1 Research Profile

I am broadly interested in specification, construction, and analysis of distributed computer based communicating systems including networked, embedded, and real-time systems. Reviewing my research conducted so far I find that it can be described as two lines of research.

One line of research is on languages, methods, and environments for construction of distributed systems and networks. This research follows the very practical and empirical tradition that has been established in the computer systems community, and that aims at making efficient use of the technologies available at a given time. My research here has focused on the distributed programming paradigms Actors [1, 14, 15] and Linda [19], and on empirical evaluation of networking technologies with respect to both functionality and performance. Examples of empirical studies are the performance measurements of ATM networks [21, 23], efficient digital video multi-casting [13, 22], and recently handoff performance in mobile IPv6 [9, 17]. The nature of experimental and constructive work is very labor intensive, and has therefore often involved tight collaboration with master's students.

Another line of research is on formal methods for real-time embedded systems. This research follows a tradition that emphasizes a certain level of formal rigor and precise definitions, and efficient correct algorithms. Especially in the resent years, my research — origining in my Ph.D. thesis work — has emphasized automatic testing of communicating systems based on formal specifications. This involves applying techniques developed for model checking of formal specifications in the more novel setting of formal testing. In particular, I have shown how to apply symbolic analysis techniques for the timed automata formalism to solve an important test generation problem for real-time systems.

My research on symbolic model based testing has spawned significant interest in the formal methods and tools community, and has resulted in several publications [2, 4, 6, 8, 10, 11, 12, 18]. It has been disseminated through invited lectures in European Ph.D. schools, and has resulted in several international collaboration efforts on the subject. Also I have contributed to the start of a new series of workshops on Formal Approaches To Testing of Software (FATES) which has evolved into an international recognized workshop in its area. I am co-chairing this years Fates'04. Furthermore, this research has spawned significant interest in the local software industry.

Thus, my research ranges broadly from formal semantics and algorithms for program analysis in one extreme to hard-core performance measurements and empirical evaluation of computer networks in the other. There is, however, in my view a common underlying theme besides the subject area (distributed systems), namely that of relating (possibly formal) models of communicating systems and the physical systems being modeled. This relation can be established in two different ways, either validate through experimentation (e.g. testing and performance measurements) whether a given model reflects the reality, or by synthesizing new models or modeling techniques from experiments or constructions. The relationship may concern different properties or aspects of the models and physical systems, such as functional behavior, performance, real-time, and reliability.

Knowledge about the behavior of computer systems, models for describing it, and methods and techniques for obtaining it is an essential ingredient for the efficient engineering of computer based systems. I further believe that it is necessary to have insight in both the underlying formal theory and in the properties of the technology if solid practical solutions are to be developed.

In the future I plan to cultivate this combined approach more explicitly and systematically in the context of embedded systems for which this link is especially important, and to strengthen my research by doing more practical applications.

2 Industrial Collaboration

In the period from may 2001 to July 2002 I was employed as research associate professor sponsored in half by Siemens Mobile Phones (SMP) working on a collaboration project called "Automated Software Testing". This involved tight collaboration on a concrete development project supplied by SMP. The specific project was to implement and test a new GSM protocol called RRLP (Radio Resources Location Services Protocol) for communication of geographical position related information from the mobile terminal to the GSM network. A significant amount of time was spent at SMP studying, evaluating, and contributing to the RRLP project. The ultimate goal of the collaboration was to increase testing thoroughness, and to reduce the high amount of laborious and tedious work in the testing process. A secondary goal was to increase testing competence at SMP and to ensure industrially relevant research on testing at AAU.

A main result is the development and application of a methodology and tool for system level black box conformance testing of communication protocols for mobile phones. This approach is based on a methodology for conformance testing of telecommunication systems based on the semi-formal notations of Message Sequence Charts (MSC), Specification and Design Language (SDL), Abstract Syntax Notation one (ASN.1), and Testing and Test Control Notation (TTCN) that has been developed by the research community during the last decade.

Conventionally, SMP programs test cases in the C-language using a set of dedicated libraries containing common procedures for testing GSM protocols. That is, the dynamic behavior of test cases were written using C-language control structures, and the test data is normally hand crafted bit strings. Using the developed tool, test cases can now be specified at a high level of abstraction (using MSC, ASN.1, TTCN), automatically translated and compiled into an executable program that can be executed on the specialized base station emulator test equipment available at SMP. The resulting test suite can be executed automatically and unattended, both in its entirety and selected parts thereof.

Indeed, during the project, SMP found the methodology and tool so promising that they adopted it as the test concept for RRLP rather than their well-known, safe, traditional approach. As a consequence of this positive decision, much of the project time was spent on maturing the techniques, writing and executing test cases subject to product delivery deadlines and various resource constraints. Another consequence of this is that no hard figures exist that enable a direct comparison of the relative efficiency (number of test cases, development time) of the two approaches, but the new technique is subjectively evaluated to be a big improvement: According to Line Manager Ole Rasmussen in a SMP internal e-mail bulletin, "there exists a tool that can be applied in practice, and, that by correct application, saves even much time".

During the project I obtained indispensable insights into testing in practice, not only concerning technical issues such as GSM protocols and specialized test equipment, but also first hand practical experience with testing and development processes, including the problems of management and time pressure, uncertain specifications and time plans, the compression of the testing activities due to delays in implementation work but fixed product delivery deadlines, lacking human resources, etc., that makes testing so hard in practice.

In my experience there is a big gap between academic research and industrial practice, but the collaboration has strengthened my view in that these new techniques can be used in practice, and can improve practice.

The collaboration ended with a course for SMP engineers where the developed system and test cases were delivered to SMP. The deliverables are documented as a large set of slides and a confidential technical report [26]. The developed concept and tool is still being used and maintained by SMP after termination of the project. In conclusion, the project has successfully transferred knowledge from research to industry, and has given valuable input to testing research at AAU.

Recently I have been heavily involved in two collaboration projects between CISS (Center of Embedded Software Systems) and industry. One is a trial project with the Electronic Cooling and Refrigeration Controls Division of Danfoss to evaluate the use of UML state charts and a specific tool IAR visualSTATE as an approach to model based development (formal modeling, and analysis, test and code generation) of refrigeration controllers. The results were evaluated very positively by Danfoss, and a continuation of the project is currently being formulated. The second project is a collaboration with Simrad Marine Electronics A/S on evaluating the eCos embedded operating systems as a potential future platform for their products. The evaluation (preliminarily documented in [25]) includes creating a port of eCos to their custom hardware, a functional evaluation, and a performance evaluation - especially of interrupt performance.

Another source of direct industrial collaboration was the network in Test and Modeling of Software (ToMaS) that aims at bridging the gap between academics and the practice of software modeling and testing. I was the leader and main organizer of this network. The network has featured industrial and academic presentations, tool vendor demos, case studies, and discussions (`http://www.cs.auc.dk/~bnielsen/tomas/`).

3 Academic research projects and collaborations

I am currently engaged in several national and international research projects.

An ongoing project is the EU IST 5th framework network of excellence ARTIST (Advanced Real-Time in IST) [31] where I am one of the participating researchers from AAU. I am mainly contributing to the action item on hard real time systems. I have written a section in the year 1 deliverables (road-map) [16] on software testing. ARTIST has applied to be upgraded to a EU IST 6th framework network of excellence [28]. I have contributed to the proposal by formulating a new action item on model based testing of embedded systems.

I am also a participating researcher and co-applicant in the now funded Dutch Systematic Testing of Real-time Embedded Software Systems (STRESS) project [29], and has written parts of the research proposal. The project is a collaboration with Prof. Kim G. Larsen and Prof. Ed Brinksma from Twente University, and Prof. Jan Tretmans from Nijmegen University. Much of the motivation for this research project origins from a number of open research problems that was identified as part of my Ph.D. thesis work, especially the lack of a real-time testing theory, and the need for improved symbolic algorithms for real-time on-the-fly testing.

In 2002 AAU (represented by me) was invited to join a consortium of research institutions whose goal is to become a EU IST 6th framework network of excellence on testing called TestNet. Compared to ARTIST the scope of TestNet is much broader and aims at integrating the test communities on protocol testing and general software testing. So far the consortium has submitted an expression of interest, and plans to submit a proposal for the second call in the 6th framework.

At the national level I have been a participating researcher in a series of national research projects sponsored by the national Technical Technical Research Council ("Environments and Paradigms for Development of Reliable Distributed Real-Time Software" [27]) and the Danish Research Council ("Networks and Paradigms for the Next Generation of Distributed Systems") on distributed computing and networks in collaboration with Prof. Eric Jul, Copenhagen University, Prof. Robin Sharp, The Danish Technical University. One of the projects is concerned with the ATM (Asynchronous Transfer Mode) networking technology on local area networks, and later on wide area networks. The publications that resulted from these projects are [13, 21, 22, 23]. Latest, the consortium has focused on grid computing. Further, I am very active in the Center of Embedded Software Systems (CISS) at Aalborg University and participated in several industrial collaboration projects.

4 Ongoing research

After the completion (since ultimo August 2002) of the Siemens Automated Software Testing project, my research has re-focused on new fundamental real-time test generation techniques. One topic is optimal test generation where the goal is to automatically compute a test suite that satisfies a certain coverage criterion or testing objective, and that is the most economical to execute in terms of real-time execution time or resource usage during test execution. The aim is to enable the real-time analysis tool UppAal to generate real-time test suites automatically . However, computing optimal test suites is very challenging because of the inherent high complexity of optimal algorithms, but promising results have been published in [7, 8]. This research is conducted in collaboration with colleagues in the Distributed Systems and Semantics research unit, and with Prof. Paul Petterson, Uppsala University. We are currently working on improving and generalizing our results.

I am also collaborating with Arne Skou from Aalborg University and Jens Chr. Godskesen from the IT-University of Copenhagen [3] on extending UppAal to generate test sequences for coverage of connectivity faults i.e, implementation faults where externally observable input or output actions used in the embedded software is incorrectly connected with software drivers and hardware i/o devices.

Another current research topic is on-the-fly real-time conformance test generation and execution. The idea here is to dynamically (and in real-time) interpret a formal specification given as a network of timed automata to compute relevant stimuli to the system under test, and to check whether responses are legal according the specification. This requires that the test tool tracks the possible specification states that can be reached after the event sequence executed so far which requires representation and manipulation of a potentially large set of symbolic states. Although it at first sight appears feasible to extend a tool like UppAal with the required features, it still requires novel application of the symbolic reachability techniques in the UppAal verification engine, and further, no practical experience exists about the real-time performance of such algorithms. This research is done in collaboration with colleagues in the Distributed Systems and Semantics research unit, the Dutch STRESS project, and a group of master's students, and a PhD Student. This work has already resulted in several publications [4, 6].

An important part of my future research will be to apply and evaluate these techniques to practical testing of embedded systems.

5 Teaching

During my previous employments at the Department of Computer Science I have contributed substantially to teaching at all levels of the education in computer science, computer engineering, and software engineering at Aalborg University. This concerns both course and project supervision in the area of operating systems, distributed systems, and formal systems. I have successfully completed the course in university-pedagogy for assistant professors offered at Aalborg University. In addition, I have in numerous occasions contributed to the revision of study plans, and to the creation of new studies and study plans. In the autumn 2003 I took part in the Socrates teacher exchange programme and visited the University of Marseilles, France for one week.