year period with an intermediate evaluation after two years. The total 2-year grant is 4 mill DKK.

Participating organizations: CISS, CTIF, Institute of Computer Science, Danish Technological Institute, University College of Aarhus, Herning Institute of Business Administration and Technology, Copenhagen University College of Engineering, Terma A/S, Siemens A/S Mobile Phone Development, Sonofon.

Description: Mobile Systems offers a platform for cooperation between private companies, universities and other knowledge institutions working with mobile technology. Through a number of activities Mobile Systems develops strong ties and synergies between research and business, keep track of new trends and explore new application areas.

[15] See also http://www.ciss.dk/

Mobile Systems posses expertise within all areas of mobile systems – from the physical communication structures and hardware to the logical services that is realized. The network is organised in five interacting focus areas: Wireless Networks, Devices/Hardware, Embedded Software Systems, Mobile Services, Devices/User Interfaces.

Across the focus areas a set of technological and commercial challenges are discussed. All interested companies can join Mobile Systems.

High Technology Network: Pervasive Communication (January 2005–January 2007)

Scientist in charge: Kim G Larsen

Participants: Arne Skou

Funding: The project is funded by the Danish Ministry of Science, Technology and Innovation for a 4-year period with an intermediate evaluation after two years. The total 2-year grant is 4 mill DKK of which approximately 400.000 DKK are directly spent at AAU.

Participating organizations: Alexandra Institute, Knowledge Lab, ITU, Center for Software Innovation, Aalborg University.

Description: The aim of the project is to act as a mediator between research institutions and industries who want to exploit pervasive communication in research and development. The first year will be spent on forming the network (i.e. attracting companies and institutions) and on technology screening. Year 2 will mainly be spent on forming project collaboration, e.g. developing one or more demonstrator projects. CISS is heading one of the three subject groups (models and tools for pervasive communication).

Danish Center for Grid Computing (August 2003 - July 2006)

Scientist in charge: Eric Jul (Univ of Copenhagen), Josva Kleist (I16)

Funding: The Danish Natural Science Research Council and the Faculty of Engineering and Science. Total:10.5 MKr, AAU:2.5MKr

Participating organizations: , Aalborg University, Danish Technical University, University of Copenhagen, University of Southern Denmark.

Note: DCGC was preceeded by a number of smaller SNF founded projects.

Description:

Grid computing is based on the idea of joining individual computers and clusters of computers and organising them into a single logical entity with a common interface. This interface will act as a meta-computer offering, for example, uniform access control and resource locator services to the user applications. By using these

services, applications can be developed and tested on local machines and subsequently submitted to the meta-computer without modifications when a significant increase in computer resources are needed for the project. Although the are still a lot of unsettled issues, current grid systems are now mature enough to be used by academia. The introduction of grid systems to academic users is an important part of the evolution of these systems, as it will provide important feedback on the features that need further development.

DCGC is a inter-departmental research center. The center coordinates and integrates the Danish research within grid computing. Along with research and educational activities, the center runs a production grid providing resources and know-how to academic user of grid technology and a testbed for IT-researches and students working on grid technology. Current activities at Aalborg University focus on development of grid enabled applications, scheduling of jobs and resources, fault tolerance and monitoring. Aalborg also hosts one of the two DCGC gridsites that are setup to provide a testbed for researchers and studentsinterested in developing and applying grid technology.

Prosoft (January 2004– December 2005)

Scientist in charge: Arne Skou

Participants: Brian Nielsen, Peter A. Nielsen, Arne Skou, Ivan Aaen.

Funding: The Project is supported by the Danish Ministry of Science, Technology and Innovation, the County of Northern Juitland and the City of Aalborg. Total funding for Computer Science at Aalborg University is 2 mill. DKK.

Participating organizations: CISS, Herning Engineering School and 10 private companies

Description: The overall aim of the project is to identify and remedy the obstacles that make it difficult for the participating companies to maintain their project handbooks. The thesis is that lack of tool support for both handbook maintenance and project development is the main obstascle. The project is divided into five subprojects on handbook maintenance, development methodology, test generation, competence description, and tool support. Two prototype tools on handbook maintenance and competence description have been developed and tested through industrial case studies.

Network of Excellence on Embedded Systems Design, ARTIST2 (September 2004– August 2008)

Scientist in charge: Kim G. Larsen.

Participants: Gerd Behrmann, Hans Hüttel, Josva Kleist, Kim G. Larsen, Brian Nielsen, Anders P. Ravn, Arne Skou.

Funding: The Project is supported by the EU under FP6 as IST-004527.[16] Total funding for Computer Science at Aalborg University is expected to be 1 mill. DKK.

Participating organizations: ARTIST is a joint Network of Excellence between 34 leading European research groups on embedded systems, and a number of industrial partners. The project is coordinated by Verimag, Grenoble.

Description: The objective of ARTIST2 is to strengthen European research in Embedded Systems Design, promote the emergence of this new multi-disciplinary area and to forge a scientific community. The approach is to address the full range of challenges related to Embedded Systems Design, ranging from theory through to applications. The research activities of the network is divided into 7 clusters, and Aalborg is coordinating the cluster on Testing and Verification which includes verification of security properties for embedded systems, and also the build-up of a joint verification computing facilty based on grid technology. The work on a distributed version of the Uppaal verification engine supports this activity.

Advanced Real TimeSystems, ARTIST (April 2002– March 2005)

Scientist in charge: Kim G. Larsen.

Participants: Kim G. Larsen, Brian Nielsen, Anders P. Ravn, Arne Skou.

Funding: The Project is supported by the EU under FP5 as IST-2001-34820.[17] Total funding for Computer Science at Aalborg University is 1 mill. DKK.

Participating organizations: ARTIST is a joint project between 27 leading European research goups on embedded systems, and a number of industrial partners. The project is coordinated by Verimag, Grenoble.

Description: The aim of the project is to Coordinate the R&D effort in the area of Advanced Real-time Systems so as to: (1) Improve awareness of academics and industry in the area, especially about existing innovative results and technologies, standards and regulations, (2) Define innovative and relevant work directions, identify obstacles to scientific and technological progress and propose adequate strategies for circumventing them.

The main overall results of the project are a roadmap of research and industrial practice within the area, and a proposed curriculum of courses to be given at universities. The roadmap is published as volume 3436 of Lecture notes in Computer Science, and the curriculum is presented in a special issue on education in embedded systems: ACM Transactions on Embedded Computing Systems (TECS) archive Volume 4 , Issue 3 (August 2005), pages 587–611. Parts of the funding has also been applied to support the ongoing development of the Uppaal tool.

[16] http://www.artist-embedded.org/FP6/
[17] http://www.artist-embedded.org/

AMETIST. Advanced Methods for Timed Systems

Local scientist in charge: Kim G. Larsen

Local participants: Kim G. Larsen, Gerd Behrmann, Arne Skou, Jacob Illum Rasmussen, Patricia Bouyer, Emmanuel Fleury

Funding: The Project is supported by the European Union, contract number IST-2001-35304.

Participating organizations: AMETIST is a joint project between Aalborg University, University of Nijmegen, Bosch, Cybernetix, Axxom, Terma A/S, University of Dortmund, VERIMAG, Weizman Institute, LIF Marseille, University of Twente.

Description: The main objective of the AMETIST project was to develop a powerful modelling methodology supported by efficient computerized problem-solving tools for the modelling and analysis of complex, distributed real-time systems. In particular, the project addressed problems in connection with time-dependent behaviour and dynamic resource allocation. Problems of this type are manifested under different names in application domains such as manufacturing, transport, communication networks, real-time software and digital circuits.

The main contributions of Aalborg University are in the application of timed automata verification technology to the area of planning and scheduling. We have developed extensions of timed automata suitable for these domains and tools supporting these extensions. One such tool, UPPAAL CORA, was used extensively by the other partners in the project in addressing the case studies of the project.

VHS, Verification of Hybrid Systems (April 1998 – June 2001)

Scientist in charge: Kim G. Larsen.

Participants: Kim G. Larsen, Gerd Behrmann, Arne Skou.

Funding: The Project is supported by the EU under FP5 as Esprit Project 26270. Total funding for Computer Science at Aalborg University is DKK 600,000.

Participating organizations: Verimag (F), Weisman (Israel), Nijmegen, Amsterdam (NL), Kiel, Dortmund (D), Gent (B).

Description: Hybrid systems comprise systems which depend critically on the interaction between the discrete dynamics of a digital controller and the continuous dynamics of the environment in which it is embedded. The project aims at developing a framework for hybrid systems allowing for modelling, simulaiton, verification, synthesis and implementation of such systems. The main activity of the project is centred around a number of academic and industrial case studies. The project uses, among others, the models of timed and hybrid automata to express hybrid phenomena. Several tools for analyzing systems expressed inthis formalism have been built, and the project uses them for automatic verification.

Support of Network Services for Distributed Applications (January 2000– December 2002)

Scientist in charge: Arne Skou

Participants: Mikkel Christiansen, Josva Kleist, Brian Nielsen and Arne Skou.

Funding: The Project is supported by the Danish National Science Foundation. Total funding for Computer Science at Aalborg University in the evaluation period is 100.000 DKK.

Participating organizations: Technical University of Denmark, Copenhagen University, University of Southern Denmark, Aalborg University.

Description: The aim of the project is to investigate how to support efficient network services for contemporary distributed applications. The main result has been an experimental investigation on the effects of various types of internet router packet drop strategies as documented in the Ph.D. thesis by Mikkel Christiansen. Part of the funding has supported the build-up of an experimental platform for internet router traffic.

API. Autonomous Plant Inspection (November 2000– April 2003)

Scientist in charge: Anders P. Ravn

Funding: The Project is supported by the Danish Ministry of Food, Agriculture and Fisheries and a national industry consortium. Total funding for Computer Science at Aalborg University 1,300,000 DKK.

Participating organizations: API is a joint project between the Danish Institute of Agricultural Sciences, The Department of Agritechnology of The Royal Veterinary and Agricultural University, and the departments of Control Engineering and Computer Science at Aalborg University.

Description: The project has developed and deployed an autonomous scout vehicle which can map weed densities in a field with a specific crop. The prototype has been used successfully for other survey operations, and is be extensible to later take over field operations, e.g. weeding.

Furthermore the strategy software is prepared for operating collections of such vehicles. The Department of Computer Science (Anders P. Ravn, Piotr Makowski) was responsible for one of 4 major work packages: Systems Architecture. It defines and documents the overall system structure.

Agrobotics (March 2004– November 2005)

Scientist in charge: Anders P. Ravn

Funding: The Project is funded by the Danish Technical Research Council. Total funding for Computer Science at Aalborg University 420,000 DKK.

Participating organizations: Agrobotics is a joint project between the Danish Institute of Agricultural Sciences, The Department of Agritechnology of The Royal Veterinary and Agricultural University, The Department of Control Engineering at the Technical University of Denmark, and the Department of Computer Science at Aalborg University.

Description: The objective of Agrobotics is to set up a context for investigating and developing a novel software framework to advance the deployment of unmanned agricultural mobile robotic systems (or situated agents). The challenge involves establishing the basis for understanding desirable agent behaviours in the agricultural domain, generating guidelines for agent assessment and architecture comparison. Based on these results we investigate and develop an architecture with focus on vehicle safety and fault-tolerance. Although the project investigates a general software framework we put special focus on on agent behaviours related to coordination. The Department of Computer Science (Anders P. Ravn, Piotr Makowski, Lorenzo Sella) was responsible for one of 4 work packages: Agent coordination with algorithms and designs that enable multi-vehicle coordination and action.

Centre for Agro Technology - Aalborg University (September 1999–December 2004)

Scientist in charge: Anders P. Ravn (director)

Funding: Funded by an annual grant of 100 000 DKK from the Faculty of Engineering and Sciences at Aalborg University.

Participating organizations: A network of groups within the Engineering and Science Departments

*Description:*Â A network of groups within the Faculty of Engineering and Sciences at Aalborg Universitythe that work with problems related to Agriculture. The Centre was formed by the Faculty of Engineering and Sciences in September 1999 and is funded by an annual grant of 100 000 DKK until the end of 2004. The Faculty appointed Anders P. Ravn as director of the Centre. During 2005, the Centre has been embedded into the Network Centre of The Faculty of Engineering and Sciences.

MindPass Center for Distributed Systems (October 2000 - October 2001)

Scientist in charge: Josva Kleist

Financing: MindPass A/S and the Faculty of Engineering and Science (0.5Mkr)

Participating organizations: Aalborg University, MindPass A/S

Description:

MindPass Center for Distributed Systems (MindPass-CDS) was established as a research and development collaboration between the private company MindPass

A/S and researchers at the Computer Science Department, Aalborg University. MindPass-CDS was created with the following objectives in mind:

- To develop a high-quality, internationally oriented research group within distributed systems at the Department of Computer Science, Aalborg University.
- To develop a tradition for research and development activities within distributed systems that is technologically innovative, theoretically well-founded, and based on collaboration and exchanges between industry and academia.
- To establish and develop research and development activities within distributed computing at MindPass as an integral part of their business strategy and practice.
- To contribute to the educational environment at Aalborg University providing expertise within distributed systems.

Calculi and verification techniques for security and mobility (1999-2001)

Scientist in charge: Hans Hüttel

Local participants: Hans Hüttel, Josva Kleist.

Funding Göran Gustafssons Stiftelse (The Göran Gustafsson Foundation).

Participating organizations: Aalborg University, Uppsala University.

Description: The family of π-calculi provides a rich mathematical theory for studying the properties of systems whose communication properties change dynamically. An important spin-off of this theory is the Mobility Workbench, an automatic software tool for verifying properties of pi-calculus processes. Recently, Abadi, Gordon and others have used the closely related spi-calculus to describe the behaviour of security protocols. The project has as a main goal that of developing the theory of the spi-calculus and to use it in the construction of a software tool for verifying properties of security protocols, and subsequently integrating this tool with the Mobility Workbench, if possible.

VVS. Verification and Validation of Large State-machines

Local scientist in charge: Kim G. Larsen

Local participants: Kim G. Larsen, Arne Skou, Gerd Behrmann, Kåre Kristoffersen

Funding: The project was supported by the Danish Center for Information Technology.

Participating organizations: Aalborg University, Technical University of Denmark, Baan VisualSTATE A/S.

Description: The project developed techniques that were deployed in a new generation of the commercial visualSTATE tool that moved the limit on the complexity of the embedded software that can be verified by several orders of magnitude. The first result of the cooperation was the /verification of a design with more than 1400 concurrent state machines in less than an hour /on a standard PC.

The technique dubbed *compositional backwards reachability* or CBR were patented and are stilled used in the visualSTATE tool. The technique has since been extended to hierarchical state-machines, CTL model checking and to timed automata.

STRESS, Systematic Testing of Real-Time Software Systems (November 2002 – November 2005)

Scientist in charge: Kim G. Larsen and Brian Nielsen

Participants: Kim G. Larsen and Brian Nielsen.

Funding: The Project is funded by NWO FP5 as Esprit Project 26270. Total funding is DKK 900,000 with Computer Science at Aalborg University getting expenses for travel and accommodation covered.

Participating organizations: Twente University (NL) and Aalborg University (DK).

Description: The project is concerned with on-line testing of real-time systems following the model-driven approach. That is given a design model techniques for assessing whether a given real-time systems conforms to this model are developed in terms continuous stimuli and observation of reactions. The project aims at developing a theoretical foundation including metrics for coverage as well as tool development by combining the features of ToRX and UPPAAL.

Ravenscar Real Time Java (August 2005– January 2007)

Scientist in charge: Arne Skou

Participants: Bent Thomsen, Anders P. Ravn, Arne Skou.

Funding: The project[18] is supported by CISS, Vitus Bering Denmark, and FOSS Inc. The total budget for the project is 0.5 mill. DKK, and CISS is funding approximately half of the expenses.

Participating organizations: Ravenscar Real Time Java is a joint project between the funding institutions.

Description: The aim of the project is to (1) analyse whether Ravenscar-Java is a realistic Java profile for industrial real-time systems; this is done by implementating the Ravenscar-Java profile on the aJ-100 processor (2) show how Real-Time UML is used as a design tool; this is done by designing an industrial case using the UML real-time profile, and (3) compare a Ravenscar-Java solution of the case with an existing C++ solution.

[18] https://www.cs.aau.dk/ravenscar/

Software process improvement by using JavaCard (September 2002– September 2003)

Scientist in charge: Kim G Larsen.

Participants: Anders B Christensen.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 250.000 DKK).

Participating organizations: S-Card A/S, Aalborg University.

Description: So far, Smartcards are mostly developed by using low level programming languages. JavaCard is a candidate for a more high-level approach, but it is still lacking e.g. abstract datatypes. In this project, investigations were performed into how the programming and testing activities can be improved through the application of formal methods characterized by being mathematically well-founded. In specific, researchers looked into opportunities for generating model-based programs as is known for instance from the VisualSTATE tool. Furthermore, research was conducted into how such models can form part of a test procedure emphasizing a large degree of automation. The project resulted in the design and prototype implementation of a graphical tool for development of JAVA card applications.

Test and evaluation of eCos as an embedded operating system for Simrad's product and hardware platform (October 2003– January 2004)

Scientist in charge: Mikkel Christiansen.

Participants: Brian Nielsen, Tue Olesen.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 250.000 DKK).

Participating organizations: Simrad A/S, Aalborg University.

Description: When developing navigation systems, there is a need for an efficient operating system kernel to handle concurrent processes and external equipment. As an alternative to proprietary kernels, Open Source kernels like eCos are now emerging. The project has analysed the problems related to the adaption of eCos to a proprietary print board. After the analysis and prototype implementation, the company has become able to continue the installation of proprietary subsystems.

Design and implementation of automatic test generation mechanisms (October 2003– October 2004)

Scientist in charge: Kim G Larsen.

Participants: Ulrik Nyman

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 1 mill. DKK).

Participating organizations: IAR Systems, Aalborg University.

Description: The aim of the project is to design and implement automatic test generation from a design model in the VisualState tool. The tool already includes a verification facility whereby a given model can be fully analysed for a number of properties like deadlocks, unused transitions, etc., and the idea behind the project is to adapt the existing verification algorithm to be able to generate tests. The project has resulted in a prototype implementation, which the company has finalised and released in its commercial product.

Application of eCos on the Gefion platform (March 2004– September 2004)

Scientist in charge: Emmanuele Fleury.

Participants: A MSc student group.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 500.000. DKK).

Participating organizations: AeroMark, Aalborg University.

Description: AeroMark delivers systems for tracking lorries in Europe. The idea is to enable hauliers to follow the location of their lorries. The current solution uses a GPS unit, which positions the lorry. This information is sent back to AeroMark via mobile telephone technology, and AeroMark then passes the information on to their clients who can follow the location of the lorry by plotting the given positions into a map. In connection with moving the system to a new ARM9-based hardware platform known as Gefion, AeroMark is interested in using the eCos real-time operating system. The project developed a prototype version of eCos on the ARM processor, and the company has adapted the prototype to its proprietary platform, which has later been released to its costomers.

Model Driven and Object Oriented Software Development of Embedded Systems (March 2004– June 2005)

Scientist in charge: Arne Skou.

Participants: Peter A Nielsen, Anders P Ravn, Jan Stage.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 500.000. DKK).

Participating organizations: Siemens Mobile (Now BenQ), Aalborg University.

Description: The aim of the project has been to investigate the feasability of applying Model based and Object oriented techniques in the development of embedded mobile systems. The project was carried out through introductory courses and project coaching on-location in the company. The project gave important practical insight and in particular it demonstrated the need for further research on interface specifications.

Security in Alarm Boxes (September 2004– January 2005)

Scientist in charge: Emmanuel Fleury.

Participants: A group of M.Sc. students.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 200.000. DKK).

Participating organizations: TDC, Aalborg University.

Description: The project has developed a protection framework for Linux kernels whereby it is possible to guarantee that the access rights of authenticated binary code are respected at run time. A prototype version has been installed at the company's proprietary platform to be applied in its various alarm boxes.

Automated test of cooling thermostates (January 2004– June 2004)

Scientist in charge: Brian Nielsen.

Participants: Ulrik Nyman, Kim G Larsen, Marius Mikucionis, Arne Skou.

Funding: The project is funded via the CISS grant and a private company (overall budget approximately 150.000. DKK).

Participating organizations: Danfoss A/S, Aalborg University.

Description: The project investigates the feasibility of applying the Uppaal Tron tool for automated test of one of the company's thermostates. The project was carried out by developing a Uppaal model for a substantial part of the product, and by writing adaption software for the test execution. The project revealed minor unclarities in the product specification and also challenged the performance of the state estimation engine of the tool.

Model Based Testing of Internet Protocol Specifications (September 2004– September 2007)

Scientist in charge: Arne Skou.

Participants: Kim G Larsen, Saulius Pusinskas.

Funding: The project (a Ph.D. project) is funded via the CISS grant and a private company (overall budget approximately 1.5 mill. DKK).

Participating organizations: Telebit Ericsson A/S, Aalborg University.

Description: Modern Internet protocols are normally specified by formulating a number of scenarios that jointly form the total set of requirements. Ideally, these scenarios should form the basis for the generation of a test suite for any protocol implementation. The project investigates the feasibility of using a new formalism, Live Sequence Charts (LSC's), to the formal specifacation of protocol scenarios, and also to which extent test cases can automatically be derived from LSC's.

Model Based Development (September 2003– September 2006)

Scientist in charge: Anders P Ravn.

Participants: John Knudsen, Arne Skou.

Funding: The project (a Ph.D. project) is funded via the CISS grant and a private company (overall budget approximately 1.5 mill. DKK).

Participating organizations: MAN B&W A/S, Aalborg University.

Description: The aim of the project is to investigate how UML and supporting tools may be applied for the development of control software for modern ship engines. Such software is normally developed incrementally and over a very long time period (more than 10 years). Hence, one of the main challenges of the project is the question of integrating a large existing code base with new functionalities in an UML setting. Focus is therefore both on reverse engineering and component modelling.

Intelligent Sensor Networks in StablesModel Based Development (September 2003– September 2006)

Scientist in charge: Kim G Larsen

Participants: Jens Alsted Hansen.

Funding: The project (a Ph.D. project) is funded via the CISS grant and a private company (overall budget approximately 1.5 mill. DKK).

Participating organizations: Skov A/S, Aalborg University.

Description: The objective of this project is, as the title indicates, to improve and expand on sensor systems collecting data from stables. The networks can be improved by making the sensors more robust towards erroneous measurements and enable them to reason regarding their surroundings. The expansion of the sensors takes place in connection with the creation of opportunities for new sensor input, e.g. the use of images.

6.7.2 Unfunded projects

Type Inference for Security Protocols

In recent years, researchers, including Martin Abadi, Alan Jeffrey and Andrew D. Gordon, have suggested type checking as a vehicle for checking properties such as secrecy and authenticity for security protocols specified in the spi calculus.

This project, a collaboration with Andrew D. Gordon from Microsoft Research at Cambridge, aims at finding and implementing type inference algorithms for such type systems.

Network Firewalls

Our main contribution is to use decision diagrams (and more precisely Interval Decision Diagrams, IDD) in order to represent the network filter of a firewall [37]. Indeed, this representation has two main advantages, the first one is that it turns the filter into a predicate logic formula (soundness) and the second one is that the complexity of the filtering operation is no more depending of the number of rules in the specification of the filter (efficiency). Moreover, this decision diagram representation of a firewall can be used to modelize networks and perform some checks on it.

Operating Systems

We have mainly worked for embedded softwares platforms (mobile phones, consumer electronics, . . .). This work has been done through many collaborations with companies (mainly TDC and Panasonic but with some contacts in firms such as Phillips, IBM, Sony, . . .). The result of this collaboration has been implemented as an Open Source project called Umbrella (developed with some Masters students).

Umbrella (`http://umbrella.sourceforge.net`) is a security mechanism that implements a combination of Process-Based Access Control (PBAC) and authentication of binaries through Digital Signed Binaries (DSB). Umbrella is implemented on top of the Linux Security Modules (LSM) framework. The PBAC scheme is enforced by a set of restrictions on each process. This policy is distributed with a binary in form of execute restrictions (attached in the binary) and within the program, where the developer has the opportunity of making a ”restricted fork” for setting restrictions for new children.

6.8 Organization and Staff

6.8.0 Luca Aceto

Academic Degrees

1991	DPhil in Computer Science, University of Sussex, UK
1986	Laurea (M.Sc.) in Computer Science, University of Pisa, Italy

Positions

2004–	Professor, Reykjavik University, Department of Computer Science
1996–	Associate Professor, Aalborg University, Department of Computer Science
1995	Visiting Research Professor, Aalborg University, Afdeling for Matematik og Datalogi (February 1995–June 1995)
1994–1996	BRICS Senior Research Fellow, BRICS (Basic Research in Computer Science), Aalborg University, Afdeling for Matematik og Datalogi (September 1994–September 1996)
1993	Invited Researcher, Aalborg University Centre, Afdeling for Matematik og Datalogi (August 1993–December 1993)
1992–1996	Lecturer in Computer Science and Artificial Intelligence, University of Sussex, School of Cognitive and Computing Sciences (October 1992–September 1996)
1991-1992	Research Fellow, Hewlett-Packard Laboratories, Pisa Science Center (July 1991–September 1992)
1991	Professeur Invité, Centre de Mathématiques Appliquées, INRIA-Sophia Antipolis (January 1991–June 1991)
1987–1990	Research Fellow, University of Sussex, Computer Science and Artificial Intelligence Subject Group (October 1987–December 1990)

Key publications

[21, 23, 18, 26]

6.8.0 Gerd Behrmann

Academic Degrees

2003	Ph.D. (Computer Science), Aalborg University
1999	M.Sc. (Computer Science), Aalborg University, Denmark

Positions

2004–	Associate Professor, Aalborg University
2002–2004	Post doc., Aalborg University
1999–2002	PhD student, Aalborg University

Awards

2005	Spar Nord Basic Research Award

Key publications

[184, 30, 31, 93]

6.8.0 Anders Bo Christensen

Academic Degrees

2001	Cand. scient. (Computer Science), Aalborg University

Positions

2001–2003	: Research Assistant, Aalborg University

6.8.0 Mikkel Christiansen

Academic Degrees

2002	Ph.D, Aalborg University
1997	Cand.polyt., Aalborg University

Positions

2001–2004	: Assistant Professor at Aalborg University
1997–2000	: Ph.D. Student, Aalborg University

Key publications

[37, 38, 105]

6.8.0 Alexandre David

Academic Degrees

Ph.D.	Uppsala University (Computer Science), 2003
Licentiate	Uppsala University (Computer Science), 2001
M.Sc.	Uppsala University (Computer Science), 1998
Engineer	École Nationale des Télécommunications de Bretagne, 1998

Positions

2003–2005	: Assistant Professor at Aalborg University (Dep. of Computer Science)
1999–2003	: Ph.D. Student at Uppsala University (Dep. of Computer Systems)

Key publications

[88, 104, 213, 89]

6.8.0 Zoltan Esik

Positions

2001-2002	Visiting Professor at Aalborg University, Department of Computer Science
1997–	Professor, Department of Foundations of Computer Science, Szeged University, Hungar
1987–1997	Assciate Professor, Department of Computer Science, Szeged University, Hungary
1979–1986	First Assitant Professor, Department of Computer Science, Szeged University, Hungary
1974–1978	Assitant Professor, Department of Computer Science, Szeged University, Hungary

Academic Degrees

1978	Ph.D., Hungary

Key publications

[42, 18, 17, 41]

6.8.0 Emmanuel Fleury

Positions

2003–05	Assistant Pr. at Aalborg University, Department of Computer Science
2001–03	Post-Doc at Aalborg University, Department of Computer Science
1998–2002	Ph.D. Student at LSV, Cachan, France.

Academic Degrees

2002	Dr. scient, ENS Cachan, France

Key publications

[37, 36, 104, 147]

6.8.0 Hans Hüttel

Academic Degrees

1992	Ph.D. in Computer Science, University of Edinburgh, Scotland
1988	Cand.scient. (M.Sc.) in Computer Science and Mathematics, University of Aalborg
1986	B.Sc. in Computer Science, University of Aalborg
1985	B.Sc. in Mathematics, University of Aalborg

Positions

1995–	Associate Professor, Aalborg University, Department of Computer Science
1991–1995	Assistant Professor, Aalborg University, Department of Computer Science
1988–1991	Ph.D. research position, Institute of Mathematics, Århus University, Denmark

Awards

2005	Lecturer of the year, Faculty of Science and Technology, Aalborg University.
2004	Lecturer of the year, School of Science, Aalborg University.

Administrative duties

1997?2001	Chairman of the commitee on Masters programmes in Computer Science, School of Science

[47, 134, 49, 48]

6.8.0 Anna Ingólfsdóttir

Academic Degrees

1994	DPhil in Computer Science, University of Sussex
1987	Cand. scient. (M.Sc.) in Mathematics/Computer Science, Aalborg University
1976	B.Sc. in Mathematics/Physics, The University of Iceland

Positions

2000–	Associate Professor, Department of Computer Science, Aalborg University
1998–99	Research Assistant, Department of Computer Science, Aalborg University
1998 Visiting	Researcher at LSV, ENS de Cachan, Paris, France and at The Chinese Academy of Sciences
1997–98	Researcher, The University of Florence, Italy
1995–97	Research Assistant, Department of Computer Science, Aalborg University
1991–95	Assistant Professor, Department of Computer Science, Aalborg University
1990	Research Fellow, The University of Sussex

Key publications

[43, 51, 21, 52]

6.8.0 Bertrand Jeannet

Academic Degrees

2000	Ph.D. in Computer Science, Institut National Polytechnique de Grenoble, France.

Positions

2001–02	Post-Doc at Aalborg University, Department of Computer Science

Key publications

[117, 39, 81, 138]

6.8.0 Josva Kleist

Academic Degrees

2000	Ph.D. in Computer Science, Aalborg University.
1994	Cand.scient. (M.Sc.) in Computer Science, Aalborg University.

Positions

2001–	Lektor (Associate Professor), Aalborg University, Department of Computer Science.
2001	Adjunkt (Assistant Professor) Aalborg University, Department of Computer Science.
2000–2001	Post. doc., INRIA, Sophia-Antipolis, France.
1998–2000	Adjunkt (Assistant Professor) Aalborg University, Department of Computer Science.
1995–98	Ph.D. student, Aalborg University, Department of Computer Science.
1994–95	System developer, Modern CAD/CAM Systems, Randers, Denmark.

Key publications

[55, 64, 48, 139]

6.8.0 Morten Kühnrich

Academic Degrees

2005	Cand.scient. (M.Sc.) in Computer Science, University of Copenhagen.

Positions

2005–	Amanuensis, Aalborg University, Department of Computer Science.

Key publications

[134]

6.8.0 Kim Guldstrand Larsen

Academic Degrees

1986	Ph.D. in Computer Science, Edinburgh University, Scotland
1982	Cand. scient. (M.Sc.) in Mathematics, Aalborg University

Positions

2000–02	Industrial Professor (part-time), University of Twente, Holland
1995	Visiting Professor, Uppsala University, Sweden
1993–	Full Professor in Computer Science, Aalborg University, Institute for Electronic Systems
1992–93	Associate Professor in Computer Science, Aalborg University, Institute for Electronic Systems
1989–92	Senior Researcher (Seniorstipendiat) in Computer Science, Aalborg University, Institute for Electronic Systems
1986–89	Associate Professor in Computer Science, Aalborg University, Institute for Electronic Systems
1985–86	Assistant Professor in Computer Science, Aalborg University, Institute for Electronic Systems

Administrative duties

2002-	Director of Center for Embedded Software Systems, Aalborg, DK
2002-	Board Member of Center for Software Innovation, Sønderborg, DK
1999–	Member of the Steering Committee for European Educational Forum
1999–	Member of the Steering Committee for the Danish Research Net.
1999–03	Member of the Board of Directors for Institute of Computer Science, Aalborg.
1998–	Director of Aalborg section of BRICS
1996–02	Chairman for ”‘Bonusudvalget”’ (Danish Natural Sci- ence Research Council)
1996–03	Administrator of the Computer Science and Engi- neering Ph.D. Programme, Aalborg University
1991–97	Member of Danish Natural Science Research Council.
1987–89	Co-chairman of the Department of Mathematics and Computer Science, Aalborg University

Awards

2005	Danish Citation Laureates Award, Thomson Scientific award as the most cited Danish computer scientist in the Period 1990-2004
2003-	Member of the Danish Academy of Technical Sciences
2000-	Member of the Royal Danish Academy of Sciences and Letters, Copenhagen
1999	Honorary Doctor (Honoris causa), Uppsala University, Sweden

Key publications

[8, 145, 88, 35]

6.8.0 Didier Lime

Academic Degrees

2004	Ph.D. (Dr. Scient.) University of Nantes, France
2001	M. Sc. Ecole Centrale de Nantes, France

Positions

2005 –		Maitre de Conférences, Ecole Centrale de Nantes, France
2004	–	Post-doc, CISS / University of Aalborg, Denmark
2005		
2001	–	Engineer and Ph.D. student, Ecole Centrale de Nantes, France
2004		

Key publications

[104, 60, 159, 168]

6.8.0 Brian Nielsen

Academic Degrees

2000	Ph.D. in Computer Science, Aalborg University
1993	Cand. Polyt. (Master of Science in Engineering, MSc. EE.), Aalborg University

Positions

2004–	Associate Professor at the Department of Computer Science, Aalborg University
2003–2004	Temporary Associate Professor at the Department of Computer Science, Aalborg University
2002–2003	Amanuensis at the Department of Computer Science, Aalborg University
2001–2002	Siemens Research Associate Professor at the Department of Computer Science, Aalborg University
2000–2001	Amanuensis at the Department of Computer Science, Aalborg University
1999–2000	Visiting Researcher at the University of Bremen, Germany
1997–00	Assistant Professor at the Department of Computer Science, Aalborg University
1994–97	Ph.D. student at the Department of Computer Science, Aalborg University
1995–96	Visiting scholar at the University of Illinois at Urbana-Champaign, Illinois, U.S.A.
1993–94	Teaching Assistant at the Department of Computer Science, Aalborg University

Administrative duties

2003	Leader of NouHauz Industrial Network in Test and Modelling of Software (ToMaS)

Key publications

[162, 151, 164, 66]

6.8.0 Anders P. Ravn

Academic Degrees

1995	Dr. techn., Technical University of Denmark
1973	Cand.scient. (M.Sc.) in Computer Science and Mathematics, University of Copenhagen

Positions

2004–	Professor, Department of Computer Science, Aalborg University
1999–04	Professor (research), Department of Computer Science, Aalborg University
1998–99	Visit. Professor, Department of Computer Science, Aalborg University
1989–99	Reader (Docent), Department of Information Technology, Techn. Univ. Denmark
(1994)	Visit. Professor, Christian-Albrechts UniversitÂŠt zu Kiel, Germany
1984–89	Lecturer, Deptartment of Computer Science, Techn. Univ. Denmark
(1985–89)	Adjunct Lecturer, Department of Mathematics, Royal Vet. and Agricultural Univ.
1982–83	Visiting Scientist, IBM T. J. Watson Res. Cen., Yorktown Hgths., USA
1980–84	Lecturer, Department of Computer Science, Univ. Copenhagen
1976–80	Assistant Professor, Department of Computer Science, Univ. Copenhagen
1972–76	Systems programmer, A/S Regnecentralen
1969–73	Teaching assistant, Department of Computer Science, Univ. Copenhagen

Key publications

[63, 67, 83, 174]

6.8.0 Arne Skou

Academic Degrees

1990	Ph.D. in Computer Science, Aalborg University
1975	Cand. scient. (M.Sc.) in Computer Science, Copenhagen University

Positions

1989–	Associate Professor in Computer Science, Aalborg University, Institute for Electronic Systems
1986–89	Ph.D. Scholarship, Århus University, Computer Science Department. Visiting University of Sussex, UK, for 7 months during the Ph.D. study.
1986	Research assistant, Copenhagen University.
1975–86	Member of the senior scientific staff at the computing centre of Aalborg University. Head of the computer networking group.
1971–75	Teaching assistant, Department of Computer Science, Copenhagen University.

Administrative duties

1998–00	Course planning for unemployed engineers
1996–00	Board member, Institute of Electronic Systems
1999–00	Head of computer resources committee
1996–98	Head of Department

Key publications

[66, 130, 163, 214]

6.8.0 Jiri Srba

Academic Degrees

2005	Ph.D. in Computer Science, Masaryk University in Brno
2003	Ph.D. in Computer Science, BRICS, University of Aarhus
1998	Mgr. (master's degree) in Computer Science, Masaryk University in Brno
1996	Bc. (bachelor's degree) in Computer Science, Masaryk University in Brno

Positions

2005–	Associate Professor, Aalborg University, Department of Computer Science
2003–2005	Assistant Professor, Aalborg University, Department of Computer Science
1999–2002	Teaching Assistant, Aarhus University, Department of Computer Science
1998–1999	Assistant, Masaryk University in Brno, Faculty of Computer Science

Key publications

[178, 179, 13, 70]

6.8.0 External faculty

Ed Brinksma

1994	Ph.D. in Computer Science, University of Twente, The Netherlands
1988	M.Sc. in Mathematics, University of Groningen, The Netherlands

Positions

2004–	Adjoint Professor, Aalborg University, Department of Computer Science
1991–	Professor, Faculty of Computer Science, University of Twente, The Netherlands
1988–1991	Associate Professor, Faculty of Computer Science, University of Twente, The Netherlands

Jens Christian Godskesen

Academic Degrees

1994	Ph.D. in Computer Science, University of Aalborg
1988	Cand.scient. (M.Sc.) in Computer Science and Mathematics, University of Aalborg
1986	B.Sc. in Computer Science, University of Aalborg
1985	B.Sc. in Mathematics, University of Aalborg

Positions

2003–	External Associate Professor, Aalborg University, Department of Computer Science
1999–	Associate Professor, IT University of Copenhagen, Denmark.
1997–1998	External Associate Professor, Aalborg University, Department of Computer Science
1996–1998	School of Computer Science at Roskilde Business College, Denmark.
1994–1996	Researcher at Tele Denmark.
1989–1991	Researcher at TFL (Telecommunication Research Laboratory), Denmark.

6.9 Ph.D. Projects

6.9.1 Project Descriptions

The Performance of HTTP Traffic Under Random Early Detection Queue Management

Name: Mikkel Christiansen

Education: M. Sc. Computer Science, Aalborg University

Duration: August 1997 – January 2002

Status: Completed

Funding: Aalborg University

Advisor: Arne Skou

In RFC (Request For Comments), the active queuing mechanism RED has been purposed for widespread deployment on Internet routers. This thesis presents an empirical study of the active queuing mechanism RED where we focus on the question: How will RED affect HTTP response times and can RED be tuned to optimize these?

The empirical study is conducted on a laboratory network in which we model a typical scenario in which a router operates and becomes a bottleneck. A realistic HTTP traffic load is provided by a set traffic generator programs. These simulate the behavior of browsing users using an empirical model of HTTP traffic that is both well-founded as well as being widely accepted and used. Response time performance is measured for each request made in the simulation of browsing users, thus providing a detailed insight on the performance experienced by the end-user.

The study consists of finding the optimal RED parameters under different offered loads. Where the offered load describes the average bandwidth utilization produced by the traffic generators on a network with no bandwidth constraints. To determine the impact of using RED we compare the response time performance with our choice of optimal RED parameters with the optimal performance of tail-drop queuing and the performance on the laboratory network without bandwidth constraints.

The results of the study can be summarized as follows:

- Contrary to expectations, compared to tail-drop queuing, RED has minimal effect on HTTP response times for offered loads up to 90% of the link capacity. Response times at loads in this range are not substantially effected by RED parameters.

- Between 90% and 100% load, RED can be carefully tuned to yield performance somewhat superior to tail-drop queuing, however, response times are quite sensitive to the actual RED parameter values selected.

- In heavily congested networks, RED parameters that provide the best link utilization produce poorer response times.

In total, we conclude that for links carrying Web traffic, RED queue management appears to provide no clear advantage over tail-drop for end-to-end response times.

Reliable Real-Time Applications, and how to use tests to model and understand

Name: Peter Krogsgaard Jensen

Education: Master of Science in Electrical Engineering

Duration: 1/9 1995–1/3 2001

Status: Completed

Funding: Danish Technical Research Council (STVF)

Advisor: Arne Skou

The task of verifying timing properties of critical computing systems during development is important, due to the serious or fatal consequences if such systems fail. The importance is growing because more and more software is involved in controlling the everyday life of humans. As we need to develop and verify more and more complex and larger systems, the software engineering process must be improved to maintain the quality of the end product. On way to improve is by making it more automatic, such that trivial and error prone manual task can be handled by tools.

The development of software for industrial use will involve a testing phase, with the purpose of "verifying" the requirements of the product. Traditionally tests have targeted functional requirements, but the thesis in this work is that tests can also be the foundation of analysis and verification of timing requirements. To support our thesis, we develop tools to analyze timing information from (instrumented) systems under test. An industrial sized control application is used as a case study, and all tools and techniques that we have been developing are used in the case study. The case study works as a proof-of-concept, displaying the pros and cons of the tools and techniques.

During a test all paths of the implemented program text should be executed (in theory), but for a real-time application with fast periodic task a particular path is executed many times. If the test is thorough this path is executed with different parameters, leading to different execution times due to conditional and loop statements. We suggest a Reliable Worst Case estimate, called RWC, which is an upper boundary of the statistical model of the variation of such execution times. This RWC is used for two things: 1) to visualize the structure of real-time applications, and 2) to evaluate deadlines in scheduleability analysis. The RWC is a new approach to worst case execution time estimation for real-time programs.

One problem in many analytical analyzes of a real-time program is that it can only handle a process model consisting of threads that serve one purpose. Much of the complexity in the work presented here originates from a larger process model where tasks are more complex. It is our aim to be able to analyze systems that use all these facilities. It is not desirable to use a smaller process model because sound software design principles for software engineering cannot be followed when using simple models. Limitations cannot be completely avoided because we want a temporal predictable application.

As part of the work with the case study we have developed middleware and extensions for a real-time kernel so that we can observe the structure and timing of systems under test. It turns out that only 1.5% of the CPU power is consumed by the extension, and this convinces us that it is feasible for an industrial system.

Also to aid observation a trace language is suggested that can describe the structure of a larger range of real-time applications. This language is a formal description of real-time applications, and we demonstrate its use as a part of the case study. The Observed Model, is the name we use for a model of an application described by a set of strings from the trace language, and all our analysis of the temporal behavior is based on this model.

In the thesis, a test inspection technique is suggested. It is a postmortem traceability analysis which creates an end-to-end connection from input event to output event. With this analysis the structure of the real-time application can be visualized, based on worst case estimate of execution time of the program text.

Detailed timing information annotated to the trace language model makes it possible to do scheduleability analysis on the involved tasks. The scheduleability analysis is based on RWC values, which substitutes the WCET in the analysis. With an additional model that describes the real-time kernel, properties of the complete real-time system becomes verifiable. Part of the cases study is a presentation of a technique where model checking is applied to an Observed Model including a model of the kernel. With this model checking, it is possible to verify deadlines and maximum jitter of events, by applying the real-time model checker UPPAAL.

Routing in mobile ad-hoc networks

Name: Thomas Heide Clausen

Education: Cand.polyt

Duration: 1/7 1999–13/12 2005

Status: Defended

Funding: Aalborg University

Advisor: P. Jacquet (INRIA Rocquencourt), Arne Skou

This thesis addresses a growing trend in the Internet: increased mobility of connected devices. With the Internet being initially designed for mostly-static scenarios, the advent of mobile wireless devices has brought an increased network

dynamism – initially on ”the edge” where laptops and PDAs connect to different networks as their owner moves around, but lately mobility has crept into the network core, with routers disconnecting, moving, and then reconnecting. As such, the traditional model of the Internet being stable, with a definitely stable core of routers, is changing.

Currently, the ultimative mobility challenge is the class of networks called Mobile Ad hoc NETworks (MANETs). In such networks, each device has the ability to act both as a communications endpoint (host) and network forming device (router) at the same time. The devices being inheritly mobile, this type of networks are mainly characterized by having a frequently changing topology and links with limited capacity. The task of providing and maintaining connectivity in such a MANET is, therefore, vastly different from that of providing connectivity in the traditional Internet.

The trend in the Internet, of the network topology becoming steadily more and more dynamic, implies that (parts of) the Internet may in the years to come assume characteristics similar to those of a MANET. As such, studying MANETs and understanding how to ensure connectivity in this kind of networks is an important step towards being able to develop the Internet in the future. This thesis is, therefore, dedicated to the study and evaluation of mechanisms for maintaining connectivity of MANETs.

More specifically, the thesis devleops a routing protocol, called the Optimized Link State Routing Protocol (OLSR), evaluates its performance characteristics both through simulations and practical experiments, as well as that of its individual components. This allows us to compare the protocol against alternative MANET routing protocols, and make a quantitative statement of OLSR as the most feasible solution to the problem of MANET routing.

The thesis also presents OLSR as a solution to the increasing Internet topology dynamics by exposing a set of scenario of ”nested mobile networks”, in which classical Internet mechanisms fail painfully short of providing reasonable connectivity – but in which deploying OLSR yields an optimal situation. This is just one example of deployment of OLSR in MANETs, but it is indicative of both the utility of OLSR and of the trend that the Internet is in part approaching MANET characteristics. Indeed, the Internet Engineering Task Force has recognized this, and as a concequence standardized OLSR as MANET routing protocol in RFC 3626.

Data management on Grid

Name: Henrik Thostrup Jensen

Education: M. Sc. Computer Science, Aalborg University

Duration: December 2005–November 2008

Status: Ongoing

Funding: Danish Center for Grid Computing and Aalborg University

Advisor: Josva Kleist

Managing data is currently one of the most time consuming tasks, if not the largest, in working with current Grid systems. All major Grid projects are currently struggling with this task. Currently most solutions have central components, and therefore fails to provide a lot a the facilities expected from a Grid. Their scalability, fault tolerance, and availability is questionable. This projects will try to answer how a scalable, fault tolerant, and highly available data management systems can be build? Resources in a Grid continually disappear and move, so a high degree of automation is required. The proposed system must respect the administrative domains and existing security mechanisms. Furthermore, the system should be easy to use, due to the high cost of administrating data.

Framework for analysing and synthesizing autonomous robots

Name: Piotr Makowski

Education: M. Sc. Computer Science, Warsaw University, Poland

Duration: January 2000 – May 2005

Status: Completed

Funding: API amd Agrobotics project

Advisor: Anders P. Ravn

A rapidly evolving research area is design and development of so-called /situated autonomous agents/. An autonomous agent is a system that tries to meet a predefined set of goals on its own (without any need for human support or guidance). A situated agent operates in a complex, dynamic and unpredictable environment. It can sense the changes in the environment trough its sensors and act upon the environment using a set of actuators.

In the past years many architectures have been presented as a patterns for constructing autonomous situated agents in the way that would assure maximal robustness, effectiveness and reliability. To the most popular architectures presented in the literature belong *deliberative*, *reactive*, *hybrid* and *behaviour-based* systems.

The purpose of this work is to develop a framework dedicated to situated agent domains that would allow to compare and asses various architectures in an objective manner, be applicable to most known architectures and allow us to abstract agent architecture properties from its physical implementation (but define clear requirements that the underlying hardware must fulfill).

A major case study - the Autonomous Plant Inspection System - illustrates the architectural framework.

Tool Integrated Verification and Testing of Model Based Embedded Systems Using UML

Name: John Knudsen

Education: Cand. Scient in Computer Science, Aalborg University

Duration: September 2003 – August 2006

Status: In progress

Funding: CISS and Aalborg Universityt

Advisor: Anders P. Ravn and Arne Skou

The area of embedded systems has always been subjected to substantial dependability requirements, thus a major part of the development effort is spent on system validation, verification and testing, however traditional testing methods do no longer suffice for the complex systems of today. An important challenge is to integrate available research results on verification and testing into model based development tools. This impose several challenges within this field. Current tools only uses UML as a syntactic notation and at best provide a very concrete operational semantic manifested in a translation to a programming language. In contrast to this the research tool for verification and testing are based on more precise semantics, typically as transition systems. One challenge is thus to find a proper subset of UML, that can be given a semantic. Another challenge is in the task of specifying the properties to be verified or tested. These specifications must be available in a form, such that they relate to the developers expectations and still is processable by the available tools, which typically employ logic based specification languages.

Expressiveness in process calculi with locations and migration

Name: BjÃ¸rn Haagensen

Education: Cand. scient. (M.Sc.) in Computer Science, 2004

Duration: August 2004 – July 2007

Status: In progress

Funding: Aalborg University

Advisor: Hans Hüttel

The focus of the Ph.d. project is on issues related to expressiveness in process calculi with locations and migration. In order to derive useful properties of distributed programs, process calculi such as the pi-calculus have been extended with primitives supporting network locations and migration of processes between locations. It is often unclear how, or whether at all, these extensions adds to the expressive power of the pi-calculus. In particular we suggest comparing the expressive power of the epi-calculus, which is known to be more expressive than the pi-calculus, with the Dpi-calculus. The epi-calculus has the ability to synchronize on more complex structures than just atomic names as known from the pi-calculus. Existing work suggests that this increase in expressive power is comparable to certain constructs in languages such as Dpi. In a wider perspective the ultimate goal is to establish whether the calculus of Mobile Ambients, and related calculi are more

expressive than even the epi-calculus. Depending on the outcome results of this type can be useful from the perspective of possible implementations of calculi with locations and migration as well as from a more theoretical point of view.

Automatic test case generation and distributed model checking

Name: Jacob Illum

Education: Cand. scient. (M.Sc.) in Computer Science, 2003

Duration: August 2004 – July 2007

Status: In progress

Funding: Aalborg University

Advisor: Kim Guldstrand Larsen

The motivation behind the project is to extend the applicability of formal models of software systems, by two different approaches: Model based test case generation and distributed model checking algorithms. The aim of model based test case generation is to automatically generate relevant test cases from a formal model. The aim of distributed model checking is to extend the domain of models that can be verified within reasonable time. The possibilities in using the power of distribution in combination with testing will also be explored.

Data Structures and Algorithms for the Analysis of Real Time Systems

Name: Gerd Behrmann

Education: Cand. scient. (M.Sc.) in Computer Science, 1999

Duration: August 1999 – May 2003

Status: Completed

Funding: Aalborg University

Advisor: Kim Guldstrand Larsen

This thesis presents data structures and algorithms for the analysis of real time systems in various modelling formalisms. Algorithms for reachability analysis (a special case of model checking) and static scheduling analysis are presented. The modeling formalisms range from traditional state/event systems as used in the commercial tool visualSTATE? over hierarchical state/event systems and timed automata to linear priced timed automata.

Data structures used range from reduced ordered bi- nary decision diagrams (ROBDD) used in symbolic model checking of state/event systems, over clock difference diagrams (CDD), an ROBDD like data structure for real time systems, to priced zones used for representing the state space of cost annotated timed automata.

The thesis is a collection of six papers. The first two papers deal with model checking of visualSTATE? models – in fact, the current version of visualSTATE uses the patented techniques proposed in the first paper. The third paper considers alternative data structures for representing the state space of a real time system (CDDs).

The remaining three papers deal with how real time model checking techniques like those used for timed automata, can be used to answer static scheduling problems and in particular, how one can specify and find optimal schedules. The techniques presented in the thesis have been experimentally evaluated using either a prototype of the visualSTATE model checker or the academic timed automata verification tool Uppaal.

A Configurable Process for Design of Object-Oriented Software Architectures

Name: Birgitte LÃ¸nvig

Education: M.Sc., Electrical Engineering, 1992

Duration: August 1995 – May 2001

Status: Completed

Funding: Aalborg University

Advisor: Charlotte Pii Lunau

When we design large complex software systems, such as systems in the telecommunications world, and we follow one of the standard object-oriented methods or processes, we end up with a system that fulfils the requirements of functionality. However, it is difficult to ensure that other requirements, such as modifiability and reusability, are fulfilled. Furthermore the architecture is not explicitly described and is therefore difficult to comprehend.

This Ph.D. dissertation defines a configurable process for design of object-oriented software architectures. The process can be regarded as an extension to standard object-oriented methods and processes. Software architecture is in focus by making its design explicit in a process and the process is configured for a specific domain.

Configuring ensures that the process contains only relevant process elements, contrary to a general process that must cover all possible combinations of problems and solutions in a number of different domains. The workflow of how to configure a process for a domain is although applicable for different domains.

The software architecture design process is based on a general conceptual framework consisting of domain characteristics, requirements, architectural levels, architectural patterns, and architectural structures

Live Sequence Charts as specification language for communication protocols

Name: Saulius Pusinskas

Education: M.Sc. GPS Technology, 2004

Duration: August 2003 – July 2006

Status: In progress

Funding: Aalborg University

Advisor: Kim Guldstrand Larsen and Arne Skou

The goal of this project is to adapt the visual formalism of Live Sequence Charts (LSC) to capture requirements from communication protocols. Requirements for communication protocols are defined by means of textual RFC documents. Up to now, thousands of RFCs have been published, some of them redefining or obsoleting certain requirements defined by their predecessors. Requirement is the smallest part which constitutes the protocol specification.

Some existing tools like REMoRDS can generate from the LSC chart a LTL formula ready to submit into the model checker. In our approach the LSC specification shall be translated chart-by-chart into the timed automata supported by UPPAAL, where all the model checking, simulation or testing activities are performed.

Through this project we will define the set of constructs from LSC formalism that are suitable to capture the communication protocol requirements, investigate what types of requirements in RFC and to what extent can be formalized using chosen formalism, define and perform conversion of requirements from LSC to other formalisms where the specifications can be simulated, verified and used as the oracle in conformance tests, and propose the investigated techniques and formalism to capture requirements from current and future RFC documents.

Automated Online Testing of Timed Systems

Name: Marius Mikucionis

Education: M.Sc. in Systems Software Engineering, 2004

Duration: August 2004 – July 2007

Status: In progress

Funding: Aalborg University

Advisor: Brian Nielsen

In this Ph.D. project we study automated online testing of timed systems. Our thesis is that online testing is an efficient technique in finding faults and assuring

quality in embedded software systems, where timing properties and event deadlines are of extreme importance. To investigate this we propose to develop real-time testing theory, implement supporting online testing tools and examine their applicability and efficiency by conducting experiments in scientific and industrial case studies. Our approach is to extend un-timed conformance testing theory with time and use the existing high performance engine from timed-model-checker to derive tests and check for conformance during test execution. We mainly follow an empirical investigation method based on a solid theory to verify and evaluate our tools and techniques.

Automatic test case generation and distributed model checking

Name: Ulrik Nyman

Education: Cand. scient. (M.Sc.) in Computer Science, 2004

Duration: August 2003 – July 2006

Status: In progress

Funding: Aalborg University

Advisor: Kim Guldstrand Larsen

The motivation behind the project is to extend the applicability of formal models of software systems, by two different approaches: Model based test case generation and distributed model checking algorithms. The aim of model based test case generation is to automatically generate relevant test cases from a formal model. The aim of distributed model checking is to extend the domain of models that can be verified within reasonable time. The possibilities in using the power of distribution in combination with testing will also be explored.

Modelling Behaviour and Specifying Requirements of Embedded Software Systems

Name: Ole Eriksen

Education: Cand. scient. (M.Sc.) in Computer Science, Aarhus University, 1984

Duration: August 2003 – July 2008

Status: In progress

Funding: Aalborg University

Advisor: Arne Skou

In industry it is a widespread tradition to use informal requirement specifications as a contract. Several problems in software development point out the informal requirement specification as the main cause. Other communities have solved the problem by disregarding the requirement specification. The approach chosen in this context is to formalize it, and focus on embedded software systems. The

project aims to bridge the gab between informal requirement specifications and software components by inventing, specifying and testing formal (based) languages supporting modelling behaviour and specifying requirements, such that systematic or automatic translation of models to executable software components is possible. Requirements should be specified by experts in domain requirements, which are not necessary people holding competences in software development. To that end the project also aims to bridge the gab between software and domain experts.

Tools and Language-support for Testing of Object Oriented Software

Name: Per Madsen

Education: Cand. polyt. (M.Sc.) in Computer Science, 1998

Duration: August 2001 – July 2004

Status: In progress

Funding: Aalborg University

Advisor: Kim Guldstrand Larsen and Kurt NÃ¸rmark

In modern software development a huge amount of time is spent on testing of the software. Still a lot of software is released containing a large number of bugs, which causes a lot of problems for the end-users of the software. Even though the activity of testing is as old as the activity of programming itself, it seems that the testing effort is not yet efficient enough.

This Ph.D. project takes two well-known ideas as a starting point: unit testing as done in Extreme Programming (Kent Beck) and in Design by Contract as done in the programming language Eiffel (Bertrand Meyer).

The basic idea of this project is to combine the use of JUnit and Design by Contract. JUnit provides us with a framework for automatic execution and to some degree automatic evaluation of test cases. If we combine JUnit with Design by Contract we can reuse the assertions written as pre- and postcondition and class-invariants in the test cases. This gives us a testing approach with automatic execution and evaluation of test cases.

If we can come up with an automatic way to generate and setup test cases, use JUnit to execute the test case, and use Design by Contract to evaluate the test, then we are heading towards a fully automated testing approach. We will refer to this approach as Testing by Contract.

The main research topic for this project is to investigate how we can generate and setup appropriate test cases for Testing by Contract. One approach that seems attractive is to integrate the ideas of Equivalence Partitions and Design by Contract. This is done by describing Equivalence Partitions for each class in a program. (a set of boolean expressions defining a partitioning schema)

A prototype Java-like language with support for Design by Contract enhanced with Equivalence Partitions has been developed. A compiler to regular Java-code

as well as a tool for automatic generation of test cases is currently being build. This prototype language/tool will be used to further examine the ideas described above.

Intelligent Sensor Networks Using Approximative Bayesian Inference

Name: Jens A. Hansen

Education: Cand. scient. (M.Sc.) in Computer Science, 2003

Duration: August 2004 – July 2007

Status: In progress

Funding: Aalborg University

Advisor: Henrik Schiøler and Thomas D. Nielsen

The goal of the project is to explore the possibility of livestock welfare monitoring and diagnosis. The discrete nature of faults and possible bi-modality of welfare has lead to the use of probabilistic discrete event systems. The formalism used is that of Dynamic Bayesian Networks, which are well known within the AI community. The size of the models used makes it computationally infeasible to perform exact monitoring, thus approximations are explored. The possible results of the project is to enable the construction of intelligent control systems based on the welfare monitoring.

6.9.2 External Ph.D. students

This describes Ph.D. projects at other universities supervised fully on in part by members of the research group.

Analyzing Real-Time Systems

Name: Thomas Hune

Education: Cand. scient. (M.Sc.) in Computer Science, 1997

Duration: August 1997 – March 2001 at Århus University, Denmark

Status: Completed

Funding: BRICS

Advisor: Kim Guldstrand Larsen

In this project we study classes of cost extended timed automata and their applications.

First, we consider uniformly priced timed automata (UPTA) and linearly priced timed automata (LPTA), where a cost is associated to an execution of the automaton. We show that the minimum-cost reachability problem is decidable for both classes.

Next, we consider parametric timed automata, where parameters can be used in expressions for guards and invariants. We consider the problem of synthesizing values for the parameters ensuring satisfiability of reachability properties. The problem of synthesizing constraints for the parameters is undecidable; we present a semi-decision procedure synthesizing the constraints. The semi-decision procedure is implemented in UPPAAL and constraints ensuring correctness of a number of industrial protocols are synthesized.

We study the possibility of distributing the reachability checking to a network of computers. We have implemented a distributed version of UPPAAL and tested it on a number of the largest known case studies for UPPAAL.

We apply the general categorical framework of open maps to timed automata by presenting a category whose elements are timed automata, and a subcategory suitably for representing observations, timed words.

We give a translation from a low level programming language used in the programmable LEGOpsy226 RCXpsy228 brick to timed automata. The translation has been implemented and tested on a control program for a car.

Finally, we consider a kind of partial program synthesis for untimed systems. Given a safety specification written in monadic second order logic, we use the Mona tool to derive an automaton accepting the language of the specification.

Structure and Hierarchy in Real-Time Systems

Name: Oliver Möller

Education: Diplom-Informatiker (M.Sc. in Computer Science), 1998

Duration: August 1998 – February 2002 at Århus University, Denmark

Status: Completed

Funding: BRICS

Advisor: Kim Guldstrand Larsen

The development of digital systems is particularly challenging, if their correctness depends on the right timing of operations. One approach to enhance the reliability of such systems is model-based development. This allows for a formal analysis throughout all stages of design.

Model-based development is hindered mainly by the lack of adequate modeling languages and the high computational cost of the analysis. In this thesis we improve the situation along both axes.

First, we bring the mathematical model closer to the human designer. This we achieve by casting hierarchical structures—as known from statechart-like formalisms—into a formal timed model. This shapes a high-level language, which allows for fully automated verification.

Second, we use sound approximations to achieve more efficient automation in the verification of timed properties. We present two novel state-based techniques that have the potential to reduce time and memory consumption drastically.

The first technique makes use of structural information, in particular loops, to exploit regularities in the reachable state space. Via shortcut-like additions to the model we avoid repetition of similar states during an exhaustive state space exploration.

The second technique applies the abstract interpretation framework to a real-time setting. We preserve the control structure and approximate only the more expensive time component of a state. The verification of infinite behavior, also known as liveness properties, requires an assumption on the progress of time. We incorporate this assumption by limiting the behavior of the model with respect to delay steps. For a next-free temporal logic, this modification does not change the set of valid properties.

We supplement our research with experimental run-time data. This data is gathered via prototype implementations on top of the model checking tools UPPAAL and MOCHA.

Hybrid Action Systems

Name: Mauno Rönnkö

Education: M. Sc. Computer Science, University of Kuopio, Finland

Duration: 1/6 1997 - 1/10 2001

Status: Completed. Selected as best CS thesis in Finland 2001

Funding:

Advisor: Kaisa Sere (Turku, Finland) and Anders P. Ravn

A facility for modelling hybrid systems is added to the action systems framework developed by Ralph-Johan Banck and others. The *hybrid action* is a conservative extension of the theory of actions. Rules and refinement laws are developed that allows refinement from discrete transitions to evolutions by means of hybrid actions. The theory is used to develop a refinement methodology for hybrid systems in general illustrated by small examples and detailed proofs.

Component-based Estimation

Name: Jens Peter Holmegaard

Education: M. Sc. EE, Aalborg University

Duration: 1/3 2002 - 1/3 2005

Status: Thesis under revision

Funding:

Advisor: Peter Koch (Department of Electronic Systems, Aalborg University) and Anders P. Ravn

In development of electronic devices for embedded systems, there is a strong motivation to reuse components. However, such reuse is facilitated by tools that can estimate the impact on non-functional properties like timing, space consumption, and power consumption. The thesis develops a framework and a prototype tool for such estimations illustrated by concrete examples in the `SystemC` language.

Correct and Efficient Simulation with Ptolemy II

Name: Daniel Lazaro Cuadrado

Education: M. Sc. EE, Aalborg University

Duration: 1/3 2002 - 1/3 2005

Status: in progress

Funding:

Advisor: Peter Koch (Department of Electronic Systems, Aalborg University) and Anders P. Ravn

Ptolemy II is a design language for heterogeneous computing systems developed at Berkeley University, California by a team led by Professor Ed. Lee. It is supported by a simulation tool implemented in Java. In this project, a parallel implementation of the most popular computing model - Synchronous DataFlow - is produced. The current version is scheduled to be included in the Ptolemy II release by the end of 2005 and has already attracted attention within the community, because it gives an efficient utilization of cluster computers while maintaining a simple interface to the Ptolemy language.

Visiting Ph.D. Students

The following students have each spent a semester in the research group during the period 2001–2005.

- Johan Ernits, Department of Computer Science, Tallinn University of Technology, Estonia.*(September 2003–January 2004)*
- Martijn Hendriks, Institute for Computing and Information Sciences, University of Nijmegen, The Netherlands.
- Gregorio Diaz Descalzo, Escuela Politècnica Superior de Albacete, Spain.
- Andrzej Warsowski, The IT University of Copenhagen, Denmark.
- Michael Westergaard, Department of Computer Science, Ã…rhus University, Denmark.

6.10 Collaboration

6.10.1 Guests

The following people have visited the research group since 2000.

2001

- Carsten Weise, Ericsson Eurolab, Aachen, Germany, 25 April 2001
- Franck Cassez, IRCCyN/CNRS, Nantes, France, 2 December–12 December and 18 August 2001–08 September 2001
- François Laroussinie, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, France, 2 December–8 December and 14 January 2001–25 January 2001
- Goran Frehse, Process Control Laboratory, Department of Chemical Engineering, University of Dortmund, Germany, 19 November 2001
- Stephen L. Bloom, Stevens Institute of Technology, Hoboken, NJ, USA, 07 August 2001–19 August 2001
- Pedro R. D'Argenio, Department of Computer Science, University of Twente, The Netherlands, 22 February 2001
- Jens Christian Godskesen, IT-C (The IT University of Copenhagen), Denmark, 8 March 2001
- Martijn Hendriks, University of Nijmegen, Computer Sciences, The Netherlands, 5 August 2001–30 August 2001
- Patricia Bouyer, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, France, 2 December 2001–14 February 2002
- Morgan Björkander, Telelogic, Sweden, 17 August 2001–19 August 2002
- Antonio Petit, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, Frankrig, 19 August 2001–
- David Lee, 22 August 2001–25 August 2001
- Peter Niebert, Verimag. Imag, France, 26 August 2001–01 September 2001
- Walter Vogler, Universität Augsburg, D, Germany, 24 August 2001–30 August 2002
- Marta Kwiatkowska, University of Birmingham, United Kingdom, 7 October 2001–09 October 2001

- David Parker, University of Birmingham, United Kingdom, 7 October 2001–09 October 2001
- Jan Tretmans, University of Twente, Department of Computer Sciences, The Netherlands, 22 April 2001–26 April 2001
- Sylvain Lecamp, IRCCyN (L'Institut de Recherche en Communication et Cybernétique de Nantes, France, 19 June 2001
- Sebastien Bernicot, IRCCyN (L'Institut de Recherche en Communication et Cybernétique de Nantes, France, 19 June 2001
- Koen Claessen, Department of Computing Science, Chalmers University of Technology, Sweden, 27 May 2001
- António Ravara, Mathematics Department of Instituto Superior Técnico, Lisbon, Portugal, 25 March 2001

2002

- Ed Brinksma, Formal Methods and Tools Group, Twente University, The Netherlands, 22 January 2002–24 January 2002
- Wang Yi, DoCS (Department of Computer Systems), Uppsala University, Sweden, 03 March 2002–27 March 2002
- Paul Petterson, DoCS (Department of Computer Systems), IT (Information Technology), Uppsala University, Sweden, 8 October 2002–10 October 2002
- António Ravara, Mathematics Department of Instituto Superior Técnico, Lisbon, Portugal, 22 March 2002–27 March 2002
- Stavros Tripakis , VERIMAG, CNRS (National Reseach Center), Fault-Diagnosis of Timed Systems, France, 4 August 2002–08 August 2002
- Daniele Varacca, Computer Laboratory, University of Cambridge, United Kingdom, 14 October 2002

2003

- António Ravara, Mathematics Department of Instituto Superior Técnico, Lisbon, Portugal, 5 March 2003
- Goran Frehse, Process Control Laboratory, Department of Chemical Engineering, University of Dortmund, Germany, 07 January 2003–11 January 2003

- Franck Cassez, Ecole Centrale de Nantes, Institut de Recherche en Cybern'etique de Nantes (IRCyN), France, 4 January–25 January and 21 November 2003–19 December 2003
- Andrzej Wasowski, Department of Innovation, IT University of Copenhagen, Denmark, 10 December 2003
- Dagmar Ludewig, Axxom Software AG, Munich, Germany, 18 September 2003
- Olaf Stursberg, Department of Biochemical and Chemical Engineering, University of Dortmund, Germany, 17 September 2003
- Angelika Mader, Distributed and Embedded Systems, Department of Computer Sciencen, University of Twente, The Netherlands, 16 September 2003–18 September 2003
- Ed Brinksma, Formal Methods and Tools Group, Twente University, The Netherlands, 10 August 2003–14 August 2003
- Patricia Bouyer, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, France, 10 August 2003–14 August 2003
- K Subramani, Computer Science and Electrical Engineering, West Virginia University, USA, 29 June 2003 *(employed for a period of 3 months)*
- Juhan Ernits, Department of Computer Science, Tallinn Technical University, Estonia, 30 September 2003–30 January 2004

2004

- António Ravara, Departamento de Matemática, Instituto Superior Técnico, Lisbon, Portugal, 07 February 2004- December 02-2004
- Jan Friso Groote, Department of Computer Science, Eindhoven University of Technology, The Netherlands, 17 February 2004–29 February 2004
- Pascal Zimmer, Department of Computer Science, Århus Universitet, Denmark, 23 November 2004–23 November 2004
- Didier Lime, Institut de Recherche en Communications et en Cybernétique de Nantes, France, 16 August 2004–20 August 2004
- Gregorio Diaz Descalzo, Dept. Computer Sciences, University of Castilla - La Mancha, Spain, 18 May 2004- April 07-2004
- Bharat Bhushan, Fraunhofer FOKUS, Berlin, Germany, 18 May 2004

- Johan Bengtsson, Department of Information Technology, Uppsala University, Sweden, 27 April 2004–6 May 2004
- Hanne Gottliebsen, Queen Mary, University of London, United Kingdom, 13 April 2004–13 April 2004
- Zhiming Liu, International Institute for Software Technology, The United Nations University, Macao SAR, China, 19 January 2004–21 January 2004
- Birgit Siebenrok, Technischen Universität München, Germany, 12 August 2004–15 November 2004 *(employed for a period of 3 months)*

2005

- Bertuen Damman, Formal Methods and Tools, Department of Computer Science, University of Twente, The Netherlands, 31 July 2005–30 October 2005
- Jiří Barnat, Faculty of Informatics, Masaryk University, Czech Republic, 31 January–31 March and 4 September 2005–29 September 2005
- Jiří Simsa, Faculty of Informatics, Masaryk University, Czech Republic, 2 October 2005–30 December 2005
- Rodolfo Gomez, Computing laboratory, University of Kent, United Kingdom, 10 October 2005–13 October 2005
- Hans Søndergaard, Vitus Bering Institute, Denmark, Autumn 2005
- Pierre-Alain Reynier, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, France, 09 October 2005–21 October 2005
- Joseph Mathai, Tata Consultancy Services, 25 July 2005–27 July 2005
- Ernst-Rüdiger Olderog, Department of Computer Sciencs, Carl von Ossietzku, Oldenburg, Germany, 28 August 2005–03 September 2005
- Franck Cassez, Ecole Centrale de Nantes, Institut de Recherche en Cybern'etique de Nantes (IRCyN), France, 19 February 2005–4 March 2005
- Patricia Bouyer, Laboratoire Spécification & Vérification, Ecole Normale Supérieure de Cachan, France, 12 February 2005–18 February 2005

6.10.2 Collaborations with Academia

The collaboration between members of the research group and others has been documented elsewhere.

6.10.3 Industry Collaboration

See section 6.7 for detailed descriptions of the projects listed here.

- **FOSS Inc.** Ravenscar Real Time Java (Bent Thomsen, Anders P. Ravn, Arne Skou.)
- **Several companies** Prosoft (Brian Nielsen, Peter A. Nielsen, Arne Skou, Ivan Aaen.)
- **Several companies** Advanced Real TimeSystems (ARTIST) (Kim G. Larsen, Brian Nielsen, Anders P. Ravn, Arne Skou.)
- **Several companies** Network of Excellence on Embedded Systems Design (ARTIST2) (Gerd Behrmann, Hans Hüttel, Josva Kleist, Kim G. Larsen, Brian Nielsen, Anders P. Ravn, Arne Skou.)
- **MindPass A/S** MindPass Center for Distributed Systems (Josva Kleist, Gerd Behrmann)
- **S-Card A/S** Software process improvement by using JavaCard (Kim G. Larsen, Anders B. Christensen)
- **Simrad A/S** Test and evaluation of eCos as an embedded operating system for Simrad's product and hardware platform (Mikkel Christiansen, Brian Nielsen, Tue Olesen.)
- **IAR Systems** Design and implementation of automatic test generation mechanisms (Kim G. Larsen, Ulrik Nyman.)
- **AeroMark** Application of eCos on the Gefion platform (Emmanuel Fleury)
- **Siemens Mobile** Model Driven and Object Oriented Software Development of Embedded Systems (Peter A. Nielsen, Anders P. Ravn, Jan Stage, Arne Skou.)
- **TDC** Security in Alarm Boxes (Emmanuel Fleury)
- **Danfoss A/S** Automated test of cooling thermostates (Brian Nielsen, Ulrik Nyman, Kim G Larsen, Marius Mikucionis, Arne Skou.)
- **Telebit Ericsson A/S** Model Based Testing of Internet Protocol Specifications (Arne Skou, Kim G. Larsen, Saulius Pusinskas)
- **MAN B&W A/S** Model Based Development (Anders P. Ravn, John Knudsen, Arne Skou)
- **Skov A/S** Intelligent Sensor Networks in StablesModel Based Development (Kim G. Larsen, Jens Alsted Hansen.)

- **Several companies** AMETIST. Advanced Methods for Timed Systems (Kim G. Larsen, Gerd Behrmann, Arne Skou, Jacob Illum Rasmussen, Patricia Bouyer, Emmanuel Fleury.)
- **Microsoft Research** Type Inference for Security Protocols (Hans Hüttel)

6.11 Services

6.11.1 Program Committees

- EXPRESS'01, 8th International Workshop on Expressiveness in Concurrency, August 2001 – co-chairman. *(Luca Aceto)*
- Member of the Organizing Committee for the *Twelfth International Conference on Concurrency Theory* (CONCUR 2001) held in Aalborg, Denmark, August 21-24, 2001. *(Luca Aceto, Hans Hüttel, Anna Ingólfsdóttir)*
- *Process Algebra: Open Problems and Future Directions* (July 21-25, 2003, University of Bologna Residential Center, Bertinoro (Forlì), Italy). *(Luca Aceto, Anna Ingólfsdóttir)*
- *International Conference on Software Engineering and Formal Methods*, Brisbane, Australia, 22–27 September 2003. *(Luca Aceto)*
- Workshop on Structural Operational Semantics affiliated to CONCUR 2004, London, England, 30 August 2004. – co-chairman. *(Luca Aceto)*
- CONCUR 2004, London, England, 31 August–3 September 2004. *(Luca Aceto)*
- *FOSSACS (Foundations of Software Science and Computation Structures) 2005*, Edinburgh, Scotland, 4–8 April 2005. *(Luca Aceto)*
- *Algebraic Process Calculi: The First Twenty Five Years and Beyond* (August 1–5, 2005, University of Bologna Residential Center, Bertinoro (Forlì), Italy). *(Luca Aceto)*
- *Conference on Algebra and Coalgebra in Computer Science (CALCO)*, Swansea, Wales, 3–6 September 2005. *(Luca Aceto)*
- *Structural Operational Semantics 2005* affiliated to ICALP 2005, Lisbon, Portugal, 10 July 2005. *(Luca Aceto)*
- 25th Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS '05), December 15–18, 2005, Indian Institute of Information Technology, Hyderabad, India. *(Luca Aceto)*
- TACAS 2000, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*

- TACAS 2001, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- TACAS 2002, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- TACAS 2003, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- TACAS 2004, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- TACAS 2005, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- TACAS 2006, Tools and Algorithms for the Construction and Analysis of Systems.*(Kim G. Larsen)*
- Logic in Computer Science 2000.*(Kim G. Larsen)*
- Logic in Computer Science 2004.*(Kim G. Larsen)*
- CONCUR, International Conference on Concurrency 2001.*(Kim G. Larsen)*
- CONCUR, International Conference on Concurrency 2002.*(Kim G. Larsen)*
- CONCUR, International Conference on Concurrency 2003.*(Kim G. Larsen)*
- CAV Computer Aided Verification, 2001.*(Kim G. Larsen)*
- CAV Computer Aided Verification, 2002.*(Kim G. Larsen)*
- CAV Computer Aided Verification, 2003.*(Kim G. Larsen)*
- HSCC, Hybrid Systems: Computation and Control, 2003.*(Kim G. Larsen)*
- HSCC, Hybrid Systems: Computation and Control, 2005.*(Kim G. Larsen)*
- PAPM-PROBMIV, Process Algebra and Performance Modelling and Probabilistic Methods in Verification, 2001. *(Kim G. Larsen)*
- RT-TOOLS, Workshop on Real-Time Tools, 2001.*(Kim G. Larsen)*
- RT-TOOLS, Workshop on Real-Time Tools, 2002.*(Kim G. Larsen)*
- TPTS, Workshop on Theory and Practice of Timed Systems, 2002. *(Kim G. Larsen)*
- MOVEP, Modelling and Verification of Parallel Processes, 2002.*(Kim G. Larsen)*

- PDMC, Workshop on Parallel and Distributed Model Checking, 2002. *(Kim G. Larsen)*
- MTCS, Models for Time Critical Systems, 2002 (co-chair with Walter Vogler), 2002. *(Kim G. Larsen)*
- IFAC Conference on Analysis and Design of Hybrid Systems, ADHS03, Saint-Malo, France, June 16-18, 2003.*(Kim G. Larsen)*
- Formal Methods and Models for Codesign, MEMOCODE03, Mont Saint-Michel, France, June 24-26, 2003.*(Kim G. Larsen)*
- FORMATS: Formal Modelling and Analysis of Timed Systems, 2003 (co-chair), 2004.*(Kim G. Larsen)*
- STACS'04, 21st International Symposium on Theoretical Aspects of Computer Science, 2004*(Kim G. Larsen)*
- WODES'04, IFAC Workshop on Discrete Event Systems, Reims, France, on 22-24 September 2004.*(Kim G. Larsen)*
- RV'04, Fourth Workshop on Runtime Verification, April 3-4, 2004, Barcelona, Spain. SE2005, IASTED International Conference on Software Engineering, Innsbruck, Austria, February 15-17, 2005. *(Kim G. Larsen)*
- EPEW: First European Workshop on Performance Engineering, Sep. 30 - Oct. 2, 2004, Madrid, Spain. *(Kim G. Larsen)*
- QEST. 1st International Conference on quantitative Evaluation of Systems, September 27-30, 2004, Twente University, The Netherlands.*(Kim G. Larsen)*
- EPEW: First European Workshop on Performance Engineering, Sep. 30 - Oct. 2, 2004, Madrid, Spain.*(Kim G. Larsen)*
- MOVEP'04, Modelling and Verification of Parallel Processes, Dec.2004, Brussels, Belgium.*(Kim G. Larsen)*
- ADHS'06: the 2nd IFAC conference on the Analysis and Design of Hybrid Systems, Alghero (Sardinia, Italy) on June 7-9, 2006.*(Kim G. Larsen)*
- SE2005, IASTED International Conference on Software Engineering, Innsbruck, Austria, February 15-17, 2005.*(Kim G. Larsen)*
- FORMATS'05, 3rd International Conference on Formal Modelling and Analysis of Timed Systems, September 26-28,2005, Uppsala, Sweden. *(Kim G. Larsen)*
- ICALP 2005, International Colloquium on Automata, Languages and Programming, July 11-15, 2005, Lisboa, Portugal.*(Kim G. Larsen)*

- VVPS05, 1st Workshop on Verification and Validation of Model-Based Planning and Scheduling Systems, Monterey, California, USA, 6-7 June 2005.*(Kim G. Larsen)*
- CONCUR 2005, 16th International Conference on Concurrency Theory, San Francisco, California, 23-26 August 2005.*(Kim G. Larsen)*
- HSCC'06, Hybrid Systems: Computation and Control, Santa Barbara, California, March 29-31, 2006.*(Kim G. Larsen)*
- MOVEP'06, Modelling and Verification of Parallel Processes, June 19-23, Bordeaux, France, 2006. *(Kim G. Larsen)*
- MSVVEIS'06, the Fourth Ingternational Workshop on Modelling, Simulation, Verification and Validation of Enterprise Information Systems, May 23-24, Paphos, Cyprus, 2006. *(Kim G. Larsen)*
- QEST'06, 2nd International Conference on the QuantitatPAPM-PROBMIV, Process Algebra and Performance Modelling and Probabilistic Methods in Verification, 2001. *(Kim G. Larsen)*
- Formal Approaches to Testing of Software FATES'05 *(Brian Nielsen)*
- Formal Approaches to Testing of Software FATES'03 *(Brian Nielsen)*
- Formal Approaches to Testing of Software FATES'02 *(Brian Nielsen)*
- Hybrid Systems: Computation and Control 2001 *(Anders P. Ravn)*
- FTRTFT 2002: Formal Techniques in Real-Time and Fault-Tolerant Systems, 2002 *(Anders P. Ravn)*
- Hybrid Systems: Computation and Control 2002 *(Anders P. Ravn)*
- ACSD04: Application of Concurrency to System Design, 2004 *(Anders P. Ravn)*
- SEFM04: Software Engineering and Formal Methods, 2004 *(Anders P. Ravn)*
- ICTAC2004: International Colloquium on Theoretical Aspects of Computing, 2004 *(Anders P. Ravn)*
- ACSD05: Application of Concurrency to System Design, 2005 *(Anders P. Ravn)*
- SEFM05: Software Engineering and Formal Methods, 2005 *(Anders P. Ravn)*
- ICTAC2005: International Colloquium on Theoretical Aspects of Computing, 2005 *(Anders P. Ravn)*

- INFINITY'05: 7th International Workshop on Verification of Infinite-State Systems, 2005 – co-chairman *(Jiří Srba)*
- Tenth ACM SIGOPS European Workshop *(Arne Skou)*

6.11.2 Steering Committees

- Advisory Board Member for ICE-TCS: Icelandic Center for Theoretical Computer Science (since 2005) *(Kim G. Larsen)*
- Steering Committee member for CONCUR (since 1993) *(Kim G. Larsen)*
- Steering Committee member for ETAPS (since 2004) *(Kim G. Larsen)*
- Steering Committee member for TACAS (since 1995) *(Kim G. Larsen)*
- Steering Committee member for FTRTFT-FORMATS (since 2003) *(Kim G. Larsen)*
- Steering Committee member of European Educational Forum (since 2001) *(Kim G. Larsen)*
- Steering Committee member of ARTIST2, Network of Excellence (since 2002) *(Kim G. Larsen)*
- Hybrid Systems: Computation and Control 2003 - 2006 *(Anders P. Ravn)*

6.11.3 Invited Talks

- Bisimilarity is not Finitely Based over BPA with Interrupt. Invited talk at the Symposium on the Semantics of Concurrency, Eindhoven University of Technology, The Netherlands, 26 September 2005.*(Luca Aceto)*
- Nested Semantics over Finite Trees are Equationally Hard. Invited talk at EXPRESS'03, 2 September 2003, Marseille, France. *(Luca Aceto)*
- Kleene Through the Process Algebraic Glass. Invited talk at Fixed Points in Computer Science 2002 (FICS'2002), July 20–21, 2002, Copenhagen, Denmark. *(Luca Aceto)*
- Process Algebras with Deterministic Time. Invited course at the 1st International School on Formal Methods for the Design of Computer, Communication and Software Systems: Process Algebras, 23–28 July 2001, Bertinoro, Italy.*(Luca Aceto)*
- Dutch Model Checking Day, Twente, January 2001 *(Kim G. Larsen)*
- EWCS01, Estonian Winterschool on Computer Science, January 2001 *(Kim G. Larsen)*

- Model-based Validation of Intelligence, Stanford, March 2001 *(Kim G. Larsen)*
- MFCS'01, Mathematical Foundation of Computer Science, Aarhus, May 2001 *(Kim G. Larsen)*
- Dynamics Workshop, Brussels, July 2001 *(Kim G. Larsen)*
- IPA Fall Days on Timed Systems , Landgoed Hize Bergen, Vught, NL, November 2001 *(Kim G. Larsen)*
- Presentation at The Royal Danish Academy of Science and Letters , Copenhagen, March 7, 2002. *(Kim G. Larsen)*
- AVoCS: Workshop on Automated Verification of Critical Systems , Birmingham, UK, April 2002 *(Kim G. Larsen)*
- Dagstuhl workshop on Concurrency and Dynamic Behaviour Modelling: Pragmatics and Semantics, Schloss Dagstuhl, Germany, 10-15 March, 2002. *(Kim G. Larsen)*
- Third Workshop on Coloured Petri Nets , Aarhus, DK, August 2002. *(Kim G. Larsen)*
- CONCUR , Tools Day. Brno, Czech Republic, August 24, 2002. *(Kim G. Larsen)*
- FTRTFT: Formal Techniques in Real-Time and Fault Tolerant Systems , Oldenborg, Germany, 9-12 September, 2002. *(Kim G. Larsen)*
- 2nd School on Formal Methods (SFM): Model Checking , Bertinoro, Italy, 9-14 September 2002. EMSOFT, Third International Conference on Embedded Software, Philadelphia, USA, 13-15 October, 2003. *(Kim G. Larsen)*
- Process Algebra: Open Problems and Future Directions, Bertinoro, Italy, July 21-25. *(Kim G. Larsen)*
- DISC Summer School on "Modelling and Control of Hybrid Systems", The Netherlands, June 2003. *(Kim G. Larsen)*
- EEF Summer School on Fundations of Computer Science, Concurrency, May 16-30, Eindhoven, 2003. *(Kim G. Larsen)*
- ESSES 2003, European Summer School on Embedded Systems, Sweden July 14-October 10, 2003. *(Kim G. Larsen)*
- Beyond Safety, April 26-28, 2004, Schloss Ringberg, Germany*(Kim G. Larsen)*
- TUE Eindhoven, International Workshop, Eindhoven, The Netherlands, June 10-12, 2004. *(Kim G. Larsen)*

- Formal Methods for the Design of Computer, Communication and Software Systems: Real Time, 13-18 September, 2004, Bertionoro University Residential Center, Italy. *(Kim G. Larsen)*
- NWPT'04: the 16th Nordic Workshop on programming Theory, Uppsala, Sweden, October 6-8, 2004. *(Kim G. Larsen)*
- Third international symposium on Formal Methods for Components and Objects (FMCO 2004), Leiden, The Netherlands, November 2-5, 2004. *(Kim G. Larsen)*
- MOVEP'04, MOdelisation et VErification des Processus paralleles, Brussels, December, 2004. *(Kim G. Larsen)*
- PRISE: Principles of Software Engineering, Buenos Aires, Argentina, November 22-27,2004.*(Kim G. Larsen)*
- GVD05, German Verification Day, Oldenburg, Germany, March 4, 2005 *(Kim G. Larsen)*
- Opening of ICE-TCS, Icelandic Center of Excellence in Theoretical Computer Science, Reykjavik, Iceland, April 29, 2005.*(Kim G. Larsen)*
- ICAPS'05, The International Conference on Automated Planning and Scheduling, Monetery, California, U.S.A., June 5-10. *(Kim G. Larsen)*
- Algebraic Process Calculi: The First Twenty Five Years and Beyond, Bertinoro, Italy, 1-5 August 2005. *(Kim G. Larsen)*
- IFIP WG2.2, meeting in Kandestederne, Denmark, September 1, 2005. *(Kim G. Larsen)*
- TCS Excellence in Computer Science (TECS) Week, Tata Research Development and Design Centre, Pune, India, January 2006. *(Kim G. Larsen)*
- Testing Real-Time Embedded Systems using UppAal-TRON—Tool and Applications. ARTIST 2 summerschool on Component and Modelling, Testing and Verification, and Statical Analysis of Embedded Systems, Nässlinge, Sweden, November 2005. *(Brian Nielsen)*
- Real-time online testing at Dagstuhl Seminar on Model Based Testing, September 2004 *(Brian Nielsen)*
- Test af realtids egenskaber at Modelbaseret Test Arrangement om testaktiviteter ved CISS, August 2004 *(Brian Nielsen)*
- Model driven development and test. Industrial Software Test Seminar. Fonden Center for Software Innovation. Sønderborg, 9. december 2003. *(Brian Nielsen)*

- Model Based Testing of Embedded Systems. Industrial Seminar: Software udvikling på tværs: trends, teknologi, metoder og værktøjer til software- og systemudvikling. Teknologisk Institut, Copenhagen, 2-3. juni 2003. *(Brian Nielsen)*

- Automatic generation of real-time test cases from timed automata specifications. IPA Ph.D. School: Herfstdagen on Timed Systems. Landgoed Huize Bergen, Vught, Holland, November 26-30, 2001 *(Brian Nielsen)*

- Testing Timed Systems.Ph.D. School: MOVEP (MOdelling and Verification of Parallel Processes) 2002, Nantes, June 17-21, 2002 *(Brian Nielsen)*

- PDMC 2005 *(Gerd Behrmann)*

- ESSCaSS‘04 3rd Estonian Summer School on Computer and System Science , Pedase, Estonia, August 8 - 12, 2004 *(Anders P. Ravn)*

- DaNet Ph.D.-school on Dynamical and Hybrid Systems, Aalborg, April 4-8, 2005. *(Anders P. Ravn)*

- Formal Aspects of Component Based Systems (FACS’03), Pisa, Italy, September 2003.*(Anders P. Ravn)*

- Hybrid Systems, Oldenburg University, Germany, October 2003.*(Anders P. Ravn)*

- CC-Workshop on Hybrid and Real-Time Systems, Lund, Sweden, May 2004.*(Anders P. Ravn)*

- Dina-Danet Annual Meeting, Foulum, Denmark, May 2005. *(Anders P. Ravn)*

- Dina Workshop, Hybrid Systems, Tune, Denmark, November 2002. *(Anders P. Ravn)*

- Formal Aspects of Component Based Systems (FACS’03), Pisa, Italy, September 2003. *(Anders P. Ravn)*

- Hybrid Systems, Oldenburg University, Germany, October 2003. *(Anders P. Ravn)*

- CC-Workshop on Hybrid and Real-Time Systems, Lund, Sweden, May 2004. *(Anders P. Ravn)*

- Dina-Danet Annual Meeting, Foulum, Denmark, May 2005. *(Anders P. Ravn)*

6.11.4 Conference Related Services

Conferences and Workshops—Service Encompassing Leadership

- Member of the steering committee for ETAPS (September 2004–September 2005).*(Luca Aceto)*
- Chair of the IFIP Working Group 1.8 on Concurrency Theory under TC.1. *(Luca Aceto)*
- CONCUR 2001, International Conference on Concurrency, BRICS, Aalborg Universitet, August, 2001 (Chair) *(Kim G. Larsen)*
- CAV 2002, Computer Aided Verification, Copenhagen, 2002 (Chair, Kim G. Larsen – co-chair Ed Brinksma). *(Kim G. Larsen)*
- MTCS'02, Models for Time-Critical Systems, Brno 2002 (Chair, Kim G. Larsen – co-chair Walter Vogler, University of Augsburg) *(Kim G. Larsen)*
- FORMATS'03 Formal Modeling and Analysis of Timed Systems, Marseille, September 2003 (chair Kim G. Larsen – co-chair Pieter Niebert, Marseille University) *(Kim G. Larsen)*
- ARTIST2 summerschool on Modelling and Components, Testing and Verification and Static Analysis, Nässlinge, Sweden, September 29-October 2, 2005. (chair Kim G. Larsen – co-chairs Bengt Jonsson, Uppsala University and Reinhard Wilhelm, Saarlandes University). *(Kim G. Larsen)*

Other Conference and Workshop Related Services

- Workshop Organizer, CONCUR 2001, International Conference on Concurrency, BRICS, Aalborg Universitet, August, 2001 *(Hans Hüttel)*

6.11.5 Editorial Services

- Editor of the "Concurrency Column" in the Bulletin of the EATCS. *(Luca Aceto)*
- Editor of Journal of Logic and Algebraic Programming, Elsevier. *(Luca Aceto)*
- Editor of Acta Cybernetica. *(Luca Aceto)*
- Editor of Essays on Algebraic Process Calculi, BRICS Notes Series volume NS–05–3, 244 pages, June 2005. (ISSN 0909-3206). *(Luca Aceto)*
- Guest editor of Theoretical Computer Science volume 335(2–3):127–406, 23 May 2005. (Special issue on Process Algebra) *(Luca Aceto)*

- Guest editor of Electronic Notes in Theoretical Computer Science, Volume 128, Issue 1, 4 May 2005, Pages 1–122, Proceedings of the Workshop on Structural Operational Semantics (SOS 2004). 30 August 2004 – co-editor. *(Luca Aceto)*

- Guest editor of a special issue of the Journal of Logic and Algebraic Programming on Structural Operational Semantics, vols. 60–61C. Elsevier, July–December 2004. *(Luca Aceto)*

- Guest editor of Volume 13, Issues 4–5 of Mathematical Structures in Computer Science (special issue devoted to "The Difference between Concurrent and Sequential Computation" and to selected papers from EXPRESS'00: 7th International Workshop on Expressiveness in Concurrency; guest editor. *(Luca Aceto)*

- Guest editor of Volume 9, number 2 (summer 2002), of the Nordic Journal on Computing (special issue devoted to selected papers from EXPRESS'01: 8th International Workshop on Expressiveness in Concurrency – co-editor *(Luca Aceto)*

- Editor of Proceedings of EXPRESS'01: 8th International Workshop on Expressiveness in Concurrency, Aalborg, Denmark (August 20, 2001). Issue 1 of volume 52 of ENTCS, Elsevier, 2001 – co-editor *(Luca Aceto)*

- Guest editor of Volume 80, Issue 1, of Information Processing Letters, 15 October 2001. (Special issue on Process Algebra) – co-editor *(Luca Aceto)*

- Associate Editor for Formal Methods for System Design (since 2005) *(Kim G. Larsen)*

- Member of the Editorial and Executive board of the Nordic Journal of Computing (since 1999) *(Kim G. Larsen)*

- Editor of Proceedings for "CONCUR, Concurrency Theory, 12th International Conference", Lecture Notes in Computer Science 2154, 2001 (Kim G. Larsen – with Mogens Nielsen, Aarhus University). *(Kim G. Larsen)*

- Editor of Proceedings for "Computer Aided Verification" 14th International Conference, CAV 2002, Copenhagen, Denmark, 2002, Lecture Notes in Computer Science 2404 (Kim G. Larsen – with Ed Brinksma, Twente University) *(Kim G. Larsen)*

- Editor of Proceedings of the 3rd International Workshop on Models for Time-Critical Systems, MTCS '02, (Brno, Czech Republic, August 24, 2002), August 2002 (Kim G. Larsen – with Valter Vogler, University of Augsburg). *(Kim G. Larsen)*

- Editor of Proceedings “Formal Modeling and Analysis of Timed Systems”, First International Workshop, FORMATS 2003, Marseille, France, September 6-7, 2003, Lecture Notes in Computer Science, Vol. 2791 (Kim G. Larsen – with Peter Niebert, Marseille University). *(Kim G. Larsen)*

6.11.6 Reviews

The following list does not include services on internal and external evaluation committees for academic positions.

Reviews of conference papers

Members of the DSS group have reviewed paper submissions for the following conferences and workshops: ACSD, ADHS, AMAST, CAV, CONCUR, EPEW, EXPRESS, FATES, FORMATS, FOSSACCS, FSTTCS, FTRTFT, HSCC, ICALP, ICTAC, IFAC, MOVEP, MTCS, MSVVEIS, PDMC, QEST, RT-TOOLS, RV, SEFM, INFINITY, SIGOPS-EW’02 (Special Interest Group in Operating Systems, European Workshop), TACAS, TEAA, TLCA, TPTS, and VVPS.

Reviews of journal papers

Members of the DSS group have reviewed paper submissions for the journals *ACM Transactions on Computational Logic*, *ACM Transactions on Programming Languages and Systems*, *ACM Transactions on Software Engineering and Methodology*, *ACM Transactions on Programming Languages and Systems*, *ACM Transactions on Modeling and Computer Simulation*, *Acta Informatica*, *Actapress*, *Advances in Petri Nets*, *Distributed Computing*, *Formal Aspects of Computing*, *Formal Methods of System Design*, *IEEE Transactions on Systems, Man, and Cybernetics*, *IEEE Transactions on Software Engineering*, *Information and Computation*, *Information Processing Letters*, *International Journal of Foundations of Computer Science*, *International Journal on Software Tools for Technology Transfer*, *Journal of Logic and Algebraic Programming*, *Journal of the ACM*, *Journal of Logic and Algebraic Programming*, *Journal of Mathematical Structures in Computer Science*, *Journal of Systems Architecture*, *Journal of Systems and Software*, *Mathematical Reviews*, *Mathematical Systems Theory*, *Nordic Journal on Computing*, *Notre Dame Journal of Formal Logic*, *Science of Computer Programming*, *SIGMETRICS*, *The International Journal of Time-Critical Computing Systems*, *Theoretical Computer Science*, *Theoretical Informatics and Applications* and *Theory and Practice of Logic Programming*.

External reviews

- Henning Dierks, Habilitation, Oldenborg, Germany (2005)*(Kim G. Larsen)*
- Francois Laroussinie, Habilitation, LSV Cachan, France (2005)*(Kim G. Larsen)*

- Jinfeng Huang, Ph.D. Eindhoven University, The Netherlands (2005)*(Kim G. Larsen)*
- Michael Westergaard: Progess Evaluation, Aarhus University (2005)*(Kim G. Larsen)*
- Goran Frehse, Ph.D., Nijmeegen University, The Netherlands (2005)*(Kim G. Larsen)*
- Timo Latvala, Ph.D., Helsinki Technical University, Finland (2005)*(Kim G. Larsen)*
- Avner Engel, Ph.D. Tel Aviv University, Israel (2005)*(Kim G. Larsen)*
- Marcus Nielson, Ph.D., Department of Computer Systems, Uppsala, Sweden (2005)*(Kim G. Larsen)*
- Ronald Lutje Spelberg, Ph.D., Delft University of Technologi, The Netherlands (2004).*(Kim G. Larsen)*
- Thomas Mailund, Ph.D., Computer Science, Aarhus, Denmark (2003)*(Kim G. Larsen)*
- Matti Luukkainen, Ph.D., Department of Computer Science, University of Helsinki (2003)*(Kim G. Larsen)*
- Gerd Behrmann, Ph.D., Department of Computer Science, Aalborg University (2003)*(Kim G. Larsen)*
- Yasmina Abdedaim, VERIMAG, Grenoble, France (2002)*(Kim G. Larsen)*
- Emmanuel Fleury, ENS Cachan, Paris, France (2002) *(Kim G. Larsen)*
- Thomas E. Rasmussen, IMM, DTU, Lyngby, Denmark (2002) *(Kim G. Larsen)*
- Beatrice Berard, Habilitation, ENS Cachan, Paris, France (2002) *(Kim G. Larsen)*
- Patricia Bouyer, Ph.D., ENS Cachan, Paris, France (2002) *(Kim G. Larsen)*
- Theo Ruys, Ph.D., Twente University, Twente, The Netherlands (2001) *(Kim G. Larsen)*
- Marcus Nielson, Lic.Thesis, Department of Computer Systems, Uppsala, Sweden (2001) *(Kim G. Larsen)*
- Marc Geilen, Ph.D., Technical University of Eindhoven, Eindhoven, The Netherlands (2001) *(Kim G. Larsen)*

- Anne Labroue's Ph.D. thesis *Méthodes Algébrique pour la Vérification de Systèmes Infinis* at the Laboratoire Spécification et Vérification, Ecole Normale Supérieure de Cachan, Cachan, France (January 2002).*(Luca Aceto)*
- Frank D. Valencia's Ph.D. thesis *Temporal Concurrent Constraint Programming*, BRICS Ph.D. School, Aarhus University (February 2003).*(Luca Aceto)*
- Mauro Gattari's Ph.D. thesis *Distributed Systems: The $delta$- and γ-calculus* in Mathematical Logic and Theoretical Computer Science at the University of Siena, Italy (November 2004).*(Luca Aceto)*
- Maria Rita Di Berardini's Ph.D. thesis *Timing, Efficiency and Fairness of Asynchronous Systems* in Computer Science at the University of L'Aquila, Italy (April 2005).*(Luca Aceto)*
- MohammadReza Mousavi's Ph.D. thesis in Computer Science at the Eindhoven University of Technology, The Netherlands (September 2005).*(Luca Aceto)*
- Federico Crazzolara, Ph.D., Århus University, 15 May 2003 *(Hans Hüttel)*
- José Luis Vivas, Ph.D., Royal Institute of Technology, Stockholm, March 2001 *(Hans Hüttel)*
- Josef Tapken, Ph.D., University of Oldenburg, Germany, June 2001.*(Anders P. Ravn)*
- Gerulf Pedersen, Ph.D., Department of Control Engineering, Aalborg University, August 2005. *(Anders P. Ravn)*
- Esbjerg, Professor MSO, Spring 2005. *(Anders P. Ravn)*
- SÃ¸ren Top, Ph.D., University of Southern Denmark, Denmark, (2004).*(Arne Skou)*
- Mads Bondo Dydensborg, Ph.D., University of Copenhagen, Denmark, (2004).*(Arne Skou)*

Reviews of international projects

- Reviewer for EU 5th Framework (March 2003) *(Kim G. Larsen)*
- Advisor for EU on Embedded Systems (March, 2004) *(Kim G. Larsen)*
- Evaluating of Embedded Systems at Eindhoven University (June 2004) *(Kim G. Larsen)*
- Evaluator of Computer Science Proposal and Initiatives for Swedish Research Council (May 2004, August 2004) *(Kim G. Larsen)*

- Chair of the Evaluation of Danish Center for Scientific Computing (Autumn, 2004) *(Kim G. Larsen)*
- Evaluator for AGENCE NATIONALE DE LA RECHERCHE, France, on the Programme: Security, Embedded Systems, Ambient Intelligence (August 2005) *(Kim G. Larsen)*
- Danish Institute of Agricultural Sciences, Agricultural Engineering, Chair of International Research Evaluation Committee, Fall 2005 *(Anders P. Ravn)*.
- Reviewer for EU 4th Framework (November 2001) *(Arne Skou)*
- External Reviewer for the Swedish Research Council, Evaluation Panel for Computer Science (September 2004) *(Arne Skou)*

6.11.7 Other Academic Services

- Scientific co-director of the Icelandic Centre of Excellence in Theoretical Computer Science (ICE-TCS), March 2005 onwards. (Together with Magnús M. Halldórsson.) *(Luca Aceto, Anna Ingólfsdóttir)*
- Member of the scientific advisory board of the Bertinoro International Center for Informatics (BICI) (2002–2006). *(Luca Aceto)*

6.12 Bibliography

6.12.1 Conference and Journal Rankings

In our research group, we acknowledge conferences and journals as having different status depending on their impact. The following ranking was compiled from rankings provided by the individual members of the research group concerning their own publications.

Conference and workshop proceedings

- **Rank A:** ADPM, CAV, CONCUR, EMSOFT, FASE, FMCO, FOSSACS, FSTTCS, FTRTFT, HSCC, IEEE Conference on Decision and Control, Real-Time Systems, RTSS, STACS, TACAS
- **Rank B:** AMAST, ASE, ASM, DLT, ECRTS, FMSP, FORTE, FORMATS, ICATPN, IFIP-TCS, MTCS, PAPM-PROBMIV, SOFSEM, SPIN, WITS
- **Rank C:** AIPS, Biennial Ptolemy Miniconference, EXPRESS, Euromicro Work in Progress, FAC Workshop, FATES, ICTCS, INFINITY, International Workshop on Critical Systems Development with UML, MOVEP, NWPT, PDMC, RT-TOOLS, SAC, UNI/IIST, Workshop Brasileiro de Tempo Real, WPMC,

- **Others/Miscellaneous:** ASAE, CHEP, Conference on Embeddded Systems, ISCA, RTS
- **New/Emerging:** CALCO, EGC, FACS, MOMPES, SECCO

Rank A	39%
Rank B	27%
Rank C	26%
Others	3 %
New	5 %

Journal articles

- **Rank A:** Acta Informatica, Formal Methods in System Design, IEEE Computer, Information and Computation, Journal of Automated Reasoning, SIGMETRICS, Theoretical Computer Science
- **Rank B:** Current Trends in TCS, Journal of Logic and Algebraic Programming, Journal on Software Tools and Technology Transfer, Mathematical Structures in Computer Science, Nordic Journal on Computing, Science of Computer Programming
- **Rank C:** Electronic Notes in Computer Science, Information Processing Letters, RAIRO Theoretical Informatics and Applications
- **Others/Miscellaneous:** ARTIST Roadmap
- **New/Emerging:** Journal on Computer Science and Technology, Logical Methods in Computer Science

Rank A	45%
Rank B	22%
Rank C	28%
Others	2 %
New	3 %

6.12.2 Edited books

[1] Luca Aceto, Zoltan Esik, Wan Fokkink, and Anna Ingolfsdottir. *Process Algebra*. Number 335 in Journal of Theoretical Computer Science. Elsevier, 2005.

[2] Luca Aceto and Wan Fokkink. *Special issue of Journal of Logic and Algebraic Programming on Structural Operational Semantics*. Number vols. 60-61 in Journal of Logic and Algebraic Programming. Elsevier, 2004.

[3] Luca Aceto, Wan Fokkink, and Irek Ulidowski. *Proceedings of the Workshop on Structural Operational Semantics, London, England (August 30, 2004) Proceedings of the Workshop on on Structural Operational Semantics, London, England (August 30, 2004)*. Number 128 in Electronic Notes in Theoretical Computer Science. Elsevier, 2005.

[4] Luca Aceto and Andrew D. Gordon. *Essays on Algebraic Process Calculi*. BRICS, 2005.

[5] Luca Aceto and P. Panangaden. *Special Issue of the Nordic Journal of Computing devoted to selected papers from EXPRESS'01: 8th International Workshop on Expressiveness in Concurrency*. 2002.

[6] Ed Brinksma and Kim Guldstrand Larsen. *Computer Aided Verification*. Number 2404 in Lecture notes in computer science. Springer Verlag, 2002.

[7] Jens Grabowski and Brian Nielsen. *Proceedings of 4th International Workshop on Formal Approaches to Software Testing*. Springer Verlag Lecture Notes In Computer Science (LNCS 3395), 2004.

[8] B. Jonsson, Kim Guldstrand Larsen, W. Yi, J. A. Bergstrand, A. Ponse, and S. A. Smolka. *Probabilistic Process Algebra*. Elsevier, 2001.

[9] Kim Guldstrand Larsen, F. Larsson, P. Pettersson, and W. Yi. *Efficient Verification of Real-Time Systems*. 2001. To be published in: The International Journal of Time-Critical Computing Systems (issn 0922-6443).

[10] Kim Guldstrand Larsen and Peter Niebert. *Proceedings of First International Workshop on Formal Modeling and Analysis of Timed, Marseille, September 2003*. Number 2791 in Lecture Notes in Computer Science. Springer Verlag, 2003.

[11] Kim Guldstrand Larsen and M. Nielsen. *CONCUR 2001 - Concurrency Theory*. Number 2154 in Lecture Notes in Computer Science. Springer, 2001.

[12] Scott A. Smolka and Jiří Srba, editors. *Proceedings of the 7th International Workshop on Verification of Infinite-State Systems (INFINITY'05)*, Electronic Notes in Theoretical Computer Science. Elsevier, 2005. To appear.

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[14] W. Vogler and Kim Guldstrand Larsen. *Preliminary Proceedings of the 3rd International Workshop on Models for Time-Critical Systems (MTCS '02)*. Number NS-02-3 in Notes Series. BRICS, 2002.

6.12.3 Refereed Journal articles

[15] Luca Aceto, P. Bouyer, A. Burgueno, and Kim Guldstrand Larsen. The Limit of Testing for Timed Automata. *Theoretical Computer Science*, pages 411–475, 2003.

[16] Luca Aceto, Patricia Bouyer, A. Burgueno, and Kim Guldstrand Larsen. The Power of Reachability Testing for Timed Automata. *Theoretical Computer Science*, pages 411–475, 2003.

[17] Luca Aceto, Zoltan Esik, and Anna Ingólfsdóttir. A Fully Equational Proof of Parikh's Theorem. *Theoretical Informatics and Applications*, pages s. 129–153, 2002.

[18] Luca Aceto, Zoltan Esik, and Anna Ingólfsdóttir. Equational Theories of Tropical Semirings. *Theoretical Computer Science*, pages 417–469, 2003.

[19] Luca Aceto, Zoltan Esik, and Anna Ingólfsdóttir. The Max-Plus Algebra of the Natural Numbers has no Finite Equational Basis. *Theoretical Computer Science*, pages 169–188, 2003.

[20] Luca Aceto, W. J. Fokkink, and Anna Ingólfsdóttir. A Note on an Expressiveness Hierarchy for Multi-exit Iteration. *Information Processing Letters*, pages 17–23, 2003.

[21] Luca Aceto, Wan Fokkink, Anna Ingólfsdóttir, and Bas Luttik. CCS with Hennessy's Merge has no Finite Equational Axiomatization. *Journal of Theoretical Computer Science*, pages 377–405, 2005.

[22] Luca Aceto, Wan Fokkink, Anna Ingólfsdóttir, and Bas Luttik. Split-2 Bisimilarity has a Finite Axiomatization over CCS with Hennessy's Merge. *Logical Methods in Computer Science*, pages 1–12, 2005.

[23] Luca Aceto, Wan Fokkink, van Rob Glabbeek, and Anna Ingólfsdóttir. Nested Semantics over Finite Trees are Equationally Hard. *Information and Computation*, pages 203–232, 2004.

[24] Luca Aceto, Jens Alsted Hansen, Anna Ingólfsdóttir, Jacob Johnsen, and John Knudsen. The Complexity of Checking Consistency of Pedigree Information and Related Problems. *Journal of Computer Science and Technology*, pages 42–59, 2004.

[25] Luca Aceto and Anna Ingólfsdóttir. Corrigendum: Volume 66 (1991) 161-218, for the Article "A Domain Equation for Bisimulation" by Samson Abramsky. *Information and Computation*, pages 119–122, 2001.

[26] Luca Aceto and F Laroussinie. Is your Model Checker on Time? *Journal of Logic and Algebraic Programming*, pages 7–51, 2002.

[27] Luca Aceto, Giuseppe Longo, and Björn Victor. Foreword to Special Issue on ”The Difference between Concurrent and Sequential Computation” of Mathematical Structures. *Computer Sciences*, pages 481–484, 2003.

[28] Luca Aceto, Giuseppe Longo, and Björn Victor. Special Issue on “The Difference between Concurrent and Sequential Computation. *Mathematical Structures in Computer Science*, pages 482–798, 2003.

[29] Gerd Behrmann. A Performance Study of Distributed Timed Automata Reachability Analysis. *Electronical notes in theoretical computer science*, 68, 2002.

[30] Gerd Behrmann. Distributed Reachability Analysis in Timed Automata. *Software Tools for Technology Transfer*, 2003.

[31] Gerd Behrmann, Patricia Bouyer, Kim Guldstrand Larsen, and Radek Pelánek. Lower and Upper Bounds in Zone-Based Abstractions of Timed Automata. *International Journal on Software Tools for Technology Transfer*, 2005.

[32] Gerd Behrmann, Kim Guldstrand Larsen, Henrik Reif Andersen, Henrik Hulgaard, and Jørn Lind-Nielsen. Verification of hierarchical state/event systems using reusability and compositionality. *Formal Methods in System Design*, 21(2):225–244, 2002.

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[36] Patricia Bouyer, Catherine Dufourd, Emmanuel Fleury, and Antoine Petit. Updatable Timed Automata. *Theoretical Computer Science*, pages 54 291–345, 2004.

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[39] P. R. D'Argenio, B. Jeannet, Henrik Ejersbo Jensen, and Kim Guldstrand Larsen. Reachability Analysis of Probabilistic Systems by Successive Refinements. *Lecture Notes in Computer Science: Process Algebra and Probabilistic Methods, Performance Modelling and Verification*, pages 39–56, 2001.

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Information Systems | 7

7.1 Executive Summary

The Information System Group conducts research on the development and use of information technology. The group comprises two research subgroups that focus on human-computer interaction (HCI) and systems development (SD).

Over the past five years, the group has experienced a significant change in staff members. Currently, there are 6-7 senior and 5 junior researchers that are distributed quite evenly on the two groups.

The two groups have to a large extent fulfilled the goals that were set up in 2001 the period until 2005, and in some respects the results have exceeded the goals.

The HCI group has been established in the period. It started out as a very small group but over the past five years, it has gained considerable momentum. The members of the group are involved in a range of interesting research activities. The research activities have covered several aspects of human-computer interaction although the primary focus has been on usability evaluation methods and mobile systems. The productivity of the group has been very high, the quality of publication outlets has been adequate, and the impact has been varied. The aim for the next five-year period is to maintain the current level of activity and productivity while increasing publication quality and impact.

The SD group is a mature research group. The research areas have been redefined after some key members have left the group. The research activities have been focussed on a couple of large projects. The group has maintained its orientation towards both information systems and software engineering, combined with a new orientation towards emerging issues related to both network technologies and mobile technologies. The productivity has been good, with a clearly increasing number of publications in international journals, thereby meeting a higher standard than five years ago. The group has also maintained publishing in practitioner-oriented journals and book. The group has increased its international visibility and recognition. The plan for the coming five years is to focus particularly on increasing impact and at the same time continue publishing in high quality while maintaining its productivity.

The IS group as a whole is characterized by independent and loosely coupled research groups. This facilitates new research orientations, but the internal collaboration could be increased.

7.2 Profile of the Group

7.2.1 Research Profile

The Information System Group conducts research on the development and use of information technology. The research field is development and use of computerised systems at two levels: humans and organisations. This is reflected in the two research groups:

- Human-computer interaction (HCI): design and evaluation of the interaction between a user and a computerised system.
- Systems development (SD): development and use of computerised systems in organisations.

The two groups share the focus on the development and use of information technology. They also share the basic research approach and several research methods. The difference relates to the group of analysis, which is either a human or an organization. The shared research approach is empirical and experimental as well as theoretical.

The research is based on and makes contributions to the intersection between software engineering (as traditionally known within computer science) on the one hand, and either information systems (as traditionally known within business administration) or human-computer interaction on the other hand. Intellectual support is sought in adjacent disciplines: engineering, systems science, organisation theory, sociology, media science, theory of research, and philosophy. The empirical research approaches applied by the group encompass action research, longitudinal process research, case research, laboratory experiments, and field experiments. The research is based on qualitative as well as quantitative methods. The types of research results include:

- Theoretical frameworks to understand the field.
- Methodologies and techniques to guide action in practice.

In *human-computer interaction*, the research deals with design and evaluation of the specific interaction between a user and an interactive computerised system. The goal is to improve design and usability evaluation. This involves design of user interfaces of interactive systems for specific applications. It also involves usability evaluations of specific interactive systems in order to provide a basis for improving the design of these systems.

In *systems development*, the research deals with systems development, the organisational and social aspects of systems use, IT management, and use of IT in innovation and change. The target of the research is the professional practitioner engaged in the development and use of software and information systems in the broadest sense, e.g., developers, project managers, and IT managers. . The research seeks to improve professional practitioners' ability to engineer systems as

well as their ability to plan and manage effective social and organisational interventions.

7.2.2 Staff

In 2001 the IS group had the following staff:

Permanent staff Peter Bøgh Andersen (professor), Jan Damsgaard (associate professor), Lars Mathiassen (professor), Peter Axel Nielsen (associate professor), Jeremy Rose (associate professor), Jan Stage (associate professor), Ivan Aaen (associate professor).

Temporary staff Mikael Skov (assistant professor).

Ph.D. students Helle Damborg Fredriksen, Jan Karlsbjerg, Jesper Kjeldskov, Ram.

The IS group's staffing has changed considerably during 2001-2005. During 2002 Peter Bøgh Andersen left the department for a position as professor at Århus University, Jan Damsgaard left the department for a position as professor at Copenhagen Business School, and Lars Mathiassen left the department to become director of a research centre at Georgia State University, USA, while maintaining a 25% position at the department.

In the HCI group Mikael Skov became associate professor in 2003, and Jesper Kjeldskov became associate professor in 2005. Since 2003 three Ph.D. students have started in the HCI group: Benedikte Skibsted Als in 2003, Rune Th. Høegh first as lecturer since 2003 and as Ph.D. student since 2005, and Janne Jul Jensen in 2005.

In the SD group Palle Nowack has been a part-time assistant professor during 2001 to 2003. Lars Bækgaard has been a temporary associate professor during 2002 to 2004. Keld Pedersen has been a Ph.D. student (senior arrangement) during 2001 to 2005 and completed his Ph.D. degree in 2005. All Ph.D. students in 2001 have completed their Ph.D. degrees. In 2003 Andreas Munk-Madsen became a temporary associate professor on part-time (first 40% now 70%). In 2004 Jens Henrik Hosbond started as a Ph.D. student.

By the end of 2005 the IS group have the following staff (where HCI and SD indicate the specialisation of staff members):

Permanent staff Jesper Kjeldskov (associate professor, HCI), Lars Mathiassen (professor 25%), Peter Axel Nielsen (associate professor, SD), Jeremy Rose (associate professor, SD), Mikael Skov (associate professor, HCI), Jan Stage (associate professor, HCI), Ivan Aaen (associate professor, SD).

Temporary staff Andreas Munk-Madsen (associate professor 70%, SD).

Ph.D. students Benedikte Skibsted Als (HCI), Jens Henrik Hosbond (SD), Rune Th. Høegh (HCI), Janne Jul Jensen (HCI), Gitte Tjørnehøj (senior, SD).

7.3 Research Goals 2001-05

During the previous research evaluation the IS group set out to consolidate and further develop its research scope as *information technology engineering & management*. The common paradigm expresses a commitment to participate in professionalising the IT field, covering systems development and design, systems maintenance and use, IT management, innovation, and utilisation in change processes. Intellectual support comes from other disciplines such as management, systems, sociology, media science, knowledge production, and technology in general.

The IS group decided to do research in three areas:

- Business IS & Networked IT
- Multimedia, Mobility & Usability
- Software Excellence

The IS group planned to:

- Continue its orientation towards both information systems (i.e., the business school research communities) and software engineering (i.e., the computer science and engineering research communities).
- Increase focus as a whole on emerging issues related to network and mobile technologies.
- Consolidate the three research areas while at the same time strengthen collaboration within the group and across projects.
- Continue its use of empirical research as the main approach and the close collaboration with practitioners and IT companies while at the same time increase the use of experimental research approaches.
- Continue its policy to seek impact both through research publications and through practitioners-oriented academic books.
- Further develop the group's active international collaboration policy by attracting short-term and long-term visiting researchers, and actively support its members in organising sabbaticals.
- Maintain the balance between basic research funding in department positions and ad-hoc project funding.
- Increase activities leading to more dr.tech. and dr.scient. theses.

7.4 Activities and Results

The activities of the IS group have been conducted in research programs and projects of varying size. Below, these programs and projects are described in terms of a number of research topics.

7.4.1 Human-Computer Interaction Group

The research group in Human-Computer Interaction (HCI) has conducted research on five topics, focusing on interaction design and usability evaluation, with an emphasis on interactive systems in general and specifically on mobile systems and devices.

Interaction Design for Mobile Systems

The research activity on interaction design for mobile systems has been ongoing since 2001. Since 2004 it has involved the STVF funded talent project Indexical Interaction Design for Context-Aware Mobile Computer Systems. This research activity addresses the challenges of human-computer interaction for mobile devices, and it aims at providing theoretical as well as empirical insight into the design of user-interfaces for mobile devices.

This activity includes four aspects of mobile device interaction design. Firstly, the use of mobile devices for supporting standardised communication for coordinating distributed process control was investigated (in collaboration with Maersk-Sealand and Nordjyllandsværket). Secondly, it was investigated how combinations of input devices and dialog forms can be optimised for mobile devices. Thirdly, the use of context-awareness and indexical interaction design as a means for reducing the complexity of the interface and demands for user-interaction has been investigated. Fourthly, research in the use of mobile systems in domestic settings has been initiated.

This activity has resulted in a large number of conference and journal publications and one PhD dissertation. The research activity has primarily involved Jesper Kjeldskov, Mikael B. Skov, Jan Stage, Rune Thaarup Høegh, Bente Skattør as well as two visiting researchers Steve Howard and Jeni Paay (The University of Melbourne).

Usability Evaluation of Mobile Systems and Devices

The research activity on usability evaluation of mobile systems and devices has been ongoing since 2001.

This activity aims to understand and develop methods and techniques for evaluating the usability of mobile and handheld systems and devices. Mobile systems challenge our established ways of evaluating and understanding use and usability, because interaction with mobile systems often is closely related to the immediate physical or social context. The project has so far involved a number of studies.

Firstly, we have experimented with different setups for evaluating mobile devices in a laboratory. Secondly, we have compared the outcomes from evaluations of mobile devices and services conducted in a laboratory or the field.

This research has contributed with a large number of research publications including journal publications and several conference publications. In the period, the involved researchers have been Benedikte S. Als, Rune T. Høegh, Jesper Kjeldskov, Mikael B. Skov, and Jan Stage.

The Interplay Between Interaction Design and Usability Evaluation

This research activity started in 2004. It is mainly conducted in a large research project, the USE project, with duration from 2005 to 2008, financed by a Danish research council.

This project aims to bridge the gap that currently exists between user interaction design and usability evaluation. The USE project includes two major activities: (a) exploring and investigating tools and techniques for extending feedback from usability evaluations beyond a mere listing of problems and (b) developing and evaluating our ideas for integration in industrial software development projects. The results of the project will be a catalogue of techniques and tools for usability evaluation and feedback with measures of impact on design that are empirically validated in industrial settings, documentation of relations between usability evaluation and feqedback in industrial projects, integration of usability evaluation in software development in the participating companies, and courses, training programs and a conference for practitioners to disseminate the practical experience to the broader software industry.

This research has already produced some research publications, mainly in proceedings from international conferences. In addition, we have organized a workshop at an international conference. The PhD projects will be conducted in close collaboration with specific companies that develop interactive systems. It is expected that the project will impact these software organizations with new ways of conducting usability evaluations and integrating evaluation results in the interaction design activities. This research activity has primarily involved Mikael B. Skov, Jan Stage, Benedikte Skibsted Als, Rune Thaarup Høegh and Janne Jul Jensen.

7.4.2 Usability Engineering

This research activity was started around 2000, and since then, it has been a major area of concern. It involves a variety of projects, some which have external funding with a specific duration. Usability engineering deals with methods, techniques and work practices for evaluating and improving the usability of interactive systems. Our research activities in this area relate to four streams of work. The first stream is usability evaluation methods, where we have used existing methods

to evaluate interactive systems, e.g. in the hospital area where we conducted four full-scale evaluations of healthcare systems and enquired into new methods for usability evaluation. The second stream of work is on training in usability evaluation, where we have conducted empirical studies of web-site usability testing carried out by a diverse group of people with no formal education in software development or usability testing. The third stream of work is specifically focusing on usability engineering with children, where we investigate how emerging technologies should be designed for children and how such technologies could support the special needs of children. The fourth stream of work is centred on design of usability laboratories. Over a five-year period, we have designed and developed our own usability laboratory, a modern top-level facility for conducting experimental research in usability engineering. Based on these experiences, we have advised ETI and another organization when they designed their own usability laboratory.

This research has resulted in a significant number of publications, especially conference publications on methods for usability evaluation and on practices for usability engineering with children. In addition, the tests we have conducted have been documented in test reports (empirical documentation). Finally, the work on laboratory design has impacted external organizations. This research activity has involved Jesper Kjeldskov, Mikael B. Skov, Jan Stage, Benedikte Skibsted Als, Rune Thaarup Høegh and Janne Jul Jensen.

Virtual Reality and Multimedia Design

The research activity on virtual reality and multimedia design took place from 2001 to 2003. The activity was primarily funded by the Danish Research Ministry through the Staging of Virtual 3D-Spaces project, a large multi-disciplinary project that involved more than 30 researchers from different Danish research institutions.

The activity focused on providing methodological support for the design of emerging technologies within virtual reality and multimedia. The activity was addressed through two PhD projects. The first project on interaction design for emerging technologies developed and assessed new interaction design principles for virtual reality systems. The second project investigated the design of multimedia systems that integrate components of storytelling.

This research has contributed with a large number of research publications including two PhD dissertations, journal publications, and conference publications. In the period, the involved researchers have been Peter Bøgh Andersen, Lars Bo Eriksen, Jesper Kjeldskov, Mikael B. Skov, and Jan Stage.

Project: Indexical Interaction Design

The Indexical Interaction Design for Context-Aware Mobile Computer Systems is a STVF funded talent project running from 2004-06 involving researchers from the HCI groups at Aalborg and Melbourne Universities. The project approaches the challenges of mobile

interaction design from a novel perspective on context-awareness inspired by the semiotic concept of indexical information representation. The semiotics operates with three types of representations: symbolic (conventional), iconic (similarity) and indexical (material/causal). Symbols and icons are ways of representing information independent of context. Indexes, on the other hand, are ways of representing information with a strong relation to their context and exploiting information present in the interpreter's surroundings (i.e. signposts and information boards). The idea of applying indexicality to interface design for context-aware mobile computers is that if information and functionality can be indexed to the user's situation, then information already provided by the context becomes implicit and does not need to be displayed. Hence, the user's environment becomes part of the interface. On the basis of this interfaces can be created that carry a major part of their meaning implicitly through the settings in which they are used, thus reducing the need for explicit information representation cluttering the limited screen real estate of mobile devices.

The Indexical Interaction Design project consists of a theoretical as well as a technical stream of research. This involves field studies into the context of mobile computer system use and experimental design, implementation and evaluation of prototype systems. On the basis of this the project is generating a theoretical foundation for future research into interaction design with context-aware mobile computer systems and developing the concept of indexicality as an interaction design principle for such systems.

7.4.3 Systems Development Group

The Systems Development Group has conducted research in five topics.

Software Process Improvement

The research effort on software process improvement (SPI) has been ongoing since 1995. A large, national research project from 1997 to 1999 made a significant contribution to launching a common interest in SPI within the group. Since the beginning, this research has involved nearly all group members and this has been furthered through a major project from 2003 to 2006 on processes improvement and processes knowledge, see sidebar "Software Processes and Knowledge".

The research was initiated with the desire to first study to what extent the largely American maturity process models were applicable in Danish software organisations and then revise these to be useful in non-American contexts. The research has gradually shown that maturity process models and process measurement are not significant for software process improvement. Many other issues, however, are of significant importance.

This research has contributed with a large number of research publications of which 12 are international journal publications. The research has also resulted in one Ph.D. thesis. For the period 2001 to 2005 the involved researchers have been Ivan Aaen, Helle Damborg Fredriksen, Lars Mathiassen, Peter Axel Nielsen, Keld Pedersen, Jeremy Rose, and Gitte Tjørnehøj.

Networked information technology

The research on networked information technology has been conducted through large projects. The PITNIT project pan from 1999 to 2003 with the goal to describe, analyse and offer practical guidelines of the integration and transformation of industrial processes enabled by new networked information technology. The LOKNIT project ran from 1999 to 2001 and focused on collaboration between practitioners and researchers in connection with the PITNIT project. The goal was to disseminate research results to industry representatives.

The research has resulted in more than 40 refereed papers in conferences and journals and in two Ph.D. theses. The participating researchers were Jan Damsgaard, Jan Karlsbjerg, Ram, and Jeremy Rose in collaboration with researchers from Department of Production and Department of International Business Studies, Aalborg University, and Department of Management, Aarhus University.

E-Government

This research seeks to contribute to the increasing European and regional interest in digitalising public administration. The research continues the research on networked information technology. The research has so far been conducted through two Ph.D. studies. A Centre for Electronic Governance was established at Aalborg University in 2005 with the aim of bringing together all the university's researchers in e-government.

Recently, the most significant achievement of this activity has been leading the successful application for an EU network of excellence with a total budget of 6 mill €.

The participating researchers are Jeremy Rose in collaboration with Leif Flak and Øystein Sæbø from Agder University College both expecting to complete their Ph.D. studies at Aalborg University during 2006.

Information systems development approaches

This is a set of several research activities that share a focus on how to develop information systems. The group has researched this topic for decades and for the last five years it has been directed at agile development approaches, development of enterprise systems, systems developers' competence in development, mobile systems development, and socio-technical development. The research is based on the view that information systems development is fundamentally a social activity. Theoretical support has been found in organisation theory and social theory.

The aim of the research is by large to contribute to better and more appropriate approaches to information systems development through a more profound understanding of: (1) development practice in its organisational and social setting, or (2) the organisational and social context in which the to-be information systems will be used.

The research has resulted in several refereed papers in conferences and journals and a Ph.D. thesis. The participating researchers are Jeremy Rose, Ivan Aaen, Peter Axel Nielsen, Lars Bækgaard, Jens Henrik Hosbond and Bendik Bygstad. Part of the research as also been conducted in collaboration with Ph.D. students Hans Olav Omland and Stig Nordheim through the collaboration agreement with Agder University College.

Project: Software Processes and Knowledge

The Software Processes and Knowledge project started November 2002 and ran for a little more than 3 years until January 2006. The project was a national effort comprising all Danish SPI researchers. More than 10 researchers from 3 universities and 3 software organisations collaborated in the project. The total budget was DKK 16 million where a significant part was sponsored by the participating software organisations. The project was managed by the Systems Development group and Ivan Aaen, Peter Axel Nielsen, Keld Pedersen, Jeremy Rose, and Gitte Tjørnehøj from the group participated actively in the project. The project extended research collaboration with Ojelanki Ngwenyama (Ryerson University), Jan Pries-Heje and Thomas Elisberg (Copenhagen IT University), and Bo Hansen, Karl Kautz, and Jacob Nørbjerg (Copenhagen Business School).
Key research questions were addressed: What roles do competence and knowledge play in software process improvement (SPI)? In particular, how can understanding and modelling of knowledge processes, process knowledge, exemplary knowledge, and experience support SPI in practice? The collaboration with the software organisations have resulted in improvements in the 3 software organisations. The documented improvements and experiences will be disseminated to the Danish software industry during 2006. The research results are documented in more than 30 articles so far. In addition, two of the participants will defend their PhD thesis during 2006.
The project has been instrumental in forming the Danish SPI research effort with particular focus on: solving process problems rather than measuring maturity, process competence rather than process descriptions, implementation rather than measurement, and social processes rather than merely technical processes. The theoretical and practical stance towards maturity models and rational improvement has become critical.

Management of systems development projects

The research effort on management of systems development projects has to a large degree been empirical focusing on project managers' perceptions of challenges and appropriate actions to take. The empirical studies have been directed at project managers' competence and at learning and knowledge acquisition and diffusion inside systems development projects. The conclusions point at the discrepancies between appropriate competence and traditional project management techniques. The conclusions also point at why the conditions for learning in systems development project needs to be enhanced and how that can be achieved. Theoretical contributions are also found in research on linking these empirical findings to theory of organisational learning and on defining a project vocabulary.

The research has resulted in several refereed papers in conferences and journals and a Ph.D. thesis. Keld Pedersen, Lars Mathiassen, Jeremy Rose, Jens Henrik Hosbond and Andreas Munk-Madsen have been involved in this research.

7.5 The Group's Own Evaluation

Productivity, Quality, and Impact

In our own evaluation, we have employed the following measures for productivity, quality and impact.
Productivity is mostly a quantitative measure, involving two components. The first component is the number of research publications that we have produced. The main focus here is on papers in peer-reviewed international journals and conference proceedings. In the research areas covered by the Information System group, both journals and conferences are considered as being important outlets. The second component of productivity is the results of empirical studies of the development and use of information technology. This includes analysis and design documents, documented observations of development activities, reports from usability evaluations, etc.
Quality is mostly a qualitative measure. We have assessed it from our perceived quality of the outlets where we have published. Below, we have expressed this perception in terms of three levels: absolute top level outlets (A), high and intermediate level outlets (B) and satisfactory outlets (C).

	Research Community		**Professional community**
	Journals	*Conferences*	
A	JIS, HCI, IEEE Transactions, IJHCS, IO, ISJ, ISR, IT&P, IwC, MISQ, TOCHI	CHI, DIS, DUX, ICIS, Interact, MobileHCI	Comm. ACM, IEEE Software, ICSE
B	BIT, CompGraph, CSCW, IJHCI, IJIM, Inf & Mgt, IS Frontier, JAIS, PUC, SJIS	BCS-HCI, ECIS, HICSS tracks, IDC, IFIP 8.2, IFIP 8.6, NordiCHI, OzCHI	Annals of cases on IT, SPIP
C	AJIS, CAIS, interactions, JUS	AMCIS, AOIS, APCHI, COSIGN, CTS, DEXA, DHRS, ECEG, ERCIM, HCI International, HICSS tracks, IADIS, IRIS, PC-HCI, UI4ALL, WWCS	

Impact is exclusively a qualitative measure, involving two components. The first is the impact on the research discipline. The main focus is on citations, collaborations and exchange of research staff. The second component of impact is influence on the practice that is the object of study, i.e. development and use of information technology. Here the focus is on collaboration with and changes induced in software and user organizations.

7.5.1 IS Group

The plan in 2001 was to consolidate the then three research areas while at the same time strengthen collaboration within the IS group and across projects. The plan changed during 2002-2003 and there are now two larger groups within the IS group. The research area "Multimedia, Mobility and Usablity" is now formed into the Human-Computer Interaction Group. The research areas "Business IT & Networked IT" and "Software Excellence" have joined forces in the Systems Development Group. During the establishment of these two new groups there has been little collaboration between them.

As a whole the IS group has had more impact through research publications in terms of research productivity and quality; see details in the two groups' evaluations. The IS group's common ranking of research outlets and professional outlets have been defined as a measure of research quality, see sidebar "Ranking of IS outlets".

Despite the IS group's plan and the incentives offered by the department and the faculty none of the IS group's researchers have submitted a dr. thesis during the last five years. It is the IS group's perception that the incentives are directed at the individual researcher's and will benefit the researcher's career and is thus a rather personal matter.

7.5.2 Human-Computer Interaction Group

A key goal in 2001 was to establish research activities in Multimedia, Mobility & Usability. Over the past five years, we have fulfilled this goal by establishing a coherent research group. In the same period, we have broadened the scope of the group to human-computer interaction (HCI). The size of the group has increased considerably from one senior and two junior researchers in 2001 to three senior and four junior researchers in 2005.

The HCI group has conducted research in five overall activities, focusing on interaction design and usability evaluation, with emphasis on interactive systems in general and specifically on mobile systems and devices. This is clearly in line with our original goal of increasing the research focus on emerging issues related to network and mobile technologies.

The research has a strong empirical element. Most of the group's publications rely on studies of development or evaluation processes. Some of these processes are conducted in close collaboration with practitioners, IT companies and user organizations. Other processes are based on experimental research approaches

conducted to test specific hypotheses. This is in line with the original goal of maintaining a strong focus on empirical research approaches conducted in close collaboration with development and user organizations.

While the focus has been on establishing a new research group, the HCI group has still been able to successfully apply for external research grants to fund two large research projects, both of them granted by national research councils in 2004. There was an original goal of maintaining the balance between basic research funding in department positions and ad-hoc project funding. With these two projects, the HCI group has gone beyond the original balance between department and external funding. So far, we have not been involved in international research projects. We have been involved in a couple of potential consortia, but we have not been partners in successful applications yet.

We have completed two Ph.D. projects in the first part of the period. In the last part of the period, we have started four new Ph.D. projects that are expected to finish over the next couple of years. We have also had a considerable increase in the number of master theses we have supervised. In total, we have supervised 29 students who have completed their master thesis in the period, and more than half of them in the last two years. Several of these projects have involved development of new research ideas, and the results have been published in research papers.

or senior researchers, we have actively supported sabbaticals with stays at universities in other countries. Over the last three years, all three senior researchers in the group have stayed at least half a year at another university. In the last couple of years, we have also been able to attract external guest. In the last semester, we have had a visiting full professor and a Ph.D. student as guest researchers. The level of collaboration is also reflected by our largest project that is conducted in collaboration with a research group at another Danish university and our participation in the national network on "Mobile systems".

The production of research publications is impressive, especially for a newly established group. The productivity has been very high. We are three researchers who have been in the group for the whole period, initially we were one senior and two junior researchers, and now all three are senior researches. In the period, we have published 67 refereed journal and conference papers. We have been consistently represented at several key conferences, often with more than one paper. This is a very satisfactory productivity. In addition, the number is increasing as more than half of these publications are from the last two years.

The quality of publications is adequate. There are 16 publications in A-level outlets, 18 in B-level outlets, and 33 in C-level outlets. The quality could be improved in two respects. First, there could be more publications at A-level. Second, there is a strong bias toward conferences with 60 papers published at conferences and 7 in journals. This is not contrary to the tradition in the research area, but the proportion of conference papers is higher than what is typical. However, the publications from the last two years reflect a move towards journals and higher level outlets.

The impact is varied. Within the period, we have gained international research

impact in specific areas. Our publications on methods for usability evaluation of mobile devices and design of mobile systems are being increasingly cited. We have deliberately not aimed at gaining industrial impact or writing practitioner-oriented books. Our focus has been on establishing a research group.

In summary, the development of the HCI group has been very satisfactory. From a very limited basis, we have established a medium-size group that has already produced interesting research with good quality and impact. The priority has been on a broad approach to human-computer interaction and participation in key conferences. In the period, we have reached a level where we are internationally recognized in two specific areas. The group has also demonstrated that it has the potential to develop into a strong international research group.

7.5.3 Systems Development Group

The group has followed the research plan made in 2001 to maintain its orientation towards both information systems and software engineering. In the previous research evaluation the committee suggested that the group should seek a higher impact in software engineering and not only in information systems. The group has chosen information systems as its primary field for publishing research because that is where the more mature social theories are found. The group has expanded its publishing into software engineering through IEEE Software and academic books where professional practitioners constitute the main audience. The group has in this way continued its policy to seek impact through research publications and through practitioner-oriented academic books.

The group has increased its publishing in international journals considerably and has taken serious steps to improve the quality of published paper. As a consequence, the group has increased its international visibility and recognition. The senior group members are to a significantly higher degree invited to be editors for A-journals, program committees, and evaluation committees.

As set out in the 2001 research plan, the group has increased its focus on emerging issues. This has been done within both network technologies (through the PITNIT and LOKNIT projects) and mobile technologies (through the research on development of mobile systems and through participation in the technology transfer network “Mobile Systems”).

The group has continued the portfolio of adopted empirical approaches and thereby maintained the use of empirical research as the main research approach. The group has also worked towards improving the rigour by which these research approaches have been used.

The 2001 research plan set the goal that the group should extend its collaboration with international colleagues. The group has extended its collaboration with international colleagues considerably and the number of papers co-authored with international colleagues has increased. Additionally, one senior researcher has been on a half-year sabbatical. The strengthened international collaboration has had the consequence that the increase in collaboration within the group has been

less than desired and some opportunities were lost. The group also had the goal of attracting more short-term and long-term visiting researchers. Further, when Lars Mathiassen went on part-time leave the group searched for visiting professors that could contribute to the group by being present in $\frac{1}{2}$-1 years. This effort has not been successful.

The group has maintained a reasonable balance between basic research funding in department positions and ad-hoc projects with external funding. The external funding has primarily made it possible for the group to extend linkages with international colleagues. Only in the PITNIT project ending in 2001 has the funding covered Ph.D. scholarships. This has suited the group's activities well, but has during 2002-2005 reduced the group's opportunities more recruiting its own Ph.D. students.

Despite not explicitly part of the plans in 2001 the group has been able to respond to the changes arising from Lars Mathiassen and Jan Damsgaard leaving the IS group for other positions in 2002. Two of the research areas in the 2001 plan have now joined forces and regrouped in response to these events. The group has had to re-focus its activities into three main activities: (1) software process improvement that is primarily performed in externally funded projects; (2) information systems development; and (3) management of systems development projects. These activities fit well together and all group members are now actively involved. The focus is now broader and encompasses information systems development and not only software development.

The research focus on networked IT has now converged into a focus e-government. This means that the business focus on information systems is now directed information systems in the public sector. This has already proved to be a desirable change as it has been possible to increase visibility and the possible impact on collaborators in the public sector and to attract substantial funding in the form of an EU network of excellence.

7.6 Research Plan 2006-2010

The research plans for the coming five years are divided into three parts: the IS group, the HCI group, and the Systems Development group.

7.6.1 IS Group

The specific research direction of the IS group is defined by maintaining two research groups. The IS group as a whole has the following plan.

Collaboration between the groups and across projects should be increased and encouraged. This will be done through an open seminar series in both groups. Collaboration between the two groups will also be sought in the common interest in mobile systems. Both groups participate in the national technology transfer network "Mobile Systems" and will utilise that as a platform for the dissemination of research knowledge within the topic. Both groups have an interest in joining

forces in researching topics within mobile systems such as: development of mobile applications, mobile systems in the public sector, mobile systems in health care, usability testing of mobile applications, and design of mobile interfaces and services.

Research leadership should become more clearly defined in practice. The department's new leadership roles have just recently been established. The IS group's two research leaders will have to work out what that means in practice and how they will fill their roles. It is particularly important that they share a responsibility for the IS group as a whole.

7.6.2 Human-Computer Interaction Group

The overall aim is to maintain the strong development of the group. So far, there has been a broad focus on several areas in human-computer interaction. This has been a sensible approach in the process of establishing the group. In the next five years, our intention is to focus more exclusively on the following three research areas:

- The interplay between usability evaluation and interaction design
- Mobile and context-aware systems
- Systems for the domestic domain

The first two areas correspond to the two externally funded projects that we currently have. In both areas, we already have a well-established platform for producing original research results. The third area has emerged from our collaboration with colleagues at University of Melbourne.

Two of the areas emphasized above involve considerable external funding. Our aim is to maintain that level and obtain funding for the third area. We also want to develop our international relations with committed collaboration with a couple of international partners. In this connection, we are interested in involving ourselves in international research projects.

We have experienced a healthy relation between research and education at the highest levels. In line with this, we have increased the number of Ph.D. projects we supervise. Thus we expect to complete four to six Ph.D.'s in the next period. On master thesis level, we have already expanded, as we are currently supervising 16 students, which is more than half of the total number in the period we have just completed. This production of candidates will provide a good basis for recruitment of new staff members.

On research publications, the aim is to maintain the current productivity but increase the quality and impact. The group has had a very high productivity, but the quality and impact has been less impressive. We will fulfill this aim by publishing a higher relative proportion of papers in A-level outlets and in journals rather than conference proceedings. In addition, we want to take a leading role in the research

society by involving us in organizing conferences, running workshops and editing specials issues of journals within our three focus areas. We intend to increase industrial impact to some extent through direct collaboration with a limited number of companies.

7.6.3 Systems Development Group

It is the group's plan for the coming five years to focus particularly on increasing impact and at the same time continue publishing in high quality and while maintaining its productivity. The following outlines in more detail the group's goals and activities.

The group will focus on the following research areas. The three areas are: e-government, development of mobile information systems, and software process improvement. These areas have been chosen because (1) they are in direct continuation of the group's research profile and strongholds, (2) they are at the same time topical and thus more likely to increase the group's visibility both in the research communities and in the software-producing companies, and (3) the group is already involved in networks of collaboration at the university, nationally, or internationally.

E-government will be researched through extensive collaboration within the university's Centre for E-government and through the EU network of excellence. These two networks of collaboration are already established. Both networks for collaboration are multi-disciplinary and the group's contribution will be based on its profound knowledge of information systems development and of the social implications of networked information systems. The research challenge for the group will be to extend this from business organisations into public sector organisations. The primary research interest will be with the development and social implications of enterprise systems and information systems that are complex, integrated, information intensive, and multi-platform. The networks of collaboration make it possible to become involved with local and regional public organisations in their changes towards e-government and use of public sector information systems and thereby furthering both empirical research opportunities and impact on public organisations and the related software-producing companies.

Information systems development will be researched with a particular focus on mobile information systems. The area of mobile information systems offers several opportunities to collaborate with other researchers on mobile systems through the national collaboration network "Mobile Systems". That network's primary goal is technology transfer, but it offers opportunity for research collaboration with other research groups and software-producing companies. The group's contribution will be based on its knowledge of information systems development and software engineering. The group's research challenge will be to apply this within mobile systems where all attention traditionally is towards the underlying wireless technology and rarely with the information services provided for purposes in a mobile setting. The group will seek to collaborate on developing demonstrators rather than on large

research projects. The research interest with mobile demonstrators could for example be to participate in the development of campus-wide mobile services and through that explore the limitations and possible extensions of information systems development methodologies. It could also be to explore the applicability of agile, experimental, and innovative development approaches. The technology transfer network makes it possible to influence companies developing mobile software and thus increasing professional impact.

Software process improvement will be researched through collaboration with Danish research groups. The group has long-standing and organised co-authoring with all Danish researchers within software process improvement. The main research effort will be to elicit further empirical findings from the three-year collaboration project that has just ended. The Danish research groups have in common a critical stance towards the mainstream maturity models and have the opportunity to formulate alternative approaches to process improvement. The group will have as a goal to formulate these alternative approaches within the next five years. The group will seek to do this based on the two previous action research projects and will not seek funding for similarly large projects in the next years. There is a great need in Danish software-producing companies (private and public) to transfer the knowledge that the group already has and the group will seek ways of disseminating their research and the relevant knowledge.

To further collaboration within the group it is a goal that all group members are active in more than one of the above research areas. The group will seek research integration for at least a few years by avoiding large research projects that attract all attention.

In the three previous research evaluations the group has set the goal to publish better by publishing in journals of high quality and international esteem. The group has already achieved that while at the same time increasing its productivity. There are several contradictions involved that the group is aware of, e.g., higher quality may well lead to lesser productivity. The group is concerned that a blindfolded pursuit of higher and higher quality does not necessarily lead to higher impact. While journals like MISQ and ISR are the most prestigious research outlets they are not always targeting the most appropriate audience for the group's research. The group assess that it has reached an appropriate level of quality and productivity and has thus decided that for the coming years impact should be given higher priority than quality and productivity. This should be dome without reducing quality and productivity.

The group will face a particular challenge in recruiting more research staff. It is crucial for the group to increase its number of staff to fulfil its obligation to produce research-based education. In terms of the volume of teaching tasks the group should double its research staff. In terms of research the current group suffers from too many senior research staff that have too many management tasks. The management tasks can be reduced, but they cannot be eliminated as the role for senior researchers is to have management tasks. The long-term strategy will be to recruit Ph.D. students and assistant professors that can gradually fill more senior

position while at the same time lower the age profile of the group. The long-term strategy should be implemented immediately to have any impact on the group's working conditions. The short-term strategy will be to recruit temporary research staff in positions like visiting professor and temporary associate professor.

Appendices | 7

7.7 Detailed Description of Activities and Results

The USE project (2005-08)

Scientist in charge: Jan Stage

Participants: Mikael B. Skov, Steve Howard, Benedikte Skibsted Als, Rune Thaarup Høegh, Janne Jul Jensen

Research collaborators: Erik Frøkjær, Kasper Hornbæk, Mie Nørgaard, Tobias Uldahl-Espersen, Copenhagen University

Industrial collaborators: ETI A/S, Jobindex A/S, DialogDesign, Lyngsoe Systems A/S

Funding: Total budget 12.3 mill. DKK of which 5.4 mill DKK has been granted by the Danish Research Agency (grant no. 2106-04-0022)

In the USE project we aim at increasing the impact of usability evaluations on industrial software development. Thereby, we will bridge the gap between usability evaluation and software design that has been presented above. We do so by systematically a) exploring and investigating tools and techniques for extending feedback from usability evaluations beyond a mere listing of problems, and b) developing and evaluating our ideas for integration in industrial software development projects.

Indexical Interaction Design for Context-Aware Mobile Computer Systems (2004-06)

Scientist in charge: Jesper Kjeldskov

Participants: Jeni Paay (The University of Melbourne)

Funding: Grant from Danish Technical Research Council (STVF): 1.5 mill (talent project ref. 26-04-0026)

The IID project aims at creating a theoretical and practical foundation for future research into interaction design with context-aware mobile computer systems and to develop the concept of indexicality as an interaction design principle for such systems. The IID project will generate a theoretical understanding of context and explore and develop the concept of indexicality in context-aware human-computer

interface design; develop a design principle that allows designers to make use of information implicitly and explicitly embedded in the user's context to streamline the interface of mobile information and communication technologies.

Mindkids (2003-)

Scientist in charge: Mikael B. Skov

Participants: Benedikte Skibsted Als, Janne Jul Jensen

Research collaborators: SIGCHI.Kids in Denmark (Aalborg University, Southern University of Denmark, Århus University)

Industrial collaborators: Studio 1-2 A/S and SIGCHI.Kids in Denmark (HitKit ApS, UNI-C, KMD A/S).

This project aim at better understanding children's needs and requirements of information technologies and it includes a number of different sub-projects. Design of children's technologies has received increased attention during the last years. The research has two primary objectives. First, we investigate how emerging technologies should be designed for children and how such technologies could support the special needs of children. Secondly, we explore how these technologies can be evaluated by children and thus, how children can be involved in the evaluation process. The project started in 2003.

Usability Evaluations for Mobile Systems (2001-)

Participants: Jan Stage, Jesper Kjeldskov, and Mikael B. Skov

Research Collaborators: University of Melbourne

This project aims at understanding and developing methods and techniques for evaluating mobile and handheld mobile systems and devices. Mobile systems challenge our established ways of evaluating and understanding use and usability as interacting with mobile systems often is closely related to the immediate physical or social context. The project has so far involved a number of studies. First, we have experimented with different setups for evaluating mobile devices in a stationary laboratory. This approach focused on six techniques for evaluating the usability of mobile computer systems in laboratory settings. The purpose of these techniques is to facilitate systematic data collection in a controlled environment and support the identification of usability problems that are experienced in mobile use. Secondly, we have conducted a series of usability studies comparing the outcomes from evaluations of mobile devices and services based on laboratory- and field-based techniques as field-based usability studies are difficult to conduct, time consuming, and the added value is unknown. On the basis of this, we have developed new methods and techniques for increasing the realism of laboratory setups and improving data collection in the field.

SUE: Simplified Usability Evaluation (2000-)

Participants: Mikael B. Skov, Jan Stage

The SUE project focuses on dissemination of usability engineering competence to a wider audience. We have conducted empirical studies of web-site usability testing carried out by a diverse group of people with no formal education in software development or usability testing. Teams of four to eight first-year university students with an interest but no education in information technology were trained in a simplified approach to web-site usability testing that can be taught in one week. The objective of the project is to develop a course that provides the training of novice usability testers on practical usability testing which further enables them to conduct meaningful usability tests. The course has been modified and improved according to our evaluation of the first empirical study.

Design and Use of Mobile Multimedia: Mediating Strong-Tie Relationships (2004)

Scientist in charge: Jesper Kjeldskov

Participants: Steve Howard, Frank Vetere, Martin Gibbs, Marcus Bunyan, Sonja Pedell, Karen Mecoles, Florian Muller

Funding: The Danish Technical Research Council (STVF ref. 26-03-0341), the Australian Smart Internet Technologies Cooperative Research Centre

Industrial collaborators: Novell Pty, Melbourne

The Mediating Strong-Tie Relationships project addresses the challenges of designing technologies for use in the private sphere specifically context-aware mobile multimedia systems for supporting communication in intimate and strong-tie relationships. Intimacy is a crucial element of domestic life that has received very little attention from Human-Computer Interaction (HCI) researchers despite their rapidly growing interest in the design of interactive technologies for domestic use. Intimate acts differ from other activities, and there are unexplored opportunities to develop interactive technologies to support these acts. Investigating the phenomenon of technology use in strong-tie and intimate relationships, this project involved an ethnographic study of people's communication and interaction habits using cultural probes, development of novel design ideas and implementation of functional prototypes.

MobileWard (2003-05)

Scientist in charge: Mikael B. Skov

Participants: Jesper Kjeldskov and Rune Thaarup Høegh

Funding: The Danish Natural Science Research Council (grant no. 21-03-0301)

Collaborators: Frederikshavn Hospital.

Interaction Design for the Context-Aware Mobile Internet This project is a research project aiming at understanding the potentials of context-awareness in supporting work activities in a hospital ward. The project was initiated as a response to the lack of focus on supporting work activities in context-awareness research. In the project, we studied selected work activities for nurses at a local hospital, and designed and implemented a running prototype of a context-aware mobile electronic patient record called MobileWard. The prototype was evaluated in several studies to assess context-awareness in relation to the work activities of the nurses.

The TramMate Project (2002-03)

Scientist in charge: Jesper Kjeldskov

Participants: Connor Graham, Steve Howard, Frank Vetere, Jennie Carroll, John Murphy, Jeni Paay, Sonja Pedell

Funding: The Faculty of Technology and Science, The University of Melbourne

Industrial collaborators: Novell Pty, Melbourne

Conducted as a part of the Interaction Design for Emerging Technologies PhD project, the TramMate project was a collaborative research project on the design and evaluation of mobile information systems conducted in collaboration with local researchers and IT industry in Melbourne, Australia. The TramMate project investigated the potentials of supporting public transportation use by means of location-based information services on mobile devices. Investigating into this challenge, we explored current travel practices and possible future practice of business employees as they traveled to appointments in the inner city of Melbourne. On the basis of our fieldwork we designed a location-based information service for mobile devices such as PDAs and mobile phones. A prototype system was evaluated it in both laboratory settings as well as in the field on board trams in Melbourne, Australia.

The Communicator Project (2000-04)

Participants: Jesper Kjeldskov, Jan Stage

Industrial collaborators: Maersk-Sealand, Nordjyllandsværket

The purpose of this project is to design a device that solves communication and coordination problems in safety-critical industrial process control. Today, this communication is typically based on VHF radios which is highly sensitive to noise and inherent limitations of spoken communication. The project has involved two major empirical case studies in collaboration with Maersk-Sealand and Nordjyllandsværket and the design and evaluation of two mobile communication prototype systems. In the first case study, conducted in collaboration with a major international container shipping company, the project focused on the communication on

board large container ships between the captain on the bridge and officers managing the crews that are working at the bow and stern when a ship is arriving at or leaving the harbor. Based on ethnographic observations and object-oriented analysis a mobile communication system prototype was designed and implemented facilitating text-based communication and partial automation.

In the second case study, the lessons learned from the evaluations of the first prototype informed the design of a mobile communication and communication tool for distributed workers at a large regional power plant furthering our knowledge about interaction design for mobile devices and the use of text-based communication in safety-critical domains.

The Digital Hospital (DDS) (2002-04)

Participants: Jesper Kjeldskov, Mikael B. Skov, Jan Stage

Funding: Nordjyllands amt (0.5 mill. DKK)

Research collaborators: Virtual Centre for Health Informatics, Aalborg University

External collaborators: Nordjyllands amt, Sygehus Vendsyssel, Frederikshavn, Aalborg Sygehus Syd

The DDS project concerns the evaluation of usability in a range of applications for use in hospitals e.g. digital patient case records and diet planning tools for diabetics. The project is a part of a larger research project at the hospitals of Frederikshavn and Skagen conducted. The aim of the overall project is a full-scale implementation and use of digital information technology within healthcare. The project conducted four usability evaluations over a two years period. Each usability test resulted in a self-contained usability evaluation report. Two types of applications were tested: 1) Digital patient case records used by the hospital staff and 2) diet planning tools for diabetics used by doctors as well as patients. The usability evaluations were performed both in our dedicated usability lab and in the field by observing actual use at the hospitals.

Usability-Lab: Design of a Usability Laboratory (1999-03)

Participants: Jesper Kjeldskov, Mikael B. Skov, Jan Stage

Funding: Nokia, Siemens, Aalborg University, Faculty of Technology and Science and Department of Computer Science

Research collaborators: Swinbourne University of Technology, University of Melbourne

Industrial collaborators: Nokia, Siemens, ETI

This project has designed and developed a laboratory for conducting usability tests of communication systems and small mobile devices. The first usability laboratory was designed and established in 1999 to facilitate a broad range of tests

and products, including software running on work stations and PCs. The shapes, sizes, and physical positions of the rooms available were given in advance. Otherwise there were no major restrictions on the design. The design of this laboratory was based on general descriptions of usability laboratories (Rubin) and experience from existing facilities (Kommunedata). Yet it was quickly realised that the testing of devices as well as communication based on devices raised new problems. These experiences were the basis for designing the second laboratory. In the spring of 2001, it became possible to move the usability laboratory to a place much closer to the research group using it. In this setting, we are experimenting with work practices for two kinds of usability tests. The first is testing of small mobile devices. The size and lack of a fixed physical position raises several practical problems. The second is testing of communication based on either computerized systems or mobile devices.

The Staging of Virtual 3D-Spaces (1998-01)

Participants: Mikael Skov, Jan Stage, Jesper Kjeldskov and Peter Bøgh Andersen

Funding: The Danish Research Ministry

Industrial collaborators: Deadline Software, Interact

This project was a large multidisciplinary effort that started in 1998 and continues until 2001. More than 30 researchers from different Danish research institutions participated in the project. The project was supported by the Danish Research Ministry with a total budget of DKK 22 million. The activities of the project were divided in three teams concerned with analysis, construction, and methodology related to the development of computerised interactive media that stage virtual inhabited 3D-spaces. The construction team concentrated on developing architectures for agents in 3D-environments. The idea was that agents are the smallest building blocks in interactive narratives, and, in this capacity, should be designed to function as actors. It was assumed that interactive narratives are not told, but enacted. The methodology team focussed on analytical and experimental approaches to software development. These approaches were characterised and their relevance for design of interactive media were evaluated through qualitative empirical experiments. In relation to the information systems group, the Staging of Virtual 3D-Spaces resulted in 1 PhD dissertation.

Centre for Electronic Governance

CEG is a cross disciplinary research centre (funded by the university) set up in 2005 by the Department of Computing Science in collaboration with other faculties and departments to promote research and teaching in the area of e-government. The intention is to co-ordinate the activities of the university's staff, to develop local and international networks and to strengthen the university's position in this emerging field.

DEMO-NET

Scientist in charge: Jeremey Rose

Funding: EU

Demo-Net is a network of Excellence funded by the European Commission under the Sixth Framework Research program. It is designed to promote lasting integration of European research in the areas of e-participation and e-democracy. The consortium consists of twenty international partners and will be funded over five years to a maximum of 6,000,000€. Aalborg University is the lead partner and the preparation, consortium formation and application work has been principally located in the information systems group, taking most of 2005. Contracts are expected to be signed before the end of 2005.

PITNIT

Scientist in charge: Jan Damsgaard

Participants: Jan Karlsbjerg, Rens Scheepers, Jeremy Rose and Jan Kristensen.

Funding: Danish Research Council (total budget DKK 7,5 Million)

The PITNIT project was a large multi-disciplinary research effort that involved researchers from department of computer science, department of production, department of international business studies at Aalborg University, and department of management, Århus University. It started in 1999 and continued until 2003. It is supported by the

Participants from information systems were

The goal of the PITNIT project were to describe, analyze and offer practical guidelines of the integration and transformation of industrial processes enabled by new networked information technology. The key research challenges included

- The merger between a number of process innovation concepts and associated IT.
- The Extended Enterprise that emerges from a multitude of different co-operating organizations and associated IT.
- Network-based interaction with the environment using new IT for marketing purposes.
- The project resulted in two books and over 40 refereed papers in conferences and journals.

LOKNIT (1999-2001)

Scientist in charge: Jan Damsgaard

Participants: Jan Karlsbjerg, Rens Scheepers, and Jan Kristensen

Funding: The total budget DKK 4.7 million.

The LOKNIT project focused on collaboration between practitioners and researchers in connection with the PITNIT project. The goal was to disseminate research results mainly from the PITNIT project and to interact with industry representatives. This was done through a series of monthly meetings and through annual conferences.

Socio theoretical accounts of information systems

Scientist in charge: Jeremy Rose

The group has a long-standing collaboration with the Judge Management Institute at Cambridge University, UK, and The Joanna Mack Business School at Georgia State University, USA, in the development of social theories as explanations of information systems in organizations (with a particular focus on enterprise resource planning systems) which has directly or indirectly resulted in 18 publications over the last five years.

Software Processes and Knowledge (2002-2006)

Scientist in charge: Peter Axel Nielsen

Participants: Ivan Aaen, Jeremy Rose, Gitte Tjørnehøj, Helle Damborg Fredriksen, Keld Pedersen.

Funding: Total budget 16.4 mill. DKK og which 1.8 mill DKK has been granted by the National Center for IT Research.

Research collaborators: Jan Pries-Heje and Thomas Elisberg, IT University Copenhagen; Karl Kautz, Jacob Nørbjerg, and Bo Hansen Hansen, Copenhagen Business School.

Industrial collaborators: Systematic Software Engineering A/S, Logimatic Software A/S, and Rovsing Space A/S.

Software Processes and Knowledge is a research project organised as a large collaborative effort between the group, the IT University Copenhagen, and Copenhagen Business School with a primary research interest and 3 software developing companies with a primary improvement interest. The research approach is fundamentally action research where the collaboration with the companies focuses on creating lasting improvements in each of the companies. The improvements are guided by both a desire for more mature software processes and for more appropriate knowledge management processes.

The research project ends by January 2006. So far the project has produced more than 30 publications.

Information Systems Development

Scientist in charge: Peter Axel Nielsen

Research collaborators: Hans Olav Omland, Stig Nordheim, and Bjørn Erik Munkvold, Agder University College; Bendik Bygstad, Norwegian IT College.

This research is performed in collaboration with Agder University College, Norway, and it is governed by an agreement concerning Ph.D. studies. The research is directed at understanding information systems development and how it is organised and managed and how we may provide improved methodologies, models and techniques based on this. More specifically, the focus is on systems developers' competences, methodologies in adapting ERP systems, and on socio-technical models for managing IS development projects.

The research collaboration is ongoing and has so far resulted in several published papers and a Ph.D. degree (Bendik Bygstad).

Development of Mobile Systems

Scientist in charge: Peter Axel Nielsen

Participants: Jens Henrik Hosbond, Ivan Aaen.

The research in directed at understanding the uniqueness of the development of mobile systems compared to systems development in general and based on this design, improve and test methodologies and techniques relevant for software companies on this particular market.

The research is in an initial phase, but some results have already been published. The research is expected to expand and continue for several years.

7.8 Organization and Staff

7.8.1 Present Staff

7.8.1 Ivan Aaen

Academic Degrees

1990	Lic. Scient. (Ph.D.) in Computer Science, Aalborg University
1980	Cand. Polyt. (M.Eng.) in System Construction, Aalborg University

Positions

1991-	Associate Professor in Computer Science, Aalborg University

Key Publications

[2, 43, 42, 1]

Keywords

Software engineering, software process improvement, agile software development, lean software development

7.8.1 Lars Bækgaard

Academic Degrees

1993	Ph.D. Computer Science, Aalborg University.
1988	Cand.scient (M.Sc.). Computer Science. Aalborg University.

Positions

2004-05	External teacher, Aalborg University
2001-04	Visiting associate professor, Aalborg University
1996-00	Associate professor, Århus School of Business
1992-96	Assistant professor, Aalborg University
1988-90	Amanuensis, Aalborg University
1995-96	Visiting researcher, University of Maryland
1990-92	Visiting researcher, University of Maryland
1994-86	Systemudvikling, KMD
1980-82	Systemudvikling, KMD

Key Publications

[61, 60, 59, 58]

Keywords

Information systems, systems development, business modeling, event-based modeling

7.8.1 Jesper Kjeldskov

Academic Degrees

2003	Ph.D. in Computer Science, Aalborg University
2000	Master of Arts (M.A.) in Humanistic Computer Science and Sociology, Aalborg University
1997	Bachelor of Arts (B.A.) in Humanistic Computer Science and Informatics, Aalborg University

Positions

2005	Honorary Fellow, Department of Information Systems, The University of Melbourne, Australia
2004-	Associate Professor, Department of Computer Science, Aalborg University
2004	Research Fellow, Department of Information Systems, The University of Melbourne, Australia
2003-04	Assistant Professor, Department of Computer Science, Aalborg University
2001-03	Ph.D. Candidate, Department of Computer Science, Aalborg University

Key Publications

[154, 19, 20, 91]

Keywords

Mobile interaction design, context-awareness, indexicality, usability

7.8.1 Lars Mathiassen

Academic Degrees

1998	Dr. Tech. in Computer Science, Aalborg University
1981	Dr. Scient. (Ph.D.) in Computer Science, University of Oslo
1975	Cand. Scient. (M.Sc.) in Computer Science, Aarhus University

Positions

2002-	Research Director, Center for Process Innovation, Georgia State University, USA.
2002-	Full Professor, Computer Information Systems, Georgia State University, USA.
2002-	Visiting Professor, Computer Science, University of Aalborg, Denmark.
2001-02	Visiting Professor, IROB, Warwick Business School, UK.
2001-	Visiting Professor, IT-University, Göteborg, Sweden.
1998-03	Visiting Professor, Viktoria Institute, Göteborg, Sweden.
1997	Visiting Professor, CIS, Georgia State University, USA.
1997-00	Research Director, Danish National Center for IT Research.
1990-98	Visiting Professor, Institute Theseus, Sophia Antipolis, France.
1987-02	Full Professor, Computer Science, University of Aalborg, Denmark.

Key Publications

[21, 14, 15, 11]

Keywords

Business process innovation, software engineering, IT management, management of change.

7.8.1 Andreas Munk-Madsen

Academic Degrees

1987	Lic. Scient. (Ph.D.) in Computer Science, Aarhus University
1978	Cand. Scient. (M.Sc.) in Computer Science and Mathematics, Aarhus University

Positions

2003-	Associate Professor in Computer Science, Aalborg University (parttime)
1986-	Managing Director, Metodica, supplying training and consultancy to the software industry
1983-86	Scientist, Aarhus University
1981-83	Scientist, Danish Datamatics Center
1978-81	System developer, Private Companies

Key Publications

[119, 163]

Keywords

Project management, storytelling, object-oriented analysis & design, software process improvement.

7.8.1 Peter Axel Nielsen

Academic Degrees

1990	Ph.D. in Information Management, Lancaster University, UK.
1986	Cand.scient. (M.Sc.) in Computer Science, Aarhus University

Positions

2002-	Visiting professor, Agder University College, Norway
2001-05	Visiting International Research Scholar in Information Systems, Virginia Commonwealth University, USA.
1992-	Associate professor in Computer Science, Aalborg University
1989-92	Assistant professor in Computer Science, Aalborg University
1986-89	Ph.D. scholarship, Faculty of Science, Aarhus University.

Key Publications

[15, 28, 27, 29]

Keywords

Information systems development, requirements methodologies, software process improvement, software engineering processes.

7.8.1 Jeremy Rose

Academic Degrees

2000	Ph.D. in Management School, Lancaster University
1992	M.Sc. Information Management (with distinction), University of Lancaster
1979	ARCM (teaching qualification in music), Royal College of Music, London
1976	Post Graduate Certificate of Education (teaching qualification for higher level schools), University of Bristol
1975	BA (Hons) English (2.1), University of Cambridge

Positions

2005-	Director of Centre for E-Governance, Aalborg University
2002-	External lecturer, Department of Informatics, Copenhagen Business School, Denmark
2001-	Associate Professor, Department of Computer Science, Aalborg University
1992-01	Senior lecturer, Department of Business Information Technology, Faculty of Management and Business, Manchester Metropolitan University, England
1979-91	Freelance musician, music teacher and music administrator

Key Publications

[16, 32, 36]

Keywords

Information system development, information system management, organisational computing, eGovernment

7.8.1 Mikael B. Skov

Academic Degrees

2002	Ph.D. in computer science, Aalborg University
1995	Cand. scient. (M.Sc.) in computer science, Aalborg University

Positions

2003-	Associate Professor, Department of Computer Science, Aalborg University
2001-03	Assistant Professor, Department of Computer Science, Aalborg University
1998-01	PhD Candidate, Department of Computer Science, Aalborg University
1996-98	Project-Coordinator, the Danish National Centre for IT Research 1995-96 Systems Developer, Den Danske Bank, Århus

Key Publications

[160, 39, 86, 38]

Keywords

Human-computer interaction, usability, mobile technologies, context-awareness.

7.8.1 Jan Stage

Academic Degrees

1989	Dr. scient. (Ph.D.) in Computer Science. University of Oslo
1984	Cand. scient. (M.Sc.) in Computer Science. Aalborg University

Positions

2002-03	Visiting Lecturer in Information Systems, University of Auckland, Department of Management Science and Information Systems
1991-	Associate Professor in Computer Science, Aalborg University
1991	Visiting Assistant Professor in Information Systems, State University of New York
1988-91	Assistant Professor in Computer Science, Aalborg University

Key Publications

[51, 20, 38, 105]

Keywords

Usability evaluation, design of human-computer interaction, methods for analysis and design in system development.

7.8.2 Prior Members of Staff

7.8.2 Peter Bøgh Andersen

Academic Degrees

1991	Dr. Phil. In Information Science, University of Århus
1971	Ph.D. in Danish language, University of Århus

Positions

2003-	Professor, Department of Information and Media Science, University of Århus
2000-04	Professor, Department of Computer Science, University of Aalborg
1993-99	Professor, Department of Information and Media Science, University of Århus
1981-93	Associate Professor, Humanistic-Informatic Curriculum, University of Århus
1971-80	Assistant Professor, Department of Scandinavian Languages and Literature, University of Århus

7.8.2 Jan Damsgaard

Academic Degrees

1996	Ph.D. and European Doctorate in Information Systems, Aalborg University, Denmark
1993	Master of Science in Computer Science, Aalborg University, Denmark

Positions

2003-	Professor, Department of Informatics, Copenhagen Business School
2001-02	Visiting Associate Professor, Department of Information Systems, Weatherhead School of Management, Case Western Reserve University
2000-03	Associate Professor, Department of Computer Science, Aalborg University
1999-00	Associate Professor, Department of Management, Aarhus University
1996-99	Assistant Professor, Department of Computer Science, Aalborg University

Key Publications

[7, 4, 8, 6]

7.8.2 Palle Nowack

Academic Degrees

2000	Ph.D. in Computer Systems Engineering, University of Southern Denmark. Grant (1,1 Mkr) provided by the Danish Technical Research Council (STVF).
1996	M.Sc. in Computer Engineering, Specializing in Programming Systems, Aalborg University, Denmark.

Positions

2002-	Assistant Professor, Maersk Institute, University of Southern Denmark
2000-01	Part-time Assistant Professor, Dept. of Computer Science, Aalborg University and part-time Research Assistant Professor, Maersk Institute, University of Southern Denmark

7.9 Ph.D. Projects

7.9.1 Project Descriptions

Design of Interactive Narratives: Concepts, Methods, and Architectures

Name: Mikael B. Skov

Education: M.Sc. in Computer Science, Aalborg University, 1995

Duration: August 1998 – July 2001

Status: Degree awarded

Funding: Research Grant

Advisor: Jan Stage

This thesis deals with the design of interactive narratives. Interactive narratives are software systems that enable users to create stories when using the system. The thesis addresses three research questions within interactive narratives design: 1) What are the key concepts for understanding design of interactive narratives?, 2) What are the key challenges during the design process of interactive narratives and how can object-oriented methods support the design process?, and 3) What characterises design architectures for interactive narratives? First, the concepts of interaction and narration define key properties of interactive narratives. Different understandings of the two concepts are applicable and signify different kinds of interactive narratives. This thesis identifies temporal-oriented and spatial-oriented interactive narratives primarily based on the definition of narration. Secondly, a key challenge in interactive narratives design is the creation of the narrative. During the creation of the narrative is not obvious how users could be involved in determining functional requirements to the system. More key activities in object-oriented design methods are of limited value because the focus on work domains does not necessarily hold for interactive narratives. Thirdly, two architectures are proposed to support the design of either temporal-oriented or spatial-oriented interactive narratives. The architectures identify two different understandings of narration and addresses interaction at two different levels.

Human-Computer Interaction Design for Emerging Technologies

Name: Jesper Kjeldskov

Education: M.A. in Humanistic Computer Science, Aalborg University, 2000

Duration: October 2000 – July 2003

Status: Degree awarded

Funding: Departmental Scholarship

Advisor: Jan Stage

This thesis deals with interaction design for a class of upcoming computer technologies for human use characterized by being different from traditional desktop computers in their physical appearance and the contexts in which they are used. These are typically referred to as emerging technologies. Emerging technologies often imply interaction dissimilar from how computers are usually operated. This challenges the scope and applicability of existing knowledge about human-computer interaction design. The thesis focuses on three specific technologies: virtual reality, augmented reality and mobile computer systems. For these

technologies, five themes are addressed: current focus of research, concepts, interaction styles, methods and tools. These themes inform three research questions, which guide the conducted research. Three empirical sources contribute to the results. Experiments with interaction design inform the development of concepts and interaction styles suitable for virtual reality, augmented reality and mobile computer systems. Experiments with designing interaction inform understanding of how methods and tools support design processes for these technologies. Finally, a literature survey informs a review of existing research, and identifies current focus, limitations and opportunities for future research

Making Use of Software Metrics

Name: Helle Damborg Frederiksen

Education: M.Sc. in Matematics and Computer Science, Aalborg University, 1992

Duration: August 2000 – February 2004

Status: Degree awarded

Funding: Co-funded by KMD and Department of Computer Science

Advisor: Lars Mathiassen

Many software organizations introduce metrics programs for management and improvement of their software operation. The implementation of such programs is, however, often complicated and the programs are seldom used as intended. This was also the case in the Danish software company, KMD. That motivated this research into how metrics in KMD could be improved to better support management and improvement purposes. The research was organized as an industrial Ph. D. study with the following overall research question: How can metrics be made useful for managing and improving the operation in large software organizations? We perceived metrics programs as information systems providing information for software managers and software process improvement agents. Hence, we used theoretical frameworks from the information systems discipline to analyze on and intervene into the metrics practices in KMD and to subsequently reflect on our improvement practices. Collaborative practice research was adopted as the research strategy with a mixture of action research and practice studies in KMD depending on the specific needs of each focused research effort. We had the opportunity to create a strong collaborative team of practitioners and researchers by involving practitioners in KMD, by having me as the leading researcher-practitioner inside the organization, and by having my supervisor and other researchers actively participate throughout the process. This way we were able to gain a deep level of understanding of the use of metrics in KMD. The resulting thesis consists of this summary with a coherent presentation of the research process and findings and five papers that were published during the course of the study.

Standard Information Systems in Organizational Information Infrastructures

Name: Jan Karlsbjerg

Education: M.Sc. in Computer Science, Aalborg University, 1995

Duration: September 1999 – July 2004

Status: Degree awarded

Funding: Research Grant

Advisor: Jan Damsgaard

The project concerns standard information systems and their role in organizational information infrastructures, with an emphasis on selection and implementation strategies in companies' choice of software standards. The theoretical background is in the standards literature, the information systems infrastructure literature and in network economics. The data collection methods are qualitative, through structured interviews, and the research philosophy primarily interpretative. The work is both descriptive of relevant practice in organisations, and normative in that it offers guidelines and frameworks for software selection and implementation.

Diffusion of Electronic Public Procurement in Denmark

Name: Ramanathan Somasundaram

Education: 2001 – 2004

Duration: Degree awarded

Status: Research Grant

Funding: Jan Damsgaard

Advisor:

Electronic public procurement (e-PP) is being implemented in many countries worldwide. Preliminary analysis bring to attention many challenges that are likely to be encountered while implementing e-PP nation wide. For example, government organizations might face difficulty in authoritatively negotiating frame agreements with suppliers, multiple islands of e-PP computing infrastructure could emerge and suppliers might resist participating in e-procurement. There has been little research effort taken to document challenges encountered in implementing e-PP and to theorize their occurrence. As a remedy, this study is designed to answer the research questions; "what challenges are encountered in implementing ePP? Why do these challenges arise?" Explorative case study design is adopted for answering the research questions. The Danish nation is regarded an embedded unit of analysis. The implementation of multiple e-PP networks is studied. The term "diffusion" is used in the thesis title to denote that the spreading of e-PP in Denmark is studied.

Primary data for the study is collected using semi-structured interviews. The interviews are primarily guided by IOS adoption literature. Thirty three stakeholders belonging to multiple stakeholder types are interviewed about their involvement in the diffusion of e-PP. The interview data is analyzed using explanation building technique.

Managing Learning in Systems Development Projects

Name: Keld Pedersen

Education: M.Sc. in Computer Science, Aalborg University, 1992

Duration: September 2001 – July 2005

Status: Degree awarded

Funding: Faculty

Advisor: Lars Mathiassen

This thesis deals with issues concerning learning in systems development projects. Systems development organizations depend on learning to address customer needs and to improve their capability to develop useful and competitive solutions. However, managing learning in systems development projects is difficult and the discipline still suffers from learning related problems. This was the case in the systems development projects reported here, as well as in previous research reported within the field. The overall research goal is therefore to increase our understanding of how learning takes places in systems development projects, and to support developers and systems development projects by offering advice about how to manage projects in a way that improves learning. The level of analysis is the project, i.e. we study learning from the perspective of individual systems development projects and focus on what developers can do to improve the possibilities for learning within their projects. The research draws on organizational learning theories. These theories are used to interpret data collected through the study, to understand learning related problems in systems development practice, and to suggest new alternative practices. The research was conducted trough a multi method approach including case studies, field experiments, and Delphi studies in collaboration with systems development practitioners. Even though different approaches have been used, the research is primarily based on the interpretive research paradigm.

The research contributes to systems development theory and practice by adding new insights to knowledge sharing in systems development, iterative systems development, and post mortem evaluations. The research contributes with rich understanding of how learning processes unfolds in systems development projects and it offers several suggestions on how to improve learning in systems development projects. The research illustrates the value of using organizational learning theory to improve our understanding of systems development practice, and it explicates important limitations in the current prescriptive systems development literature that claim to facilitate learning.

Mutual Adaptation between Technology and Organisation in Iterative Development Projects

Name: Bendik Bygstad

Education: Master in Sociology, University of Oslo

Duration: 2002 – 2005

Status: Degree awarded

Funding: Norwegian School of IT

Advisor: Peter Axel Nielsen and Bjørn E. Munkvold

This thesis explores the mutual adaptation between technology and organisation in the context of modern systems development, seen from the perspective of the information systems project manager. The research approach is interpretive and contextual, using mainly the Longitudinal Process Research method. A set of socio-technical temporal patterns is identified on three levels. At the lowest and most practical level a window of opportunity for mutual adaptation in an iterative IS development project is identified; the window of opportunity emerges when both the information system and the organisational processes are malleable. At a higher level the notion of process interaction is introduced to describe the necessary interaction between the software development project and the organisational development project in a large organisation. At a more general level four patterns of integration are introduced to illustrate different and contextual strategies for integration. The socio-technical patterns bridge socio-technical IS development and software engineering research, and extend the scope of iterative and incremental software engineering research. These patterns also broaden the perspective of the IS project manager, by offering a better analytical and managerial tool for contributing to IT-based business innovation.

Strategic Software Process Improvement

Name: Gitte Tjørnehøj

Education: M.Sc. in Computer Science, Aalborg University 1995

Duration: August 2003 – July 2008 (expected)

Status: In progress

Funding: Faculty

Advisor: Peter Axel Nielsen

Many Danish companies invest in improvements of their working process since software process improvement (SPI) is becoming a parameter of competition on more and more markets. A literature survey of the research field of SPI showed that The Capability Maturity Model (CMM) by the Software Engineering Institute still is the dominating model in the field, though many other strategies and models

have been suggested over the years. Most literature in the field is prescriptive and suggests formal and model-based approaches, which requires many improvements of significant complexity and rather big investments. On the other hand an increasing number of failures from this strategy have been reported in the later years. It is for example well known within SPI that the model is not adequate for the improvement issues in small software companies. This doctoral work therefore strives to describe and categorize different strategies for SPI and to develop and test a tool for choosing appropriate strategies in companies to benefit return of the investments in SPI. The work is based on collaborative practice research within a national research project in collaboration with three system development organisations and a number of researchers. A long history (8 years) of improvements initiatives in one company is studied in detail, the latter two years through participation as action researcher.

Mobile Systems Development

Name: Jens Henrik Hosbond

Education: M.Sc. in Computer Science, Aalborg University, 2004

Duration: August 2004 – August 2007 (expected)

Status: In progress

Funding: Departmental scholarship

Advisor: Peter Axel Nielsen

Mobile systems development is the subject of the PhD study. Development of mobile software is a challenging task surrounded by a high level of uncertainty: Rapid technology development and lacking standardisation, short time-to-market, lacking end-user adoption, missing killer applications are just some of the conditions creating an uncertain environment. Despite, the much uncertainty surrounding mobile systems development, contributions on the subject have been sparse. The PhD study seeks to answer the following questions: What are the characteristics and issues of developing mobile systems? Why are these issues apparent? What are the development processes in practice and how may these be assessed? The PhD study is highly empirical and includes: (1) an exploratory multiple case study of the Danish mobile software development industry and (2) a longitudinal process research study involving two large International development companies. The PhD study is expected to contribute both practically and theoretically. The contributions will be proposed based on an in-depth analysis of current practice in development organisations and related theoretical areas from research. Through empirical analysis frameworks, development guidelines, and principles for mobile systems development practice are proposed, all contributing to reducing the uncertainty associated with mobile systems development. As research on mobility, so far, has not taken a systems development perspective, the aim of this Ph.D study is to contribute to a theoretical grounding of the discourse in research.

ICT Support of Mobile Work: Design and Usability for Exposed Physical Working Environment

Name: Bente Skattør

Education: Cand. Scient, Oslo University, 1995

Duration: December 2002 – February 2007 (expected)

Status: In progress

Funding: Sørlandets Kompetanse Senter

Advisor: Jan Stage and Lars Line

The main objective of this research project is to provide insight about ICT support in mobile work. The focus will be on design methods and usability issues. The context of use will be occupational use by blue-collar workers (e.g. "non-office" workers) having a work situation that might be exposed to rough climate, dust and noise. The recent advances in mobile ICT have opened possibilities for ICT support in use context that until now has had little ICT support. It is a great challenge to design services that are accepted and will benefit both individuals and organisation. It is a challenge to make the technologies accommodate the way we naturally interact and work. In relation to this new technology, important and interesting research issues will be how to design and develop ICT services that support mobile workers. This research project will aim to contribute to the design and usability testing of services in mobile settings. The overall research questions will be: 1) How can we design and develop mobile services supporting mobile work? 2) What are the benefits and limitations of Contextual Design used in mobile settings? 3) What factors explain usability of services within mobile settings? 4) How can we do usability testing in a mobile setting?

Identifying and addressing conflicting stakeholder interests in e-Government

Name: Leif Skiftenes Flak

Education: Master of Science in Information Systems (Agder University College)

Duration: April 2003 – April 2006 (expected)

Status: In progress

Funding: Agder University College

Advisor: Jeremy Rose and Maung K. Sein (Agder University College)

This research project has two distinct, yet interrelated objectives: 1) to increase our understanding the variety of stakeholders and different and often competing interests of G2G initiatives. 2) To develop and validate an approach to revealing and handling conflicting interests in local G2G initiatives. 2 literature reviews on stakeholder theory and local e-Government together with 2 exploratory case studies

on local e-Government efforts shed light on the first objective and provide input to the second objective. An approach for revealing and handling conflicting interests will be tested in a local G2G project.

A framework of models and communication genres for conceptual development of e-Democracy implementations

Name: Øystein Sæbø

Education: Master of Science in Information Systems, Agder University College

Duration: April 2003 – April 2006 (expected)

Status: In progress

Funding: Agder University College

Advisor: Jeremy Rose and Maung K. Sein (Agder University College)

The Ph.D. project is focusing on how to increase the grounds for decision making in an early phase when developing e-Democracy project. A framework is developed based on democracy models and genre of communication. By being more precise on the objectives (democracy models) and communication patterns (genre of communication) the Ph.D. project argue that more precise decisions can be made on how to develop e-Democracy projects. The framework is developed and then implemented in an action research project.

Designing and evaluating with children

Name: Benedikte Skibsted Als

Education: M.Sc. in Informatics, Aalborg University, 2003

Duration: August 2003 – May 2007 (expected)

Status: In progress

Funding: Departmental Scholarship

Advisor: Jan Stage

The purpose of this Ph.D. project is to examine how children can be involved in designing and evaluating software systems for children. Traditionally users are first involved in the final stages of the industrial development process, this in spite of the fact that researchers for many years have stated that involving the end-users at early stages has numerous benefits. These end-users of systems were typically adults who used the computer as a work tool, and therefore all methods used for designing and evaluating with the end-user were created for adults. But what happens when the end-user are a child, who are using the software as an education, entertaining or edutainment tool, are there any differences in the way we should conduct evaluations and should the children be incorporated in the design process differently than we would have done with adults. Another aspect is the evaluation

of the system, how should these evaluations be conducted according to the age of the children. Furthermore this Ph.D. project seeks to examine if there are any differences in the different age groups, which contributions are they capable of providing for the design team, during the process, and when should they be involved to maximise their effect on the final product.

Enhancing the Interplay between Software Design and Usability Evaluation

Name: Rune Thaarup Høegh

Education: M.Sc. in Computer Science, Aalborg University, 2003

Duration: February 2005 – August 2007 (expected)

Status: In progress

Funding: Research Grant

Advisor: Jan Stage

The purpose of this Ph. D. project is to examine usability evaluation, and how feedback from the evaluations can be optimized to enhance the interplay between software interaction design and usability evaluation. Feedback from usability evaluations is traditionally presented to the development team in the form of a written report. Initial studies have shown that the report has a varied range of recipients and that the report is associated to advantages and disadvantages as a tool for developers to improve software's usability. This project examines how other forms and styles of feedback can be used to improve the quality and usability of the feedback for the recipients. The project will be founded in theoretical data from a literature study of the current research on usability evaluation, as well as empirical data collected through collaboration with a software development company. The collaboration will consist of observation of the company's development process, and experiments where different forms of feedback are given from usability evaluations. The project is a part of the USE project where other Ph.D. students conduct similar research. A part of the contribution from this project will also be to compare and evaluate results with the other USE project Ph.D. studies, in order to identify strengths and weaknesses in the experimental feedback methods. The project is expected to contribute to a better understanding of how various forms of feedback from usability evaluations can influence the interaction design for software.

The Impact of Sensitive Settings When Evaluating Mobile Systems

Name: Janne Jul Jensen

Education: M.Sc. in Software Engineering, Aalborg University, 2003

Duration: August 2005 – July 2008 (expected)

Status: In progress

Funding: Research Grant

Advisor: Mikael Skov

This project is a part of “The USE-project: Usability Evaluation and Software Design – Bridging the Gap”. The purpose of this project is to explore ways to evaluate a mobile system in its field setting in which a traditional think-aloud evaluation poses problems. This will be done through a close collaboration with a company developing a system for the home healthcare system in Denmark, where a thorough evaluation of their existing product through multiple field tests will lead to redesign suggestions, problems lists and other formats of feedback into the development cycle. The contribution of this Ph.D. project will be a novel approach to evaluating in the field when the common evaluation methods are not appropriate as well as a set of lessons learned on how best to bridge the gap between design and evaluation of home healthcare system through a set of guidelines outlining new ways of representing evaluation results and new ways of incorporating evaluation results into the design process.

7.10 Collaboration

7.10.1 Academic Collaborations

- Mikael B. Skov has visited the Department of Information Systems, The University of Melbourne, Australia in 2004 for a three months period. During this stay, he collaborated with Ass. Professor Steve Howard on interaction design for the context-aware Internet. The stay was financially funded by the Danish Natural Science Research Council (project no. 21-03-0301).

- Jesper Kjeldskov has visited the Department of Information Systems, The University of Melbourne, Australia in 2005 for a four months period. During this stay, he collaborated with Associate Professor Steve Howard on convergent mobile devices and with Ph.D. student Jeni Paay on the evaluation of a context-aware indexical prototype system. The stay was funded by the Danish Technical Research Council (STVF) (project no. 26-03-0341).

- Jesper Kjeldskov has visited the Department of Information Systems, The University of Melbourne, Australia in 2004 for a seven months period. During this stay, he collaborated with a number of local researchers on design and use of context-aware mobile multimedia systems for mediating intimacy. The stay was financially funded by the Danish Technical Research Council (STVF) (project no. 26-04-0026).

- Jesper Kjeldskov has visited the Department of Information Systems, The University of Melbourne, Australia in 2002-03 for a six months period of his Ph.D. studies. During this stay, he set up collaboration with a number

of researchers and Ph.D. students at the Interaction Design Group and initiated and managed the TramMate project on mobile information systems for public transportation.

- Lars Mathiassen has visited Warwick Business School in 2001-2002 for a 10 months period. During his visit he studied the relationship between knowledge management and the use of IT. He worked closely with the IKON group at the business school and took also active part in its outreach research activities. During the same period he also worked closely with Carsten Sørensen at London School of Economics.

- Peter Axel Nielsen has visited the Department of Information Systems, Virginia Commonwealth University for 6 months in 2001. During this stay he worked closely with Ojelanki Ngwenyama on theorizing on the three years of action research on software process improvement. The research focused in particular on explaining empirical data through the lenses of organisational influence processes and organisation culture. The stay was sponsored by the Danish Science Research Council.

- Jan Stage has visited University of Auckland, Department of Management Science and Information Systems, from August 2002 to June 2003. During this stay, he collaborated with Professor Michael Myers on usability evaluation in practice.

- Steve Howard has visited the Department of Computer Science, Aalborg University for 6 months as visiting full professor. During his visit he has collaborated closely with the group's HCI researchers on the topic of interaction design for the domestic space including guest editing a special issue of the journal of personal and ubiquitous computing in collaboration with Mikael B. Skov and Jesper Kjeldskov.

- Ojelanki Ngwenyama has visited the IS group several times during 2003-2005 as a visiting full professor. During his visits he has collaborated with the systems development researchers and given two Ph.D. courses.

- Jeni Paay has visited the Department of Computer Science, Aalborg University for 3+2 months as a part of her Ph.D. studies at the University of Melbourne, Australia. During her visits she has collaborated with Jesper Kjeldskov as a part of the Indexical Interaction Design research project. The two visits have resulted in the development and evaluation of a functional mobile prototype system and a number of conference publications.

- Jan Stage has collaborated with Richard Baskerville (Georgia State University, USA) on adaptation of method elements for use in practical situations.

- Mikael B. Skov and Jan Stage have collaborated with Erik Frøkjær and Kasper Hornbæk (Copenhagen University) on usability evalution.

- Ivan Aaen has collaborated on implementing PBL (Problem-Based Learning) at the Software Engineering and Management programme, Gothenburg IT-University
- Ivan Aaen, Peter Axel Nielsen and Jeremy Rose have co-authored with with Lars Mathiassen and Duane Truex (Georgia State University, USA)
- Jeremy Rose has co-authoring with Rikard Lindgren, Ola Henfridsson (Viktoria Institute, Göteborg).
- Ivan Aaen, Peter Axel Nielsen have co-authored with Ojelanki Ngwenyama (Ryerson University, Toronto, Canada)

7.10.2 Industrial Collaborations

- Astra Zeneca Gothenburg (Lars Mathiassen)
- B-Data (Jesper Kjeldskov, Mikael B. Skov, Jan Stage)
- Danske Bank (Lars Mathiassen)
- Ericsson Gothenburg (Ivan Aaen, Lars Mathiassen)
- ETI, Aalborg (Jesper Kjeldskov, Jan Stage)
- IBM (Jesper Kjeldskov, Mikael B. Skov, Jan Stage)
- Kommunedata (Lars Mathiassen)
- Logimatic Software (Peter Axel Nielsen, Gitte Tjørnehøj)
- NetMill (Jan Stage)
- Novell Pty. Melbourne (Jesper Kjeldskov)
- Rovsing Space (Peter Axel Nielsen)
- Siemens Mobile Telephones (Peter Axel Nielsen, Jan Stage)
- Systematic Software Engineering (Ivan Aaen, Lars Mathiassen)

7.11 Services

7.11.1 Program Commitees

- Agile Development Conference, Salt Lake City, USA, 2003 (Lars Mathiassen)
- ALOIS 2005 (Jeremy Rose)
- ALOIS 2004 (Jeremy Rose)

- ECIS 2003: European Conference on Information Systems, Naples, Italy, 2003 (Ivan Aaen, Lars Mathiassen, Peter Axel Nielsen)
- ECIS 2002: Xth European Conference on Information Systems, Gdansk, Poland, 2002 (Ivan Aaen, Lars Mathiassen, Peter Axel Nielsen)
- ECIS 01: 9th European Conference on Information Systems, Bled, Slovenia, 2001 (Associate Chair) (Lars Mathiassen)
- EMMSAD 2001 (Jan Stage)
- EMMSAD 2003 (Jan Stage)
- Group 2001: ACM 2001 International Conference on Supporting Group Work, Boulder, Colorado, USA, 2001 (Ivan Aaen)
- ICIS 2004: International Conference on Information Systems, Washington, DC, USA, 2004 (Ivan Aaen)
- ICIS 2002: International Conference on Information Systems, Barcelona, Spain, 2002 (Ivan Aaen)
- ICIS 01: International Conference on Information Systems, New Orleans, USA, 2001 (Senior Editor) (Lars Mathiassen)
- IFIP TC8 Working Conference on Mobile Information Systems 2004 and 2005 (Mikael B. Skov)
- IFIP WG 8.6: Business Agility and IT Diffusion, Atlanta, US, 2005 (Ivan Aaen, Peter Axel Nielsen, Lars Mathiassen (Program co-Chair))
- IFIP WG 8.6: Business Agility and IT Diffusion, Atlanta, USA, 2005 (Lars Mathiassen, Ivan Aaen)
- IFIP WG 8.6: IT Innovation for Adaptiveness and Competitive Advantage, Leixlip, Ireland, 2004 (Lars Mathiassen)
- IFIP WG 8.6 2003, Copenhagen (Jeremy Rose, Peter Axel Nielsen)
- IFIP WG 8.6, Sydney Australia, 2002 (Ivan Aaen)
- IFIP WG 8.6 Working Conference on Diffusing Software Product and Process Innovations, Banff, Canada, April 7-10, 2001 (Ivan Aaen)
- IFIP WG 8.2: Relevant Theory and Informed Practice: Looking Forward from a 20 year Perspective on IS Research, Manchester, UK, 2004 (Ivan Aaen, Jeremy Rose, Peter Axel Nielsen, Lars Mathiassen)
- IFIP WG 8.2: Organizational and Social Perspectives on Information Technology, Aalborg, Denmark, 2000 (Lars Mathiassen)

- IFIP WG 8.2: Realigning Research and Practice in IS Development: The Social and Organisational Perspective, Boise, USA, 2001 (Lars Mathiassen)
- IRMA2004:IRMA INTERNATIONAL CONFERENCE: New Orleans Louisiana, USA, 2004 (Ivan Aaen)
- IRMA 2003 (Jeremy Rose)
- MobiMob 2002 (Mikael B. Skov)
- 35. HICSS 2002, Big Island, Hawaii, USA (Ivan Aaen)
- 36. HICSS 2003, Big Island, Hawaii, USA (Peter Axel Nielsen)

7.11.2 Invited Keynotes

- IFIP 8.6 2001: Conference on Diffusing Software Product and Process Innovations, Banff, Canada, 2001 (Lars Mathiassen)
- ROOTS 2001: Recent Object Oriented Symposium, Bergen, Norway, 2001 (Lars Mathiassen)

7.11.3 Editorial Boards

- Journal of Database Management (Peter Axel Nielsen, Jan Stage)
- Information Systems Journal (Lars Mathiassen)
- European Journal of Information Systems EJIS (Lars Mathiassen)
- Systems, Signs and Actions (Jeremy Rose)
- Scandinavian Journal of Information Systems (Lars Mathiassen, Peter Axel Nielsen)
- Information, Technology & People (Lars Mathiassen)
- Information & Organization (Lars Mathiassen)
- MIS Quarterly (Lars Mathiassen, Peter Axel Nielsen) (Associate Editor)
- MIS Quarterly (Lars Mathiassen) (Senior Editor)

7.11.4 Reviewing

Journals

- Communications of the ACM (Jan Stage)
- Database Journal (Ivan Aaen)

- Decision Support Systems (Peter Axel Nielsen)
- European Journal of Information Systems EJIS (Ivan Aaen, Jeremy Rose)
- IEEE Computer (Jan Stage, Peter Axel Nielsen)
- Information Systems and People (Jeremy Rose)
- Information Systems Journal (Jeremy Rose, Peter Axel Nielsen, Ivan Aaen, Jan Stage)
- Information Systems Research (Jeremy Rose)
- Information and Management (Ivan Aaen)
- Information and Software Technology (Jan Stage, Jeremy Rose)
- Information Technology & People (Peter Axel Nielsen)
- Interacting with Computers (Mikael B. Skov, Jesper Kjeldskov)
- International Journal of Human-Computer Interaction (Jesper Kjeldskov, Mikael B. Skov)
- International Journal of Human-Computer Studies (Jan Stage, Jesper Kjeldskov)
- Journal of AIS (Peter Axel Nielsen)
- Journal of Database Management (Peter Axel Nielsen)
- Journal of Electronic Commerce and Organizations (Jeremy Rose)
- Journal of Enterprise Integration Management (Jeremy Rose)
- Journal of Strategic Information Systems (Jeremy Rose)
- Journal of Systems Thinking and Behavioural Science (Jeremy Rose)
- Journal of Usability Studies (Jan Stage)
- Management Information Systems Quarterly (Jan Stage)
- MIS Quarterly (Jeremy Rose, Peter Axel Nielsen, Ivan Aaen)
- Personal and Ubiquitous Computing (Jesper Kjeldskov, Mikael B. Skov)
- Scandinavian Journal of Information Systems (Jeremy Rose, Peter Axel Nielsen, Jan Stage)
- Transactions on Computer-Human Interaction, TOCHI (Jesper Kjeldskov)

Conferences

- ACM CHI (Jesper Kjeldskov, Mikael B. Skov, Jan Stage)
- ACM DIS (Mikael B. Skov, Jan Stage)
- ACM DUX (Jesper Kjeldskov)
- ACM UIST (Jesper Kjeldskov)
- AlOIS (Jeremy Rose)
- AMCIS (Jeremy Rose)
- BSC HCI (Jan Stage)
- CRIS (Jeremy Rose)
- ECIS (Jeremy Rose, Ivan Aaen)
- Group (Ivan Aaen)
- HICSS (Ivan Aaen)
- ICIS (Jeremy Rose, Ivan Aaen, Jan Stage)
- IDC (Mikael B. Skov)
- International Symposium on Collaborative Technologies and Systems (Mikael B. Skov)
- IRIS (Mikael B. Skov, Andreas Munk-Madsen)
- IFIP WG 8.6 (Ivan Aaen)
- IFIP WG 8.2 (Jeremy Rose)
- IFIP TC13 Interact (Jan Stage)
- IRMA (Jeremy Rose, Ivan Aaen)
- ISIS (Jeremy Rose)
- OzCHI (Jesper Kjeldskov, Mikael B. Skov)

7.11.5 Evaluation Commitees

- Research proposal evaluator for the European Union, the Human Potential Programme (Jan Stage)
- Swedish Research Council (Peter Axel Nielsen)
- Committee member, Position of Associate Professor, University of Copenhagen, Department of Computer Science (Jan Stage)
- Committee member, Position of Associate Professor, Copenhagen Business School (Peter Axel Nielsen)
- Committee member, Position of Associate Professor, IT University Gothenburg, Sweden (Peter Axel Nielsen)
- Committee member, Position of Associate Professor, Borås University College, Sweden (Peter Axel Nielsen)
- Committee member, Position of Assistant Professor, Copenhagen Business School (Peter Axel Nielsen)
- Committee member, Ph.D. Evaluation, Daniel May, University of Souther Denmark, 2003 (Peter Axel Nielsen)
- Committee member, Ph.D. Evaluation, Karina Ihlstrom, Gothenberg, 2004 (Jeremy Rose)
- Committee member, Ph.D. Evaluation, Rachel Maclean, Salford, 2005 (Jeremy Rose)
- Committee member, Ph.D. Evaluation, Kari Rönkkö, Blekinge Institute of Technology, 2005 (Ivan Aaen)
- Opponent, Ph.D. Evaluation, Ulrika Snis, Gothenburg, 2002 (Peter Axel Nielsen)
- Opponent, Ph.D. Evaluation, Alistair Cockburn, Oslo, 2003 (Peter Axel Nielsen)
- Opponent, Ph.D. Evaluation, Lars Taxén, Linköping, 2003 (Peter Axel Nielsen)
- Chairman, Ph.D. Evaluation, Hanne Albrechtsen, Aalborg 2003 (Jeremy Rose)
- Chairman, Ph.D. Evaluation, Jan Karlsbjerg, Aalborg 2004 (Jeremy Rose)
- Chairman, Ph.D. Evaluation, Keld Pedersen, Aalborg 2005 (Jeremy Rose)
- Chairman, Ph.D. Evaluation, Mikael Skov, Aalborg 2002 (Peter Axel Nielsen)

- Chairman, Ph.D. Evaluation, Ram Somasundarum, Aalborg 2004 (Peter Axel Nielsen)
- Chairman, Ph.D. Evaluation, Jesper Kjeldskov, Aalborg 2003 (Peter Axel Nielsen)
- Chairman, Ph.D. Evaluation, Helle Damborg Fredriksen, Aalborg 2004 (Peter Axel Nielsen)
- Chairman, Ph.D. Evaluation, Bendik Bygstad, Aalborg 2005 (Ivan Aaen)

7.11.6 Conference Related Services

Panel participation

- ALOIS 2003 (Jeremy Rose)
- IFIP 8.2 2004 (Jeremy Rose)
- ECIS 2003 (Peter Axel Nielsen)
- IFIP 8.6 2003 (Peter Axel Nielsen)
- DUX 2003 “Design for the User Experience in Practice” (Jesper Kjeldskov)
- DUX 2003 “Informing User Experience Design” (Jesper Kjeldskov)

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[7] Jan Damsgaard and K. Lyytinen. The Role of Intermediating Institutions in Diffusion of Electronic Data Interchange (EDI). *Information Society*, 17:195–210, 2001.

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Machine Intelligence 8

8.1 Excecutive Summary

The machine intelligence group performs research and teaching in several areas of artificial intelligence, especially decision support systems, machine learning, and autonomous agents. In all areas the ultimate goal is to extend the scope of intelligent behaviour performed by computers. Intelligent behaviour can manifest itself in a variety of ways, including e.g. autonomous human-like behaviour, or the ability to solve complex problems (e.g. data analysis) with a minimum of direct user intervention. Within these areas the group persues activities that range from very concrete industrial applications to foundational research.

The group specialises in reasoning under uncertainty, and in graphical probabilistic models in particular. In the beginning of the evaluation period the group's research was concentrating on decision support systems. During the period the group has begun to broaden its scope to encompass a wider range of machine intelligence areas. A central goal of the research planning for the next five years is to fully establish the two fields of data mining and autonomous agents as research areas in which the group achieves the same productivity and quality as in its traditional core area of decision support systems and Bayesian networks.

The group is well-established in the international machine intelligence community, and, more specifically, fully integrated into a network of European universities that pursue research in probabilistic graphical models. The group's international recognition is witnessed by the number of publications in major conferences and journals, by the number of international service responsibilities, and by numerous foreign visitors.

8.2 Profile of the Group

The Machine Intelligence group conducts research on intelligent reasoning and decision making under uncertainty, as well as statistical methods for machine learning and data mining.

A common basis for many of the research activities in the group are graphical probabilistic models, especially Bayesian networks and influence diagrams. Such graphical representation languages allow compact representations and efficient inference algorithms for probabilistic and decision theoretic models. Bayesian networks find application in several areas of Artificial Intelligence, and many other

fields inside and outside computer science. They are used, for example, as diagnostic models in technical and medical domains, for modeling genetic relationships in bioinformatics, and for modeling unknown environments in robot navigation.

Building on its expertise in probabilistic graphical models, the Machine Intelligence group pursues research activities in three main areas:

Probabilistic Graphical Models The group's traditional core research area. The research here is concerned with developing efficient design and inference methods for graphical models.

Machine Learning and Data Mining In this area the group investigates statistical methods for learning, especially learning of graphical models, and methods for solving data mining problems like clustering and classification.

Autonomous Agents In this field the group is interested in using graphical models for programming intelligent behavior in autonomous agents. An application area of particular interest is autonomous agents in computer games.

8.3 Research Goals 2001-05

Since the formation of the decision support systems group (now Machine Intelligence Group), its primary goal has been to establish a coherent and open research environment, where collaboration rather than competition is predominant. Substantial cohesive elements have been the weekly workshops, where open-ended problems are presented and discussed, together with the biweekly seminars, where more polished work is presented.

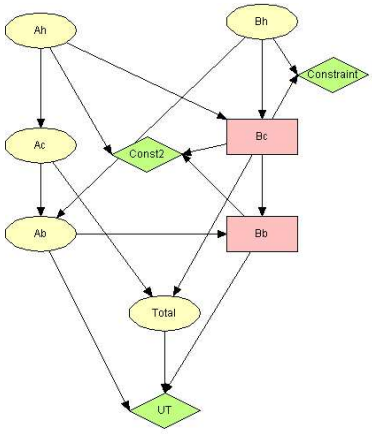
Another main goal has been to be in close contact with other strong research groups within the field of probabilistic graphical models. The group puts much effort into welcoming guests and smoothly integrating them in the group's daily work.

A third general goal has been continuously to be engaged in practical applications in collaboration with experts from the application domain.

For the period 2001-2005 the more specific goals expressed in the previous research evaluation can be summarized as follows:

- to maintain and possibly improve the current productivity, i.e. in raw numbers: two papers per staff year, out of which one in a first class journal (e.g. *Machine Learning Journal*, *Journal of Artificial Intelligence Research*, *IEEE Transactions on Systems, Man, and Cybernetics*) or top conference (e.g. *UAI*, *ECSQARU*);
- to improve industrial contacts;
- to extend contacts to European groups;
- to broaden the scope to areas close to the current research. Data mining, business intelligence, games, multi agent systems were mentioned.

8.4 Activities and Results



Within the period covered by this report, the research in the machine intelligence group was centered on graphical models for probabilistic reasoning and decision making. Our research in this area can be broadly divided into three major parts: extending the scope of traditional graphical models like Bayesian networks and influence diagrams, learning of graphical models, and applications.

Among the work on extensions of existing representation frameworks is our research on unconstrained influence diagrams, which relax the strict ordering constraints on multiple decisions that are required in standard influence diagrams (see also below).Object-oriented and relational Bayesian networks extend the basic Bayesian network language by providing more high-level, adaptable specifications for probabilistic models.

The group has taken up several research activities in the field of learning probabilistic models: equivalence search and the KES algorithm are new techniques for learning Bayesian networks, which perform the learning operations on the basis of statistical equivalence classes of Bayesian networks, rather than individual Bayesian networks. Our work on learning probabilistic decision graphs investigates the relative strengths of two distinct graphical representation languages for probabilistic models.

We have been involved in several application projects. A major collaboration with Hewlett-Packard on automating customer support ended in 2001.

In the review period over 35 journal and 50 conference papers have been published by members of the Machine Intelligence group. The monograph “Bayesian Networks and Decision Graphs” by F.V. Jensen is a widely cited standard reference for Bayesian networks and influence diagrams. It was nominated in 2003 for the DeGroot prize for books in statistical science. Three Ph.D. dissertations were completed in the group, and three international workshops or conferences were organized by the group.

In the following, two main areas of research and results obtained are described in slightly greater detail.

Graphical languages for decision scenarios with multiple decisions

A decision problem is a part of the world together with a set of possible actions, and a decision scenario is a model of the appropriate part of the world together with a specified set of options for actions and observations. The world model is used for simulation of the

effects of the various actions, and the decision scenario is solved when you have established an optimal strategy: a set of rules, which based on the past specify what to do next.
In our set up, the world model is a Bayesian network extended with utility functions, and a strategy is optimal if it maximizes the expected utility.
In a specification language you represent your decision scenario in an unambiguous way. Such a specification language has three aspects: how handy it is to use for specification, the scope of decision scenarios specifiable in the language, and the efficiency of the algorithms for exploiting the specification to come up with a solution.
Traditionally there are two graphical languages for specifying decision scenarios with multiple decisions, decision trees and influence diagrams. Decision trees can represent almost any kind of decision scenario, but as the specification grows exponentially with the number of actions and observations, it is almost impossible to use for specifying scenarios with more than five to six decisions and observations. Influence diagrams on the other hand grow linearly in the number of decisions and observations. However, they have a very limited scope: you need to have a linear temporal ordering of the decisions, and the scenario must be symmetric: which decision to address next is independent of the past.
This project is a continuation of our previous work on influence diagrams. We started off constructing algorithms for investigating influence diagrams. Specifically, we considered methods for sensitivity analysis and methods for analyzing the solution algorithm with respect to decomposition and distribution of independent tasks.
We also constructed an algorithm for learning from a decision maker's apparent inconsistent behavior. This work has the perspective of implementing virtual adaptive agents in the context of multi agent systems: agent A holds a specification of agent B's decision scenario, and therefore A knows what to expect from B. How shall A update its model, if B does something unexpected?
We have put special emphasis on extending the framework of influence diagrams. We have relaxed the linear order constraint (given the past, we may decide for some tests or we may decide for some treatments). The language is called unconstrained influence diagrams (UID), and we have constructed an efficient algorithm for solving UIDs. A strategy for a UID is not only a policy for each decision, but it is also a function which given the past returns the next decision to address.
We have designed a language (Asymmetric Influence Diagrams – AID) for specifying asymmetric decision scenarios (if the girl accepts my invitation, the next thing to decide is the restaurant to go to, if she declines the invitation I have to decide what then to do). We have also integrated the AID and UID languages, and developed an efficient algorithm for solving the specified scenario.
Finally, we have addressed the problem of different types of utilities (pain, health, money), and provided a way of handling influence diagrams with several types of utilities with parameterized linear exchange functions.

Learning probabilistic graphical models

A probabilistic graphical model (PGM) is an abstraction of a part of the world, which is used for e.g. explaining a certain set of observations (i.e., diagnosis), or predicting and simulating the effects of various observations and interventions. These models basically consist of two parts: a graphical part capturing the relations between the entities in the domain being modeled, and a quantitative part describing the strength of the relations. The prevalent PGM is the Bayesian network framework.

One way of constructing a PGM is to manually establish the structure and the numbers by consulting domain experts. Unfortunately, however, this can be a rather cumbersome process. Another approach is to learn the model automatically from a database. Here we assume that the database consists of observations from the domain in question, hence our aim is to establish a model of the process that has generated the data. The prospects of this work is not only to ease the model construction process, but also to provide valuable insight into the problem domain.
Our work builds on existing work within the area of learning Bayesian networks. We have investigated a stochastic learning algorithm that searches for a Bayesian network based on the space of equivalence classes of Bayesian networks. The algorithm has the potential of avoiding some of the suboptimal solutions that standard learning algorithm would produce, and it supports extraction and interpretation of relevant features in the problem domain.
When learning a Bayesian network we obtain a model of the problem domain, where focus is on the independences between entities in the domain. When the domain does not exhibit such independences, then standard Bayesian network learning algorithms may fail to find a good model for the domain. With outset in the so-called probabilistic decision graph (PDG) framework, we have constructed an algorithm for learning models of this type. The advantage of this approach is that PDGs provide an alternative to Bayesian networks by focusing on context specific independence structures, hence, for certain domains, the algorithm has the perspective of producing better models than standard Bayesian network learning algorithms.
Along similar lines, we have also developed a learning algorithm for so-called object oriented Bayesian networks, which were developed for domains with intrinsic object oriented properties. Algorithms for learning these types of models have been constructed, and it has been demonstrated that for these domains the learning algorithm is more efficient than standard learning.
An important applications area for PGMs is clustering and classification. In clustering we try to group related instances, and in classification we try to predict the class an instance belongs to (e.g. based on this person's credit history, will he make his principal payments on time?). With outset in the naïve Bayes models we have constructed an efficient algorithm for learning models aimed at clustering. The naïve Bayes model belongs to a special class of models called hierarchical naïve Bayes models, and for this general class of models we have constructed learning algorithms for both discrete and continuous classification domains. The learned models have shown to provide a classification accuracy that is significantly higher than standard probabilistic classifiers.

8.5 The Group's Own Evaluation

With respect to the three main goals, the group is quite satisfied with its performance. The members of the group find indeed that they are part of a coherent and open research environment with a fruitful spirit of collaboration. This is of course hard for a non-participant to evaluate. However, visitors do repeatedly confirm this point to us.

A closer investigation of the patterns of co-authorship in the group reveals that, apart from student-supervisor papers, three members of the group have the majority of co-authors outside the group, and two members write the majority of their papers together. Furthermore, all members of faculty have joint papers with guests and

with external researchers. Two members co-authors with three other members, two with two, two with one, and one member has no joint papers with other members of the group.

With respect to the second main goal: not only is the group much involved in international academic services, but it has also over the period had many guests. Three well esteemed researchers have chosen to use their sabbatical leave to spend a semester with the group, and five Ph.D. students from European universities have stayed here for a semester. Furthermore, we have had more than fifteen short-time visitors. Several joint publications with our visiting guests have been produced.

With respect to engagement in practical applications, the group has been part of a large project with Hewlett-Packard on troubleshooting (SACSO), it has been a member of a major EU project on management of fresh water resources (MERIT), it has been a member of a Swedish project on control of power plants (Värmforsk), and it has been consulting for a project on automatic control of welding and for a project on handling contaminated soil. Furthermore, we have been in serious contact with eight industrial companies, we are members of three "Forskerkontaktnetværk" (one on data mining and two on computer games), and we are a member of the EU network, APRIL-2, for applying probabilistic inductive logic. The NouHauz network called "Bessnet", and two international workshops on applying graphical models are also part of the group's activities for reaching out to applications.

This being said, we are not completely satisfied with the results of the many contacts. Currently (November 2005), our only externally funded collaboration project is APRIL-2. The group has the policy that all contacts are taken seriously. We take up to two meetings with any external contact to evaluate the potentials before we decide whether to continue the contact. As we are not willing to do consultancy free of charge, we only continue if a project has obvious research potentials on its own, or if a project is externally funded. Most of the contacts, however, did not make it beyond the two meetings. Also, it has happened that both parties had a mutual interest in continuing, but problems with IPR screwed things up.

Looking at the specific goals for 2001-05, we have met all of them to our satisfaction, except the one on improving industrial contacts (as discussed above).

The group has extended its scope to data mining. An associate professor has been appointed, and a couple of Ph.D. projects are addressing aspects of machine learning. We have also started research and education activities in computer games (we are part of the Danish Academy for Digital Interactive Entertainment), and we have started Ph.D. projects and internal research activities on autonomous agents.

The group has faced problems with under-staffing, and we have tried to attract researchers all over the world. In the beginning of the period we were pretty successful, but with the booming interest in graphical probabilistic models it seems to get increasingly difficult. There are more high class research groups in the world than five years ago, and maybe a small town in a small country with a strange language are not sufficiently attractive?

8.6 Research Plan 2006-2010

8.6.1 General Goals

Currently the group is internationally recognized in the field of probabilistic graphical models. Our main goal for the next five years is to broaden the scope of the group's research profile, and to establish the group also in the areas of data mining and autonomous agents. At the same time, the group strives to maintain its inner coherency by centering the research in all areas around the common reference point of probabilistic models of uncertainty. This goal is also reflected by the organizational structure of the group, where regular internal workshops and seminars are used to ensure communication and collaboration within the group.

Apart from basic research the group aims to work on applications, either on other areas of scientific research, or in an industrial context. We want to maintain the current high number of contacts with other European and non-European research groups and industrial partners, and try to extend some of these contacts to more formal collaborations (e.g. European academic networks).

The recognition and impact achieved by the research group will be measured, in part, by standard metrics, such as number of publications and citations, or invited talks. In all areas, we aim at a productivity and quality that manifests itself in at least two publications per group member and year, at least one of which in a major conference or journal. Another indication for the group's impact is the number of foreign visitors it receives. Prototypical implementations can also be a means of propagating research results and creating impact. Apart from purely academic impact, the group also aims to make an impact by knowledge transfer to industry, and by collaborations with industrial partners.

8.6.2 Research Plans in Main Areas

Probabilistic Graphical Models

The area of probabilistic graphical models has been the core research area of the group since it was formed. Within this broad area, the group has begun work in three specific research directions that also constitute the directions that will be pursued in the coming period:

- decision graphs,
- multi-agent decision making, and
- learning graphical models.

The standard frameworks for representing decision problems have a rather narrow scope w.r.t. the class of decision problems that can be represented efficiently. As a result, the group has been involved in the development (in collaboration with other partners) of several new frameworks. Up until now, the main focus of the these frameworks has been on the modeling languages, which, to some extent, has

been at the expense of the solution algorithms. Specifically, the more expressive power has come at the cost of high computational complexity. In order for these frameworks to be more widely accepted and applied, this part needs to be developed further and possibly supplemented with prototypical implementations. The additional development will aim in two directions. First of all, we will consider efficient algorithms for calculating exact solutions, and, secondly, we will look for approximate and anytime algorithms for solving the models.

The traditional approach to modeling a decision problem with several decision makers has been to consider it from a monolithic perspective, where the decision makers have either been assumed to e.g. have identical preferences and beliefs (in effect, they can be considered as a single decision maker), or it has been assumed that they have an agreed-upon protocol for coordinating their actions. However, both of these two approaches endow the decision makers with capabilities that are not necessarily reflected in the decision problem. An alternative and more general course of action is to explicitly consider each of the decision makers as an agent with its own capabilities, desires and beliefs. As a result we are dealing with a multi-agent decision problems, where the agents (inter)act and coordinate with other agents. Taking the normative perspective, this means that the agents should maximize their own expected utilities based on (among other things) models of the other agents. This involves developing models for how the agents interact as well as methods that will allow the agents to learn/adapt models (both probabilities and utilities) of the other agents based on their observed behavior.

Learning of graphical models has been an active research area over the last decade, and it has been one of the group's research interests during the last five years. This research direction will also be pursued in the next period, but where we previously considered learning general models we plan to focus on learning models for specific tasks such as classification and clustering. More specifically, we will focus on learning algorithms, where the model search is guided by a score function that e.g. reflects the classification/clustering properties of the model rather than the model's general properties.

The group is already well-established within the international research community related to the area of learning graphical models. Specifically, we are involved in a European workshop series on probabilistic graphical models (PGM) and we are also involved in the organization of a bi-annual European conference on reasoning with uncertainty (ECSQARU). We plan to maintain and possibly extend our current contacts, and together with other European research groups we are currently involved in the construction of a European academic network for probabilistic graphical models.

In addition to basic research activities we have several contacts with industrial partners, and as an annual event we are organizing a workshop on applying probabilistic graphical models where one of the aims is to bring industry/practitioners and researchers together. So far, however, it has proved difficult to extend the contacts into more formal projects, but we will continue to pursue and explore the possibilities for such collaborations.

Data Mining

Building on our existing expertise in probabilistic models for relational domains, the main focus of our developing data mining research activities will be on relational data mining. This area has seen a rapid growth over the last three years, and there exists a large diversity of approaches to learning from relational data. Most of these approaches are based on existing learning methods from inductive logic programming and Bayesian network learning. We intend to develop and investigate data mining techniques for relational data from first principles. We hope to identify basic statistical and algorithmic principles and techniques, that address the inherent structural properties of relational data more directly than currently existing techniques. Our research will be both theoretical and practical: on the theoretical side, our results should provide a theoretical foundation for the analysis of relational learning problems, and the various approaches to their solution. On the practical side, we intend to extend our existing *Primula* system with implementations of prototypical learning methods.

With regard to applications (both for relational and possibly other techniques), our research will mostly focus on bioinformatics.

Through the participation in the European April-2 project, the group is well-integrated in the international research community for relational data mining. We hope to maintain and extend the existing contacts, with a view to participating in possible follow-up projects.

Apart from working in purely academic research and application domains, the group has in the past also had many contacts with companies that presented us some data analysis problem. In most cases, these contacts only developed to a stage where we consulted with the companies on how to apply standard machine learning techniques to their problem. While, thus, it has proven difficult to establish collaborations with industry on topics that are closely connected with our scientific research, we will continue to explore the possibilities of collaborations with industry, especially with a view towards co-sponsored Ph.D. projects.

Autonomous Agents and Computer Games

The area of autonomous agents and computer games is a rather new research area for the group. Within this broad area the group plans to work in four specific research directions that will be pursued in the coming period:

- A general framework for autonomous agents.
- Online learning.
- Automatic generation of interesting interactive stories.
- Believable and varied dialog in computer games.

We will focus on the development of a general framework for implementation of autonomous agents. More specifically the aim will be to develop a modeling language for specifying agents i.e., their perceptions, beliefs, intentions and behavior. In analogy to our work in probabilistic graphical models a possible solution is to represent an agent's belief with a Bayesian network or an influence diagram. One problem which arises is when agents have to reason about other agents. This may end in an endless reasoning which historically has been approached from a game-theoretic point of view. However, we wish to use bounded rationality in the specification of agents and to apply it in the underlying calculations of strategies. Furthermore, efficient algorithms must be developed, which can perform calculations on these new models.

Another goal is to develop efficient learning techniques which are suitable for autonomous agents in computer games. Our framework, based on graphical models, is used as our representation language of an agent. As opposed to our research in data mining the learning must be done using an online technique. In general the technique must be able to learn reasonable models from relatively few observations. With respect to computational efficiency there is generally very little time available for agent learning in games. Therefore the efficiency of the learning algorithm has high priority.

Narration and interaction are often viewed as contrary properties in computer games. Games with a high degree of interaction fail to provide a coherent narration and the player's interaction seldom has any direct impact on the narrative. Games with a high degree of narration often tells a linear story similar to books or movies with little room for the player to interact. The main idea is that the narrative is not fixed from the beginning but instead constructed as the game progresses based on the player's interaction. The standard frameworks for creating interactive stories neither ensures that the stories generated are interesting nor that they have a meaningful ending. As a result the group is involved in the development of a framework addressing these issues.

In computer games, dialog between the player and computer controlled characters are very shallow and fixed. This often means that whenever a specific character is encountered, the dialog is reduced to the player trying to find the right path in the dialog tree. Once this is found, the rest of the dialog tree will not be used in new games, as the player already knows how to respond to the computer controlled character. The group is involved in creating a framework for specification of dynamic dialogs where the player's previous interactions with both the computer controlled characters participating in the dialog and the player's other interaction with the game has an impact on how the dialog flows. The computer controlled character will have a personality which governs the interaction and it is important that the dialog is not identical between two games, even if the two games have been played identically.

The group is in contact with several institutions in the context of educating students for the computer game industry. These contacts have already resulted in two ongoing collaborative research projects. We will try to explore these contacts for

further research projects. The main body of the Danish computer game companies are situated in Copenhagen, and we have found it difficult to establish collaboration with them. By our research activities we hope to facilitate the establishment of spin-off companies in the north Jutland region, and help to build up a local computer game industry. To this end, the group has already been active in the creation of the researcher contact network ComITop and Dreamgames. Dreamgames was established by Aalborg Erhvervsråd (Aalborg Business Council), and is a network for entrepreneurs in the field of computer games.

8.6.3 Funding

In order to achieve our research goals, the group will have to procure external funding for additional Ph.D. students and post-docs. External funding is needed to enable us to offer foreign researchers post-doctoral research positions that are competitive in the international market. We also aim to increase the number of Ph.D. students in the group. In the past we were sometimes unable to offer promising young graduates (cand. scient.) a Ph.D. grant, and their research talent may or may not flourish elsewhere. An increased recruitment of post-docs and Ph.D. students is also a measure that is needed to alleviate potential problems with filling future vacant faculty positions in the group.

In the past it has proven very difficult to obtain funding from the Danish national research councils. In the future we will therefore try to obtain funding through European projects and through industrial projects. In light of the good integration of the group in the European research community it seems feasible to establish research projects on a European level. In our diverse industrial contacts, mostly with Danish companies, we will pursue more aggressively the possibility of having Ph.D. students co-funded by industry, university and government.

8.6.4 Staffing

The group is currently understaffed with regard to its teaching obligations. To alleviate this problem, the group aims at attracting both temporary and permanent staff members so that the teaching capacity will match the teaching load. The plan of recruitment should not only accommodate the teaching requirements, but also facilitate a continuing expansion of the group's research activities. First of all, within each research area the group should obtain the critical mass required to achieve the specific research goals as set out for the area. Secondly, the number of staff members associated with the two new research areas (data mining and autonomous agents in computer games) should reach a level, where the group can consolidate itself within these areas and establish a research profile at an international level. By the end of the five year period the group aims at having an equal distribution of staff members within each of the three research areas.

Appendices 8

8.7 Detailed Description of Activities and Results

8.7.1 Funded Projects

HP Lab. for Normative Systems (1998-2003)

Scientist in charge: Finn V. Jensen

Participants: All researchers of the group.

The laboratory existed in the period 1998-2003. It was an umbrella for funding the research acitivities in the group. In the period 2001-03 it received a total of 3.25 mill. kr., partly from Hewlett-Packard and partly from Erhvervsministeriet.

SACSO (1997-2001)

Scientist in charge: Uffe Kjærullf

Funding: The AAU part of the project was in 2001 funded by Hewlett-Packard with 0.5 mill. kr.

The SACSO project was a collaborative research and development effort between our research group and Hewlett-Packard (HP). The project was funded jointly by HP and the Danish National Centre for IT Research (CIT).

The aim of the project was development of systems for automated customer support operations (SACSO) through the use of decision-theoretic methodologies. The overall aim of the SACSO project was to establish a proof of concept for the application of Bayesian network technology in the area of troubleshooting electro-mechanical systems, specifically networked printer systems.

The research and development was carried out in a collaboration involving a combination of 3 full-time and 2-3 part-time researchers from the group and 1-2 full-time and 3-5 part-time research and development engineers of HP.

On the scientific side, methods and algorithms were developed for generic interactive troubleshooting guiding the user to carry out cost effective troubleshooting sequences as well as methods and algorithms for validation and maintenance of troubleshooters, including methods for manual as well as automatic adaptation of model structure, probabilities, and costs. The research activities of the project resulted in 4 patents, 17 reviewed scientific papers, 11 technical reports, 10 working papers, and 13 presentations.

On the deployment side, systems for interactive construction and execution of decision-theoretic troubleshooting models were created, and complete troubleshooting models for four HP high-end laser printers were developed. As a spin-off of the SACSO project, Dezide ApS was founded in 2001 by former employees of Hewlett-Packard R& D. Dezide develops and sells innovative software for support of complex problem solving, primarily focusing on automation of customer service in telecommunication businesses, ISPs, and mobile operators.

MERIT

Scientist in charge: Finn V. Jensen (AAU part)

Funding: 1.2 mill. kr for AAU.

Participating organizations: Geological Survey of Denmark and Greenland (Copenhagen, Denmark), Institute of Hydrology (Wallingford, UK), Politecnico di Milano (Italy), Regione Abruzzo (L'Aquila, Italy), Sperimentale Italiano Giacinto (Milano, Italy), University of Castilla La Mancha (Albacete, Spain), University of Birmingham (UK) and Aalborg University (Denmark).

The project, Management of the Environment and Resources using Integrated Technologies (MERIT), was an ESPRIT project that started in 2001 and ended in 2004. The aim of the project was to generate a highly adaptable, integrated water resource assessment and management tool that can be applied at the catchment and aquifer unit scale throughout Europe. It uses Bayesian networks as the basic framework ([57], And [5]).

Värmforsk

Scientist in charge: Finn V. Jensen

Funding: 150.000 DKK for AAU.

Together with Mälerdalens Högskola, Västerås, Sweden, The Machine Intelligence Group was part of the project "Värmforsk" (2003-04). Together with ELSAM we had a project on establishing a monitoring system giving early warnings when a production plant may be heading into serious production disturbances. A special property of this domain type is that there is (usually) a lack of both knowledge and data concerning possible faults, and it is therefore infeasible to learn/construct a standard classification model for doing fault detection. As an alternative, fault detection can be based on a model of normal system operation only. This means that it does not rely on information about the possible faults, and discrepancies between sensor readings and the model are then taken as an indication of a possible fault [78].

8.7.2 Unfunded projects

Medical Decision Support Systems

Medical problems are characterized by inherent uncertainty in most tasks in the domain, making medical decision problems prototypical for graphical models. The group is primarily focusing on methodological issues involved in medical decision making, with outset in specific problems. The activities in the period has taken outset in the MUNIN system for diagnosis of neuromuscular disorders and activities has been initiated in problems in the diagnosis of Lyme disease.

The challenges in the MUNIN system is how to deal with complexity issues in large models. This has lead to new proposals for methods for diagnosing multiple disorders [33] and for modularization of inference [29]. Modeling aspects has also been considered in order to improve the diagnostic performance [42] and to ease specification and maintenance of large models [47].

Lyme disease is an infection evolving over time and the challenge in this domain is to capture the temporal aspects in the model and make use of it in the diagnosis of the disease [56].

Modularization of complex tasks

Divide and conquer techniques are widespread in computer science, but have not been explored thoroughly in graphical models. A method for splitting up a Bayesian network into components that can be treated independently with respect to many of the common operations has been constructed [30]. This method forms the foundation for various tasks such as distributed triangulation and hybrid inference. Special emphasis has been directed towards the development of algorithms for incremental compilation [53, 54].

Relational and Object-Oriented Bayesian Networks

Large and complex Bayesian networks are usually hard to design. Once designed, a Bayesian network may need to be adapted to changes in the domain it represents. We investigate several approaches to facilitating design and maintenance of Bayesian networks.

Several frameworks have been proposed in the past that ease the specification of Bayesian networks using object oriented ideas. The group has been working with so-called object oriented Bayesian networks, and has proposed a framework that supports a top-down modeling approach.Moreover, we have proposed methods that exploits the characteristics of object oriented domains when learning the parameters [17] as well as the structure of a network [46].

Adaptability is a central concern addressed by the language of *relational Bayesian networks*, which we develop, investigate and implement. Relational Bayesian networks are a logic-based representation language for high-level, adaptable probabilistic models. These generic models can be instantiated over concrete domains,

which leads to a domain-specific model that can then be represented by a Bayesian network. A simple example of this two-level modeling approach is a general model of (genetic) inheritance, which can be instantiated over any concrete domain consisting of members of a given pedigree. The Bayesian networks for the domain-specific models often become quickly intractable for inference with increasing size of the domain. As an alternative to Bayesian networks we have investigated *arithmetic circuits* as a computational data structure for probabilistic inference in domain-specific models [8]. Empirical results show that in typical examples we can handle with arithmetic circuits domains that are about 2-3 times as large as the largest domains amenable to inference with Bayesian networks.

The language of relational Bayesian networks is implemented in the *Primula* system [97]. Key components of *Primula* are a constructor for standard Bayesian networks from a relational Bayesian network and a concrete input domain, and an importance sampling algorithm for approximate inference for model instances not amenable to exact inference.

Probabilistic Decision Graphs

Probabilistic Decision Graphs (PDGs) combine elements of probabilistic graphical models and ordered binary decision diagrams (OBDDs). PDGs were first proposed by M. Bozga and O. Maler in the context of probabilistic verification. We have introduced a slightly generalized version of PDGs, and investigated their properties from a reasoning under uncertainty point of view [9]. Special focus of this work is a comparison with Bayesian networks with regard to efficiency of probabilistic inference, and with regard to the probabilistic independence models that can be represented by the graphical structures in the two frameworks. The results show that PDGs and Bayesian networks represent different kinds of independence structures: whereas independence structures encoded by Bayesian networks are given in terms of subsets of random variables, the independence structures encoded by PDGs are given in terms of partitions of the state space. For probability distributions exhibiting the latter type of independence patterns, one can obtain significantly more efficient representations (with regard to complexity of probabilistic inference) with PDGs than with Bayesian networks.

We also have developed and implemented a learning algorithm for PDGs [59, 14]. We have conducted experiments in which both PDG and Bayesian network models were learned from real-life data sets. Goal of the experiments was to determine whether for some types of data the learning algorithms for the two frameworks would produce models with significantly different inference complexity. Somewhat surprisingly, the results showed that the learned models in the two representation languages exhibited quite similar complexity characteristics.

Incomplete Data and Ignorability

Most data sets encountered in machine learning and data mining mining are incomplete: not all data records contain the values of each of the data attributes. Most common statistical and machine learning techniques will only provide useful results on incomplete data when the mechanism that causes certain attribute values to be unobserved is *ignorable*, i.e., it needs not be represented explicitly in the statistical model for the data. The standard way of obtaining ignorability is via the *missing at random* assumption. We have conducted an in-depth study of the connection between the missing at random (and similar) assumption, ignorability, and explicit procedural models for mechanisms that cause missing data [10, 13]. One result we obtained shows that the standard argument used to infer ignorability from the missing at random assumption is incomplete, and suitable additional assumptions on the data generating process may need to be made in order to establish ignorability. We also have characterized natural types of random mechanisms that will lead to missing at random data. These results provide some natural criteria by which one can evaluate whether the missing at random assumption is appropriate for a given data set.

Extending the scope of graphical models

The influence diagram framework serves as a powerful modeling language for decision problems with a single decision maker. However, efficient use of the influence diagram framework imposes some rather severe structural constraints on the decision problem being modeled. For instance, a linear temporal ordering of the decisions is required in order to ensure that the decision problem is well-defined, and the decision problem should furthermore be symmetric (e.g., future decision options may not depend on past decisions and observations). The focus of this project is the development of graphical models and algorithms for extending the class of decision problems that can be modeled and solved efficiently. For instance, Nielsen and Jensen (1999) relax the requirement of a linear ordering of the decisions by giving a set of necessary and sufficient structural constraints ensuring that an influence diagram, with only a partial ordering of the decisions, is well-defined. Alternative, [64] suggest that one might take outset in a partial specification of the influence diagram (well-defined or not), and then determine a good sequence for the decisions during the solution phase. Along similar lines, graphical specification languages for representing so-called asymmetric decision problems are proposed in [28, 16]. The specification languages are much more compact than decision trees, and the solution algorithms are substantially faster than the algorithm for solving decision trees. Also, [73] presents an adjusted representation of influence diagrams to exploit deterministic relations.

Learning Bayesian networks

This project is about learning graphical models from data. Besides the general problem of learning a model [46, 19], the group focuses on learning models for two particular subtasks within this domain, namely data clustering and data classification. In data clustering we are given data in the form of a set of instances with an (unknown) underlying group-structure, and the task is then to find the best description of this group-structure according to a certain criterion. Among the different definitions, interpretations, and expectations that the term data clustering gives rise to, we focus on a probabilistic or model-based approach to data clustering rather than on a partitional approach. In the related field of data classification, we have information about the group structure for a set of instances, and the task is then to learn a model for predicting the group membership for future instances [41, 21, 20].

Elvira

The Elvira project concerns the development of the software tool Elvira (Elvira is the ancient name of Granada) for constructing model based decision support systems through the specification of Bayesian networks and influence diagrams. The development of Elvira was initiated in August of 1997, and started as a joint project with four universities as partners: University of Granada, University of the Basque country, National University of Distance Education and the University of Almería. Currently, the University of Castilla-La Mancha is also taking part as partner, and collaboration has recently been initiated with this research group of decision support systems as well as some private companies.

Further information about Elvira can be found at http://leo.ugr.es/elvira.

Decision analysis

This project deals with the development of methods for assisting a decision analyst in establishing a model for some problem domain. For example, when modeling a decision problem it can be advantageous for the decision analyst to be able to identify and focus on local parts of the problem rather than working with the decision problem as a whole. One way of achieving this is to identify the set of variables which is relevant for a particular decision variable, i.e., the set of variables that may potentially influence that decision [76, 24]. This analysis could then be supplemented with an analysis of how sensitive the model is to variations in the utility and probability parameters [27]; if the model is particular sensitive w.r.t. a certain parameter, then the analyst can focus on this parameter during the elicitation process.

Equivalence Search in Learning Bayesian Networks

This project focuses on model-selection algorithms for learning Bayesian networks. The impact that the search space connectivity has on the result is investigated in some detail and general guidelines for defining efficient neighborhoods that allows optimality are developed [6]. These guidelines are formulated in terms of local transformations on DAG Markov models, and are therefor directly applicable to many model-selection algorithms that define their neighborhood by local transformations. The quality of these guidelines has been demonstrated in the development of a stochastic equivalence search (SES) algorithm and the k-greedy equivalence search (KES) algorithm[74].

Animated Computer Games

Since the beginning of the fall of 2001 the group has been engaged in research related to animated computer games. The focus of the group's research is variations in computer games. Usually variations are built into computer games through (hard-wired) diversity, e.g. simple randomness. But variations can, for instance, also be achieved by having the agents adapt to different situations based on past experience. This is, however, not a traditional optimization problem, since if the agent is (almost) always successful, there is no suspense. Similarly, if the optimal strategy is easy to find for the player, the game looses interest.

8.8 Organization and Staff

Staff overview:

Olav Bangsø	assistant professor	August 2002-
Manfred Jaeger	associate professor	August 2003-
Finn Verner Jensen	professor	1998-
Uffe Kjærulff	associate professor	1997-
		(on leave 2001-2004)
Kristian Grønborg Olesen	associate professor	1999-
Thomas Dyhre Nielsen	associate professor	September 2003 -
	assistant professor	August 2001 - August 2003
Tomas Kocka	assistant professor	October 2001-June 2003
Helge Langseth	assistant professor	2001- August 2002
José Peña	assistant professor	August 2001- June 2003
Jiri Vomlel	assistant professor	2001- June 2002
Marta Vomlelova	assistant professor	2001-June 2002

Current PhD students:

Nicolaj Søndberg-Madsen	2005-
Jens Dalgaard Nielsen	2003-
Søren Holbech Nielsen	2003-

Graduated PhD students:

Olav Bangsø	graduated 2004
Gytis Karciauskas	graduated 2005
Thomas Dyhre Nielsen	graduated 2001

8.8.0 Olav Bangsø

Academic Degrees

2004	Ph.D. in Computer Science, Aalborg University
1998	Cand.scient. (M.Sc.) in Computer Science, Aalborg University
1996	B.Sc. in Mathematics and Computer Science, Aalborg University

Positions

2002–	Assistant Professor, Aalborg University,
1999–2002	Ph.D. Student, Aalborg University
1998–1999	Research Assistant, Aalborg University

Key publications

[17, 43, 94]

8.8.0 Manfred Jaeger

Academic Degrees

2002	Habilitation in Computer Science, University Saarbrücken, Germany
1995	Ph.D. in Computer Science, University Saarbrücken, Germany
1991	Diploma in Mathematics, Freiburg University, Germany

Positions

2003–	Associate Professor, Aalborg University, Department of Computer Science
1997–2003	Research associate, Max-Planck-Institute for Computer Science, Saarbrücken, Germany
1996–1997	Postdoctoral research affiliate, Stanford University, U.S.
1995–1996	Research associate, Max-Planck-Institute for Computer Science, Saarbrücken, Germany
1992–1995	Ph.D. Student, Max-Planck-Institute for Computer Science, Saarbrücken, Germany

Key publications

[10, 12, 9]

8.8.0 Finn Verner Jensen

Academic Degrees

2004	Dr. Techn. in Computer Science, Aalborg University
1974	Dr. Math. in Mathematical Logic, University of Warsaw
1970	Cand. Scient. Aarhus University

Positions

2001–2004	Chairman for the Aalborg University Board for Patents and Contracts
1998–	Professor, Aalborg University, Department of Computer Science
1989–1998	Reader, Aalborg University
1986–1989	Project Manager, Judex lmtd.
1974–1986	Associate professor, Aalborg University

Key publications in the period

[15, 1, 64, 28, 16]

8.8.0 Uffe Kjærulff

Academic Degrees

1993	Ph.D. in Computer Science, Aalborg University
1985	cand. polyt. (M.EE.), Aalborg University

Positions

2005–	Head of School of Science, Aalborg University
2001–2004	Chief Technology Consultant, Hugin Expert A/S, Aalborg
1997–	Associate Professor (lektor), Aalborg University
1996–1997	Assistant Professor (adjunkt), Aalborg University
1995–1996	Research Fellow (forskningsadjunkt), Aalborg University
1994–1995	Assistant Professor (adjunkt), Aalborg University
1993–1994	Research Assistant Aalborg University
1990–1993	Ph.D. student, Aalborg University
1989–1990	Ph.D. student, Judex Datasystemer A/S
1985–1989	Research Engineer, Judex Datasystemer A/S, Aalborg
1985–1985	Research Engineer, Nordjysk Udviklings Center

Key publications

[15, 67, 7]

8.8.0 Nicolaj Søndberg-Madsen

Academic Degrees

2004	Cand.scient. (M.Sc.) in Computer Science, University of Aalborg

Positions

2005–	PhD. student, Aalborg University, Department of Computer Science
2004–2005	Research Assistant, Aalborg University, Department of Computer Science

Key publications

[83]

8.8.0 Jens Dalgaard Nielsen

Academic Degrees

2002	Cand.scient. (M.Sc.) in Computer Science, Aalborg University

Positions

2003–	PhD. student, Aalborg University, Department of Computer Science
2002–2003	Research Assistant, Aalborg University, Department of Computer Science

Key publications

[74, 82, 59]

8.8.0 Thomas D. Nielsen

Academic Degrees

2001	Ph.D. in Computer Science, Aalborg University
1998	Cand.scient. (M.Sc.) in Computer Science, Aalborg University
1996	B.Sc. in Mathematics and Computer Science, Aalborg University

Positions

2003–	Associate Professor, Aalborg University,
2001–2003	Assistant Professor, Aalborg University,
1998–2001	Ph.D. Student, Aalborg University

Key publications

[19, 25, 28, 16]

8.8.0 Søren Holbech Nielsen

Academic Degrees

2003	Cand.scient. (M.Sc.) in Computer Science, University of Aalborg

Positions

2003–	Ph.D. Student, University of Aalborg

Key publications

[75]

8.8.0 Kristian G. Olesen

Academic Degrees

1992	Ph.D. in Computer Science, Aalborg University
1985	Cand.scient. (M.Sc.) in Computer Science and Mathematics, Aalborg University

Positions

2000–2005	Head of School of Science, Aalborg University
1999–	Associate professor, Aalborg University, Department of Computer Science
1995–1999	Associate professor, Aalborg University, Department of Medical Informatics
1991–1995	Assistant professor, Aalborg University, Department of Medical Informatics
1990–1991	Research assistant, Aalborg University, Department of Medical Informatics
1988–1989	Project Manager, Nordjysk Udviklingscenter, Aalborg
1986–1988	Ph.D. student, Aalborg University, Department of Computer Science
1985–1986	Teaching assistant, Aalborg University, Department of Computer Science

Key publications

[79, 30, 29, 53]

8.9 Ph.D. Projects

8.9.1 Project Descriptions

Object Oriented Bayesian Networks

Name: Olav Bangsø

Education: Cand. scient. (M.Sc.) in Computer Science, 1998

Duration: August 1999 – August 2004

Status: Completed

Funding: This research was supported by the HP Laboratory for Normative Systems

Advisor: Uffe Kjærulff

The framework of Bayesian Networks (BNs) is a popular framework for representing knowledge of domains with inherent uncertainty. A Bayesian network (BN) is a compact representation of a domain capturing the interaction among uncertain entities (random variables). A BN consists of two parts; a qualitative part (a graph) and a quantitative part (the joint probability distribution over the nodes in the graph). The task of constructing a BN representing a domain can be a very time consuming process, and there is a strong need for tools supporting decomposition and top-down construction. In programming languages, object oriented

methods have met this need, and they facilitate an intuitive way of representing entities along with a class hierarchy.

In this dissertation we propose a framework for constructing object oriented BN models. This framework is inspired by the object oriented programming language paradigm, and facilitates hierarchical and modular construction of BNs. An object consists of a BN fragment with a set of *internal variables*, and a set of *interface variables* encapsulating the internal variables. All communication with other objects is formulated in terms of probability statements on interface variables.

We extend this communication constraint to belief propagation. That is, the triangulation is constrained such that each separator in the junction tree is a set of variables from the same object. This constrained triangulation method supports what we call *plug and play* for object oriented Bayesian networks: when you add, remove or modify an object, the resulting changes of the junction tree are easily identified.

A nice feature of object oriented specification is that multiple instances of identical BN fragments are precisely identified through a class regime. We exploit this in methods for structural as well as parameter learning.

Learning with Hidden Variables

Name: Gytis Karčiauskas

Education: Cand. scient. (M.Sc.) in Computer Science

Duration: August 2002 – July 2005

Status: Completed

Funding: Departmental Stipend

Advisor: Finn V. Jensen

One challenge in learning Bayesian networks is the identification of hidden, unobserved variables, and their integration into the model. Induced hidden variables can greatly simplify the generated model, and thereby make it both more efficient for probabilistic inference, and enhance its explanatory value for causal dependencies in the domain. In this project the focus is on latent class (LC) and hierarchical latent class (HLC) models. In these models the structure of the network with the hidden variables is assumed as given, and the main problem becomes that of identifying the correct number of states of the hidden variable.

Learning LC or HLC models requires repeated estimation of parameters for models with latent variables of different cardinalities. Each estimation requires iterative procedures like the EM algorithm. Since EM is not guaranteed to produce optimal parameters, multiple restarts of this time consuming procedure may be necessary. In this project the reuse of parameters for initialization of the EM algorithm is investigated. The basic idea is that optimal parameters for a LC model with a latent variable of cardinality $k + 1$ will be somewhat similar to optimal parameters for a model with cardinality k. This suggests to perform the search over

different cardinalities by incrementing or decrementing the cardinality of a previous model by 1, and to compute an initial parameter estimate of the model with the new cardinality from the estimated parameters for the previous model. This basic idea has been turned into a working learning procedure by defining *split* and *merge* operations, which perform the necessary parameter transformations from one cardinality to the next.

This project investigates both theoretical and practical aspect of the parameter reusing approach using the split and merge operations. In the theoretical analysis conditions are identified under which these operations are guaranteed to enable the construction of models with higher likelihood scores, given that the current model is not yet optimal. In practical experiments the performance of the new approach is compared to similar procedures without parameter reuse. The results indicate that parameter reuse leads both to faster learning, and to higher scoring final models.

Reasoning and Rational Decision making under uncertainty in Multiagent Systems

Name: Nicolaj Søndberg-Madsen

Education: Cand. scient. (M.Sc.) in Computer Science, 2004

Duration: August 2005 – July 2008

Status: In progress

Funding: The Faculty of Engineering and Science, Aalborg University

Advisor: Finn V. Jensen

When reasoning in multi-agent systems in a partially observable world agents must reason under uncertainty. Influence Diagrams are well suited for modeling beliefs about an uncertain environment and to find the optimal solution. However, the Influence Diagram framework assumes one single decision maker. Therefore a framework is desired which allows reasoning with uncertainty with multiple decision makers and in which the decision makers may have a common or a conflicting goal.

Rational decisions have often been addressed from a game-theoretic point of view. Often a search for an optimal strategy reduces to the search for a Nash Equilibrium. However, there are obstacles that render this method infeasible. Agents have belief about the environment they operate in, but they also have belief about other agents as a part of the environment. Moreover, as a part of its belief it has beliefs about other agent's beliefs. When reasoning an agent will eventually reason endlessly. For instance: "I know that you know that I know that you know...". This is solved by establishing Nash Equilibria. However, they assume unbounded rationality. Humans do not have that and the thesis address the problem from the perspective of bounded rationality.

The aim is to develop a general framework for implementing multi-agent systems. A new modeling language should provide the ability to express agent's beliefs, perceptions, intentions and behavior. Efficient decision-theoretic algorithms must be developed for the framework which should be based on bounded rationality. Finally, a generic virtual world is developed for specifying and testing multi-agent systems.

Graphical models for partially sequential decision problems

Name: Thomas D. Nielsen

Education: Cand. scient. (M.Sc.) in Computer Science, 1998

Duration: August 1998 – July2001

Status: Completed

Funding: CIT project number 87.2 - "Automated Decision Support for Customer Support Operations - Phase 2"

Advisor: Finn V. Jensen

Influence diagrams serve as a powerful modeling language for symmetric decision problems with a single decision maker having a linear temporal order over the decision variables. In this thesis we deal with partial influence diagrams, i.e., influence diagrams with only a partial temporal ordering specified. We present a set of conditions which are necessary and sufficient to ensure that a partial influence diagram is well-defined. As a generalization of the partial influence diagram, we propose another framework, termed asymmetric influence diagrams, for representing and solving asymmetric decision problems (these types of decision problems cannot be represented efficiently in the influence diagram framework).

The fact that a linear ordering of the decisions is not always required, is also an indication that not all variables necessarily influence a particular decision variable. For both communicational as well as computational reasons it is important to identify such types of irrelevance. For instance, by identifying the parts that are relevant for a certain decision we can focus our efforts on these parts when eliciting the utilities and the probabilities. This approach can also be supplemented with an analysis of how sensitive the model is to variations in these numbers. We present a method for determining the parts of an influence diagram that are relevant for a particular decision variable. In this analytical context we also give two methods for determining how sensitive the model is to variations in the utilities and the probabilities.

Finally, we proposed a method for doing decision aiding based on non-expected utility. This type of decision aiding tries to accommodate the situations, where the decision maker rejects the model being proposed because it can not account for all of his choices (this can be a problem with models based on expected utility, such as influence diagrams).

Decision Support for Multiple Decision Makers

Name: Søren Holbech Nielsen

Education: Cand. scient. (M.Sc.) in Computer Science, 2003

Duration: August 2003 – July 2006

Status: In progress

Funding: Cofinanced by Hewlett-Packard sponsorship and the Faculty of Technology and Science

Advisor: Thomas D. Nielsen

In some settings several decision makers have to co-exist and should therefore adapt their strategies to each other. This can be problematic when their actions interact, and synergies and conflicts arise, or when their goals and preferences diverge or conflict. In this study we develop two methodologies for alleviating this uncertainty.
Considering the problems from a normative perspective, we could be tempted to perceive the set of decision makers as one joint (abstract) decision maker going trough the set of all decisions that the individual decision makers would have gone through. Then we can model this joint decision makers' scenario as an influence diagram and solve it. However, as the utilities of the different outcomes may vary between the decision makers, there is no obvious utility function to associate with the states of the variables in the scenario. Instead, we associate to each outcome the utility of each decision maker. More generally, to each outcome we attach a ordered series of utilities, which we assume to be of different types, or currencies, such as "$ to person A", "trees on person B's property", or in this specific setting "pleasure for decision maker 1" and "pleasure for decision maker 2". The resulting diagram we call a multi-currency influence diagram (MCID). Given an MCID we can analyze the behavior of the joint decision maker in relation to it, and reason about which of the individual decision makers that are being treated unfairly with respect to having their desires fulfilled.
A more descriptive angle, is to consider the decision makers as autonomous agents in a multi-agent environment. For an agent to act rationally in any environment, it is necessary for it to be able to reason about the most likely effects of its actions within that environment. One possible way of ensuring this ability is to equip each agent with a probabilistic model of the environment, which we assume to be a Bayesian network. It is desirable to have each agent update its Bayesian network model to observed changes in its environment, and we propose a method that based on a local conflict measure, identifies parts of the model which are invalid, and then adapts these to trends in new observations. Furthermore, the decision makers might have an advantage in pooling their knowledge of their surroundings. For instance, it may be the case that an agent leaves the environment, and upon reentry finds that the environment has changed. The agent can then benefit from having the other agents tell it about the changes that has happened. We pursue an effective

framework for such situations, by constructing a dialectic argumentation structure where agents can reason about their models. We take outset in current argumentation theory and provide the necessary alterations for reasoning about Bayesian networks.

Learning Probabilistic Graphical Models

Name: Jens Dalgaard Nielsen

Education: Cand. scient. (M.Sc.) in Computer Science, 2002

Duration: August 2003 – November 2006

Status: In progress

Funding: Stipend No. 562/06-16-23603

Advisor: Manfred Jaeger, Finn Verner Jensen

From a large body it is often of great importance to be able to give statements about the process that generated the data. If our body of data is of medical diagnostics, such statements could typically be answers to queries like ”Given that my patient has high fever and a headache, what is the probability that she has the flu?”. For such computations it is standard to first apply learning algorithms to obtain a model from the data, and then use the model to infer the answers to any arbitrary query.

My PhD. project has evolved into two separate branches that still is within the problem domain of learning PGMs. In the following I will describe the work I have done and wish to do within:

1. Learning Bayesian Network models.

2. Learning Probabilistic Decision Graph models.

Learning Bayesian Network models (BNs) is an area that has received increasing attention by researchers for the past few decades. One of the most promising methods for learning such models from data is the Greedy Equivalence Search (GES) algorithm. My work has been focused on one particular generalization of this algorithm, and on different extensions. The generalization of the algorithm (the k-greedy Equivalence Search (KES) algorithm) mitigates a problem with GES that was identified by Chickering and Meek, and furthermore significant improvement over GES in some practical applications has been reported. The extension of the algorithm is work in progress. Here we investigate ways to incorporate and take advantage of prior structural knowledge. Whether the prior knowledge comes from a domain expert or from some preprocessing of the data is not important to us. The implications of such a procedure could be the applicability of the KES algorithm in areas that has previously been intractable, or speedup in already tractable domains.

While BNs is an old representation language for probabilistic systems, Probabilistic Decision Graphs (PDGs) in its current form is a relatively recent invention [9]. The difference between BNs and PDGs are found in the classes of independence structures that can be efficiently modeled. Here, my work has been mostly focused on developing new learning techniques for PDGs. Until now, only initial experiments has been performed and non-conclusive results has been reported. We expect to refine the learning algorithm in order to say something about the general applicability of PDGs vs. BNs when we wish to learn a model from data.

8.10 Collaboration

Descriptions of collaborations, nationally and internationally.

8.10.0 Guests

The following foreign researchers have been guests for a longer stay at the Machine Intelligence group

Visiting on sabbatical leave:

Li-Yan Yuan, University of Alberta	August-November 2001
Nevin Zhang, University of Hong Kong	January-June 2002
Prakash Shenoy, University of Kansas	January-May 2004

Visiting as part of PhD studies:

David Cavallini, University of Florence	August-December 2002
Julia Flores, University of Castilla-La Mancha	February-June 2003
Massimiliano Mascherini, University of Florence	March-June 2005
Debora Slanzi, University of Padova	January 2005
Manuel Luque, University of Madrid	September-December 2005

8.10.0 Research collaborations

- A collaborative project on incremental compilation of Bayesian networks has been established with Julia Flores and Jose Gamez, University of Castilla La Mancha, Albacete, Spain.

- We are involved in the EU-funded APRIL-2 project on applications of probabilistic inductive logic programming. Within this project we are collaborating with groups from the University of Helsinki, Freiburg University, Imperial College (London), INRIA Rocquencourt, University of Florence, and York University.

- With the group of Adnan Darwiche at the University of California at Los Angeles we are collaborating on inference methods for logic-probabilistic models and their integration into the *Primula* system.
- We have been involved in a pilot project together with ELSAM and Mälardalens Högskola, Sweden. The aim of the project was to establish an alert system for a coal burning power plant.
- We have been collaborating with the French company Entelligence about analysis of data in the form of vulnerability reports for software collections. The research ended with a one month consultancy by a group member at Entelligence's offices in Chambery, France.
- A collaboration constructing an expert system for Lyme Disease is established with Ram Dessau, Næstved Hospital, Denmark and Ole Hejlesen, Department of medical Informatics, Aalborg University, Denmark.
- Work on the Munin system for diagnosis of neuromuscular disorders was carried out in collaboration with Steen Andreassen and Marko Suojanen, Center for Model-based Medical Decision Support, Aalborg University, Denmark and Bjørn Falck, Turku University Hospital, Finland.
- In the MERIT project we collaborated with several European partners. A detailed description is given in section 8.7.1.
- In the Värmforsk project we collaborated with Mälerdalens Högskala, Västerås, Sweden (see section 8.7.1).
- We were consultants for A PhD student at the Department of Production. He applied successfully Bayesian networks for automatic and adaptive control of welding.
- The group has been collaborating with Filmskolen (Copenhagen Art School of Film Production) and Århus University on the project NOLIST, on non-linear interactive storytelling in computer games.
- In 2001 we were in close contact with the French company Gemplus (a producer of smart cards). We came up with proposals for projects on intrusion detection, costumer and trust management. However, problems with IPR delayed things, and eventually the executives we were in contact with left the company.
- We had a small data mining project with Chr. Hansen A/S (a company producing enzymes). The project resulted in a preliminary report, but due to lack of research tasks, it ended there.
- As part of NouHauz, the group established the network BESSNET. It had three to four meetings a year, and it had members from seven companies and three research institutions.

- The group organizes a two-day international workshop, WAGM, on applying graphical models. At the two workshops till now, there has been participants from five companies and eleven European research institutions.

- The group is a member of two ”Forskerkontaktnetværk”, one in data mining and one in computer games. They are government sponsored networks for contact between academia and business.

- We were in contact with Nokia and had developed plans for a common project on hand-over for mobile phone stations. However, the project required the university and Nokia to make an agreement on IPR. For both parties at ”floor level” the case went out of hand. It took more than a year and a half before an agreement was reached, and staff changes at Nokia made the project obsolete.

- The group is currently collaborating with Århus University, The Human Science department of Aalborg University, among others, on the project Twilight, on applying Bayesian networks for creating believable dialog in computer games.

- The group has been co-supervising a PhD student from Høgskolen i Agder, Norway. The project was on adaptive technologies for web accessibility monitoring.

- The group has acted as consultant for a PhD student from The Swedish Geotechnical Institute. The project was to establish strategies for handling of contaminated soil.

- Within the SACSO project the group collaborated with Hewlett-Packard (cf. section 8.7.1).

- Hugin Expert A/S is a spin off company from the activities of the group. The group is in frequent contact with the company.

- Dezide APS is a spin off company from the activities in SACSO. The group is in frequent contact with the company

- Moltsen Intelligent Systems is a small company run by a graduate from the group. The group is in frequent contact with the company

- Within a Master’s thesis project on genetic linkage analysis, we collaborated with deCode genetics, Reykjavik.

- Furthermore, the group has had more than ten industrial contacts which did not go beyond two meetings.

8.11 Services

8.11.1 Invited Talks

- *Advanced Electronic Agents and Services*, Annual meeting of the Danish Informatics Network in the Agricultural sciences (DINA), Rebild Bakker, Denmark (2001), (KGO);
- *Probabilistic Classifiers in Data Mining*, Software på tværs, Copenhagen 2003, (MJ);
- *Bayesian Networks and Decision Graphs*, 44th Conference on Simulation and Modeling (SIMS), Västerås 2003 , (FVJ);
- *Bayesian Networks and Decision Graphs*, Working Conference on Reliability and Optimization of Structural Systems (IFIP), Aalborg 2005, (FVJ);
- *Graphical Models as Languages for Computer Assisted Diagnosis and Decision Making*, European Conference on Symbolic and Quantitative Approaches to Reasoning under Uncertainty (ECSQARU), Toulouse 2001, (FVJ);
- *Bayesian Networks and Decision Graphs*, Århus University 2002, (FVJ);
- *Bayesian Networks and Decision Graphs*, Lund University 2004, (FVJ);
- *Bayesian Networks and Decision Graphs*, Almeria University 2001, (FVJ);
- *Graphical Models for Scene Interpretation*, Oslo University 2001, (FVJ);
- *Bayesian Networks and Decision Graphs*, Copenhagen University 2003, (FVJ);

8.11.2 Conference Chairs

Organizing chair of The 7th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU-03) (KGO); Program co-chair of the 7'th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU-03) (TDN); General chair of The 7th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU-03) (FVJ); Program co-chair of the Nineteenth Conference on Uncertainty in Artificial Intelligence (UAI-03) (UK);

8.11.3 Program Committees

Workshop on Bayesian Models in Medicine held during The 8th European Conference on Artificial Intelligence in Medicine 2001 (KGO); Conference on Uncertainty in Artificial Intelligence 2001, 2002, 2003, 2004, 2005 (KGO, TDN, UK, MJ); International Symposium on Imprecise Probabilities and Their Applications 2003, 2005 (MJ); European Workshop on Probabilistic Graphical Models 2002,

2004 (KGO); European Conference on Symbolic and Quantitative Approaches to Reasoning under Uncertainty (ECSQARU) 2005 (MJ, TDN, KGO); Florida Artificial Intelligence Research Society Conference (FLAIRS) 2002, 2003 (KGO);

8.11.4 Other Committees

Advisory committee on ”Education and Competence” under ”The Digital Northern Jutland” (2001 (KGO); Assessment committee for Helge Langseth’s Ph.D. defense, Trondheim, Norway (2002) (KGO); Assessment committee for Julia Flores’s Ph.D. defense, Albacete, Spain (2005) (KGO); Assessment committee for Galia Weidl’s Ph.D defense, Västerås, Sweden (FVJ); Assistant supervisor for a Swedish PhD student (FVJ); Assistant co-supervisor for a Norwegian Ph.D. student (TDN, UK); Career track evaluator for professors at four universities (FVJ); Evaluation board for two Norwegian professor positions (FVJ);

8.11.5 Reviewing for Journals

International Journal of Approximate Reasoning (KGO, FVJ, MJ); *Ecological Modeling* (FVJ); *Computational Intelligence* (FVJ, KGO, MJ); *Artificial Intelligence* (FVJ, MJ); *European Journal of Operational Research* (FVJ, TDN); *Pattern Analysis and Applications* (FVJ); *Decision Analysis Journal* (FVJ); *Operations Research* (FVJ); *Networks* (FVJ); *The Journal of Applied Non-classical Logic* (FVJ); *Journal of applied Stochastic Models* (FVJ); *Computational Statistics and Data Analysis* (FVJ); *Journal of Operational Research* (TDN); *Networks Journal* (TDN); *International journal of information technology and decision making* (TDN); *Journal of Artificial Intelligence Research* (MJ, UK); *Mathematical Reviews* (MJ); *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* (MJ); *Machine Learning Journal* (MJ); *Synthese* (MJ); *Annals of Statistics* (MJ); *Theoretical Computer Science* (MJ); *Annals of Pure and Applied Logic* (MJ); *International Journal on the Foundations of Computer Science* (MJ); *Cambridge University Press (Book proposal)* (MJ); *Wiley & Sons (Book proposal)* (FVJ); *Applied Intelligence* (UK); *IIE Transactions* (UK);

8.11.6 External Conference Reviewing

The International Joint Conference on Artificial Intelligence (IJCAI) (TDN, FVJ, MJ); *Uncertainty in Artificial Intelligence (UAI)* (FVJ, UK); *The European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU)* (TDN, FVJ); *The First European Workshop on Probabilistic Graphical Models (PGM)* (TDN); *The Annual German Conference on AI* (TDN, FVJ); *Intelligent Data Analysis (IDA)* (FVJ); *International Conference on Knowledge Engineering and Decision Support (ICKEDS)* (FVJ); *Canadian Conference on Artificial Intelligence (AI)* (FVJ); *European Conference on Artificial Intelligence (ECAI)* (FVJ); *International Workshop on Artificial Intelligence and Statistics (AISTATS)*

(UK); *European Conference on Logics in Artificial Intelligence (JELIA)* (MJ); *Advances in Modal Logic (AiML)* (MJ); *IEEE Symposium on Logic in Computer Science* (MJ);

8.11.7 Editorial Activities

Guest editor for the International Journal of Approximate Reasoning (TDN); Member of the editorial board for the International Journal of Approximate Reasoning (IJAR) (FVJ); Advisory board for The International Journal of Information Technology & Decision Making (FVJ);

8.11.8 Other Activities

Chair of the Board of Directors for the Association for Uncertainty in Artificial Intelligence (AUAI) (FVJ); Member of the board for the biannual conference ECSQARU (FVJ); Reviewer for project proposals submitted to *The Netherlands Organization for Scientific Research* (FVJ); Reviewer for project proposals submitted to *The Research Council of Canada* (FVJ); Reviewer for project proposals submitted to *The Swedish Research Council* (FVJ); Reviewer for project proposals submitted to *The Research Grant Council of Hong Kong* (FVJ); Head of School of Science and chairman of the board for the science educations (2000-2005) (KGO); Scientific advisor for the project *Industrial Data Mining*, funded by ForskerKontakten (MJ); Teaching a three week graduate course at Reykjavik University (FVJ, UK); Teaching a two week Nordic PhD course on graphical models (FVJ);

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Part III

Summary in Danish

9 Resumé

Det Teknisk-Naturvidenskabelige Fakultet ved Aalborg Universitet har en politik om, at dets forskningsenheder skal evalueres hvert femte år. Denne rapport dokumenterer hermed den fjerde forskningsevaluering for forskningsenheden Institut for Datalogi (i det følgende benævnt Instituttet) og dækker perioden 2001-2005.

9.1 Formål

Retningslinjerne fra Fakultetet angiver tre formål med evalueringen, idet den skal

- vurdere om der er tilfredsstillende overensstemmelse mellem de tildelte interne og eksterne forskningsressourcer og det udførte forskningsarbejde,
- vurdere om der er rimelig sammenhæng mellem Instituttets mål for den forskningsmæssige indsats, herunder som den fremgår af Fakultetets langsigtede faglige planlægning, og den gennemførte forskning,
- rådgive Instituttet om dets fremtidige indsats og forskningsorganisering.

Instituttet tilføjede et ekstra punkt, der tildels understreger visse aspekter af Fakultetets formål:

> Indenfor Instituttet skal evalueringen, processen såvel som den endelige rapport, konstruktivt hjælpe medarbejderne med at evaluere og forbedre deres effektivitet som forskere, gruppeledere og som administratorer af forskning i Instituttet. Specielt er evalueringen en anledning til at vurdere Instituttets evne til at levere forskning af høj kvalitet.

9.2 Evalueringsprocessen

Evalueringsprocessen tog sin start i begyndelsen af 2005, hvor Instituttets forskningsledere og institutlederen påbegyndte diskussioner om, hvordan processen skulle struktureres. Som en af de vigtige aktiviteter blev evalueringsudvalget etableret. Professor Christian S. Jensen accepterede at blive Instituttets lokale repræsentant (lokale medlemmer har ingen stemmeret). Det var med stor tilfredshed i Instituttet at professor Stefan Arnborg (KTH, Sverige), Direktør Keith Jeffery (Rutherford Appleton Laboratory, UK), professor Thomas Sinkjær (Center for Sanse-Motorisk

Interaktion, AAU), og professor Ian Sommerville (Lancaster University, UK) accepterede at deltage i udvalget. Det var vores fornemmelse at dette udvalg, af anerkendte og erfarne seniorforskere og forskningsledere, ville være istand til at dække alle de forskelligeartede forskningsområder, som Instituttet rummer, og ligeledes ville være i stand til at udarbejde en indsigtsfuld evaluering.

Efter at have nedsat udvalget blev strukturen for evalueringen og denne rapport lagt fast. Strukturen for rapporten følger strukturen i de tidligere rapporter med den forskel, at den trykte rapport ikke indeholder alt det baggrundsmateriale som udvalget fik fra forskningsgrupperne.

Udkast til forskninggruppernes bidrag til evalueringsrapporten blev diskuteret i Instituttet. Disse diskussioner åbenbarede, at nogle emner omkring forskningsmetoder, resultater og organisering ikke var blevet behandlet i de tidlige udkast. De bidrag denne proces resulterede i blev samlet i en foreløbig evalueringsrapport (som del II af denne rapport er baseret på), der tidligt i december blev sendt til evalueringskomiteen.

I starten af januar 2006 afholdte det videnskabelige personale inklusiv Ph.D. studerende og gæster et to-dages seminar. Den første dag gav Instituttets forskningsgrupper mundtlige præsentationer af deres forskning, hvor komiteen og andre havde mulighed for at stille spørgsmål til rapporten og præsentationen. Om eftermiddagen på den første og formiddagen den efterfølende dag arbejde komiteen for sig selv (afbrudt af diskussioner med lederne af forskningsgrupperne og institutlederen, hvor forskellige aspekter af Instituttets organisering blev uddybet). Mens komiteen arbejdede for sig selv deltog instituttets medarbejdere i forskellige aktiviteter med relation til temaet “forsknings evaluering”. Ved afslutningen af seminaret præsenterede komiteen den overordnede konklusion på evalueringen og besvarede spørgsmål.

Efter seminaret færdiggjorde komiteen den skriftlige evaluering, samtidig færdiggjorde forskningsgrupperne den endelige version af deres bidrag. Det er udfra disse bidrag, at denne rapport er skabt. Rapporten består af 3 dele. I del I findes selve evalueringen af Instituttets forskning, desuden gives der en kort beskrivelse af formalia for evalueringen og korte CV for medlemmerne af komiteen. Del II indeholder 4 kapitler. Det første kapitel omhandler Instituttets organisering og finansiering, desuden præsenteres en forskningsplan for 2006-2010. De efterfølgende kapitler omhandler de enkelte forskningsgrupper (ét kapitel per gruppe). Hver gruppe giver et overblik over sin profil, opsummerer sine forsknings mål og resultater, og giver til slut en selvevaluering og opstiller planer for den næste periode. Detaljerede beskrivelser over aktiviteter og resultater, beskrivelse af organisering og medarbejder, Ph.D. projekter, forskningssamarbejder, og andre forskningsrelaterede aktiviteter og en bibliografi følger efter hvert kapitel som et appendix. Del III giver en opsummering af rapporten på dansk.

Evaluerinspanelets konklusion 10

Den overordnede konklusion af evalueringspanelt er, at gennemgående er kvaliteten af Institut for Datalogs forskning høj, og visse steder, international førende. Alle Instituttets forskningsgrupper har bibeholdt eller forøget deres aktivitetsniveau siden den forrige evaluering. Det er tydeligt, at Instituttet arbejder på et niveau, der er sammenlignelig med ledende datalogiske forskningsmiløjer i resten af verden. Ændringer i behovet for dataloger i Europa betyder at vækst gennem øget studenteroptag ikke længere kan tages for givet. Det er derfor vigtigt at Universitetet agerer proaktivt med henblik på at sikre at Instituttet har de fornødne ressourcer til at bibeholde og forbedre dets ledende international position indenfor forskning. Specielt, bør Universitetet søge at forøge midlerne til Ph.D. stipendier, internt og via øremærkede regionale og nationale bevillinger.

Panelet vil gerne udtrykke en vis bekymring over at Instituttet har valgt en organisering omkring 4 forskningsgrupper. Panelet føler, at denne organisering er unødvendigt ufleksibel og betyder at beslutninger af strategisk betydning for hele Instituttet bliver svære at tage. Dette kan betyde, at muligheder for ekspansion indenfor nye forskningsområder forpasses og forhindre at nye finansieringsmuligheder for forskning ikke udnyttes. Panelet anbefaler at Instituttet etablerer mekanismer, der understøtter strategisk beslutningstagning på institutniveau og ikke kun i forskningsgrupper.

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