Testing of Event-Triggered Real-Time Systems

August 18, 1999

Summary

Applying institution: Institutionen för Datavetenskap, Högskolan i Skövde.
Co-applicants: Sten F. Andler, Ragnar Birgisson, Jonas Mellin.
Partner Company: Enea Data AB

The current industry practice for testing real-time applications is often based on case-specific ad-hoc techniques. At the same, time real-time systems are often employed in environments where their correctness is of great importance, which necessitates a rigorous approach to testing. In this context, the ability to test all anticipated behaviors is strongly desirable, but in general not feasible. Our approach is based on the hypothesis that the testability of event-triggered real-time systems can be improved by applying constraints on application behavior. This makes it possible to define an upper bound on the test effort, which enables full testing. However, even in a system that uses constraints to bound the test effort, it is often not possible to perform all the necessary testing within the allotted time frame. Therefore, test-case selection methods must be employed. Moreover, the criteria for such methods must be especially suited for real-time systems and measurement techniques for evaluating the quality of the selected test cases must be produced. In this project, prototypes of automated tools for test case generation and selection are built and evaluated.

Two Licentiate/Ph.D. students will be actively working on the project under the direction of the Distributed Real-Time Systems Research Group in Skövde. In addition, members of the Enea Test group will contribute to this project through their experience and insight into current industry practice in testing of real-time systems, both in forming the problem definition and as a reference group. Further, Enea's broad range of industry contacts provides an excellent opportunity to transfer the technology produced by this project into industry.

1 Problem Statement

Software testing is a fundamental aspect of software development, and can consume as much as 50% of the total cost for a project. This is particularly true for real-time systems, which have to be rigorously tested to ensure their correctness. Further, real-time systems must not only be tested for functional correctness, but also for timeliness.

To achieve the desired level of confidence in application correctness, full test coverage is strongly desirable for real-time systems. This means that all anticipated behaviors must be tested. In general, full test coverage is not feasible, because of the large amount of test cases that must be designed, executed, and analyzed. Therefore, to enable testing with full test coverage, some constraints on application behavior must be introduced. One example of this are time-triggered real-time systems [Kop91]. However, there are situations where the time-triggered approach is not suitable, for example, the dynamic nature of some systems necessitates the use of an event-triggered architecture.

This project investigates an alternative approach that aims at bounding the test effort for event-triggered systems and, thus, enabling full testing of such systems. The basis of this approach is to use a system architecture that inherits the testability of time-triggered systems while still allowing the flexibility of event-triggered semantics. Our approach focuses on system level testing of

timeliness, assuming that functional correctness has already been tested. This can reveal incorrect assumptions about worst-case execution times and errors in schedulability analysis.

To improve the testability of event-triggered systems, three major problem areas must be addressed: (i) further improvement of the theoretical foundation, (ii) automated generation and selection of test cases, and (iii) automatic test case execution. This project addresses the first two problem areas. Addressing the theoretical foundation is necessary in order to strengthen the underpinnings of our approach. Automated methods for test case generation and selection must be addressed in order to achieve the goal of enabling fully automated test case execution. Addressing the third problem area of automatic test case execution will be more meaningful when sufficient results have been obtained in the first two problem areas and is therefore not included in this project.

The first problem area is related to identifying constraints on application behavior that reduce the required test effort. The effects of these constraints on the application and the execution environment must be investigated. The second problem area is related to using these constraints in generation and selection of test cases. Based on the constraints placed on application behavior, it must be possible to generate all the required test cases. Further, since the number of test cases may be very high, this process must be automated, and methods for test case selection must be produced. Finally, the third problem area concerns automatic execution of these test cases. A number of methods that deal with test case execution have appeared in recent years, e.g., Peleska and Siegel [PS97] and Cardell-Oliver and Glover [CG98]. However, none of these are based on the kind of state information our approach suggest. Moreover, these methods do not explicitly address full test coverage, while our approach can guarantee that all expected behaviors have been tested.

2 Main Ideas

2.1 Theoretical Foundation

Our approach is based on the hypothesis that the testability of event-triggered real-time systems can be improved by applying constraints on application behavior. Recent work by Mellin [Mel98] has suggested three constraints; (i) a bound on the number of times a task can be preempted; (ii) a bound on the number of concurrently executing tasks; and (iii) constraining the points in time where the environment can be observed. Using these constraints, an upper bound on the test effort for event-triggered real-time systems is defined by Mellin, and refined by Birgisson [Bir98]. Further, an initial study of the effects that these constraints have on scheduling, and how they can be enforced has been performed [Bir98].

The aim of this part of the project is to further strengthen the theoretical foundation for the hypothesis stated above. To accomplish this, the following objectives have been identified: (i) investigation of the constraints and assumptions made by Mellin and Birgisson; (ii) formulation of an improved upper bound on the test effort based on the selected constraints and assumptions; (iii) refinement of the current enforcement methods; and (iv) identification and solution to problems that arise in a constrained application.

2.2 Test Case Generation and Selection

Given an upper bound on the required test effort for event-triggered real-time systems, it is possible to generate all the test cases required for full test coverage. This requires defining the contents of a test case, and initial work on this has been done by Birgisson [Bir98] and Nilsson [Nil99]. The basic idea is to define a test case as consisting of the state of the system (represented by the states of active tasks) and possible future events. In addition, event parameters and the state of shared resources must be included. The combination of each system state and future events represents all anticipated behaviors of the system, and it is possible to determine if tasks miss their deadlines as a result of any of these behaviors.

While the proposed approach bounds the number of test cases, the upper bound may still be very high and, thus, it is not feasible to execute all test cases. Therefore, test case selection must be used to select a subset of the test cases. In the context of our approach, test case selection is based on identifying worst-case scenarios, i.e., system states that are likely to result in failure to meet timing constraints. Methods for measuring the quality of the selection test cases must also be produced.

The aim of this part of the project is to identify techniques that can, according to a specific criteria, automatically create all the required test cases. To achieve this, the following objectives have been identified: (i) refinement the contents of a test case; (ii) development an algorithm that creates all the test cases based on the upper bound test effort; (iii) identification of test selection criteria and methods for applying these; (iv) specification, design, and implementation of tool prototypes for automated generation and selection of test cases.

3 Expected Results and Impact

3.1 Theoretical Foundation

The expected contributions of this sub-project are:

1. A more solid theoretical foundation for using constraints on application behavior for improving testability.
2. Methods for enforcing the constraints and solutions to problems that arise in a constrained application.
3. Integration of problem-specific solutions and enforcement methods into the DeeDS prototype.

A solid theoretical foundation for using constraints on application behavior to improve testability is essential for establishing a common understanding of the implications, effects, and potential advantages of such an approach. In a constrained system, mechanisms for enforcing the constraints must be in place. A constrained system without these enforcement mechanisms cannot take full advantage of our approach, since no guarantees can be given with respect to test coverage. It is important to note, however, that even without the guarantees given by the enforcement mechanisms our approach may still be superior to current industry practice.

3.2 Test Case Generation and Selection

The expected contributions of this sub-project are:

1. Identification of test case selection criteria and methods for applying these criteria.
2. Methods for measuring the quality of the selected test cases.
3. A test case generation and selection strategy for an application using the suggested constraints that is based on the above criteria.
4. Prototypes of automated tools for generation and selection of test cases based on the suggested strategy.
5. The effect of constraints on realistic systems and the feasibility of applying the methods to systems with relaxed constraints.

Given an upper bound on the test effort for event-triggered real-time systems, the results of this project will improve current methods for test case selection. Our approach makes it possible to determine the proportion of system behaviors that have been tested, and provides test case selection methods that are specifically tailored for real-time systems. Further, the ability to measure the quality of the selected test cases makes is easier to determine when a system has been sufficiently tested. Currently, the degree to which a system is tested is determined by the

resources allocated to the testing process and test coverage metrics do not consider the quality of the selected test cases.

4 Project Plan

This section presents a project plan for each of the sub-projects, consisting of a brief description followed by a more detailed plan in table 4.1. Each sub-project has an initial phase in which current methods are investigated, resulting in a state-of-the-art report. This is followed by a second phase, where methods are developed or refined, then implemented and evaluated, resulting in reports and a thesis. Dates in boldface represent deliverables. The duration of the project is 5 years (4 years effective time).

	Theoretical Foundation	Test Case Selection
1999-10 — 1999-12	Ph.D. Student recruitment	Ph.D. Student recruitment.
2000-01 — 2000-12	Analysis of current methods for improving testability.	Analysis of current methods for test case generation and selection.
2000-12	Report on methods for improving testability.	State-of-the-art report on test case generation and selection methods.
2001-01 — 2001-12	Development of refined upper bound. Specification of enforcement mechanisms.	Development of test case generation and selection strategy.
2001-12	Intermediate report and updated project specification.	Intermediate report and updated specification of the project.
2002-01 — 2003-12	Implementation of enforcement mechanism. Solutions to application specific problems.	Development of test case generation and selection tools.
2003-12	Enforcement mechanisms and solutions to application specific problems integrated into DeeDS.	Prototypes of automated tools for generating, selecting, and analyzing the quality of test cases.
2004-01 — 2004-09	Final write-up of Ph.D. thesis	Final write-up of Ph.D. thesis.
2004-09	Ph.D. thesis.	Ph.D. thesis.

Table 4.1. Project Plan

Theoretical Foundation

The initial phase of this sub-project is concerned with analysis of current methods for improving testability by using constraints on application behavior. The second phase focuses on refining these methods, and specifying enforcement mechanisms for such a system. Solutions to specific problems that arise in a constrained application, and an enforcement mechanisms will be implemented and integrated into the DeeDS prototype.

Test Case Generation and Selection

The initial phase of this sub-project is concerned with analysis of current test case selection techniques. It also identifies suitable criteria for test case selection in a real-time system, and methods for measuring the quality of the selected test cases. The second phase focuses on producing a test case selection strategy for a system using the proposed constraints on application behavior. The test case selection strategy will provide the foundation for specifying, designing, and implementing a prototype of an automated test case generation and selection tool.

5 Preliminary Budget

We request funding for two Ph.D. students. These students will allocate 80% of their time to their graduate studies within this project and, thus, are expected to complete their Licentiate/Ph.D. degrees in 2.5 and 5 years, respectively.

6 Related Research

MARS is a framework for time-triggered distributed real-time systems, developed at the Technical University of Vienna [Kop89]. A complete test strategy and the necessary tools have been produced for the MARS approach [Sch90]. This approach uses the inherent constraints of time-triggered systems to improve testability. In contrast, our approach aims at improving the testability of event-triggered systems, and focuses on testing real-time applications for timeliness.

Methods for reducing the test effort through test case selection range from general approaches such as category partitioning [ABC82, GG75, OB87], to more specific ones based on finite state machines [FB+91], and statistical methods that randomly select inputs from an input space [DN84]. In contrast, our approach is based on reducing the test effort, while still maintaining full test coverage.

In the related ARTES-project TATOO (Test and Testability of Distributed Real-Time Systems) [TATOO, TH99], the aim is to develop methods and tools for deterministic testing of distributed real-time systems. The main approach to achieve deterministic testing of such systems is by transformation of the non-deterministic problem into a set of deterministic problems, whereas our approach is based on constraining the behavior of the system. Furthermore, the approach of TATOO is focusing on distributed real-time systems that can be statically scheduled, whereas our constraint-based approach caters to transaction-based and event-triggered systems.

7 Relation to the Profile

This project is related to three aspects of the profile, namely dependability, distributed systems, and real-time database systems. Our approach will enable full testing of real-time applications which helps make them more dependable. In situations where full testing is not feasible, our approach will still support greater test coverage than possible in an unconstrained system. Further, the use of constraints on application behavior, and our methods for measuring the quality of selected test cases, provide a better coverage measurement technique than currently available.

Our approach is primarily aimed at distributed active real-time database systems, since such systems provide many of the facilities required for implementing the test tools. The approach is, however, not restricted to such an architecture, and can be applied to any system where similar services are made available.

8 Industrial Relevance

One of the main focuses of the Enea Test department is to actively contribute to the test methods and processes used by their customers in various industries. Current industrial practice in testing

real-time systems is often based on case specific ad-hoc techniques. There is a distinct lack of a solid methodology for testing real-time systems. Therefore, it is of great importance to Enea Test to be able to provide its customers with test methods and algorithms which both improve the quality of testing and at the same time facilitate the measuring of the test quality. The customers of Enea Test cover a large proportion of the Swedish real-time industry, which provides an excellent opportunity for transferring the technology advances of this project out to the industry.

9 Context

This research will be carried out in the Distributed Real-Time Systems (DRTS) research group at the University of Skövde, under the direction of Prof. Sten F. Andler and Ph. Lic. Jonas Mellin. The DRTS group is led by Professor Sten F. Andler, Department of Computer Science, University of Skövde, Box 408, SE-54128 Skövde, Sweden (Phone: +46 (0)500 448313, Email: sten.andler@ida.his.se). The group consists of two senior researchers and three Ph.D. students, as well as one or two Master's students and a number of final year projects in any one year. The DRTS group is currently developing a prototype for an active real-time database system (DeeDS) in a project funded by NUTEK since 1994 [And96]. This project has been conducted in cooperation with first Enea Data AB and then Enea OSE Systems AB. The DRTS group is also currently co-operating with the Technical University of Munich and their industry partner Rhode & Schwartz, which is a major developer of man-machine interfaces for complex measurement instruments.

Role of Industry Partner

Enea Data AB has been involved with real-time systems for more than 30 years, both as a product development company and a consultant company. Enea Data AB has around 450 employees and its turnover was 380 MSEK in 1998. Enea's main product, marketed and developed by Enea OSE Systems AB, is the real-time operating system OSE, which is market leading in Scandinavia and one of the leading real-time operating systems in other European countries. Enea Test is part of Enea Industrial Systems, which is a has around 200 consultants working with the industry. Enea Test employs around 50 consultants, involved with testing both hardware and software. Enea Test is led by Thomas Vesterlund, Affärsenhetschef, Box 232, SE-18323 Täby, Sweden (Phone: +46 (0)8 50714000, Fax: +46 (0)8 50714040, Email: thve@enea.se.

Enea's contribution to this project is twofold. Firstly, their consultants possess extensive knowledge of industry practice in testing real-time systems, which provides valuable input to this project. Secondly, their extensive range of contacts within the industry provides a platform for validating the methods produced in this project by testing them with various clients. These skills and contacts will be used both by participation in formulating the research problem and as a reference group for discussing ideas, serve as entry points to industry, etc. Mats Grindal at Enea Test will be participating on a 20% basis during the first year of the project, and it is the aim of Enea Test to participate actively also in the further research work with an industrial Ph.D. student if possible.

A support letter from Enea Data AB dated 1999-05-19 is submitted separately.

References

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[TATOO] ARTES and PAMP Research Projects: TATOO-Test and testability of distributed real-time systems, URL: http://www.docs.uu.se/artes/project/ (Project no: A7-9805)

Appendix A - CV's for Applicants

A.1. Curriculum Vitae for Sten F. Andler

Professor of Computer Science
Dept. of Computer Science, University of Skövde
Box 408, SE-541 28 Skövde, Sweden

Research Experience

University of Skövde, Dept. of Computer Science, Skövde, Sweden.
Apr. 1993 - present, Professor of Computer Science (bitr. prof. i datalogi)

Distributed Real-Time Systems Research Group: This research group was formed in September 1993 as a competence center for database-related problems in distributed real-time systems, such as synchronization, scheduling, reactive mechanisms, debugging, distribution, etc. This group is carrying out an externally funded industrial research collaboration project called Distributed Active Real-Time Database Systems (DeeDS). This is a collaboration with first Enea Data AB and then Enea OSE Systems AB, Täby, Sweden, and is sponsored by NUTEK, the National Board for Industrial and Technical Development, since February 1994. Our short-term goal was to build an environment in which we can experiment freely with the components of a well-designed, flexible, distributed real-time database system. This has resulted in a Distributed Active Real-Time Database Systems prototype. Our long-term goal is to use this experimental system as a research vehicle with which to pursue further research in dynamic real-time scheduling, time-cognizant reactive mechanisms, and distributed event monitoring.

IBM Software Solutions Division, Santa Teresa Laboratory, San Jose, California
Feb. 1992 - Apr. 1993, Advisory Programmer.

DataHub/AIX Future Project: Defined and specified a future product to allow remote management of relational databases on AIX/6000 (a UNIX operating system running on RISC System/6000) from a DataHub workstation anywhere in the network, in a similar way that was envisioned for control of databases on the mainframe.

Information Warehouse Design Control: Participated in the Information Warehouse Architecture group, and co-produced an internal Information Warehouse Design Control document, proposing the directions for a set of early products in the Information Warehouse series, whose intention it was to make all of an enterprise's data available in understandable form to knowledge workers anywhere in the organization.

IBM Research Division, Almaden Research Center, San Jose, California
Oct. 1979 - Feb. 1992, Research Staff Member.

Electronic Imaging/Font Technology: Developed imaging engines for high-function printers and displays. Invented techniques for automatic derivation of gridfitting hints for scaleable fonts. Implemented an outline font rasterizer for Adobe Type 1 font format. This involved design and implementation of techniques for processing font hints and continuity requirements, in order to render professional-quality scaleable fonts. This Type I font rasterizer was donated by IBM, in Oct. 1991, to the MIT X Consortium for distribution as part of the X Windows System, the industry standard windowing environment for UNIX workstations. Nov 1985 - Feb 1992.

Technical Staff: Reviewed budgets and research plans for the Computer Science Department. Conducted technical reviews of Computer Science Projects. Participated in Corporate Task Force to determine what the Research Division could do to support the company's printer and display divisions. Nov. 1984 - Nov. 1985.

Workstation System Software: Developed systems software for a family of office workstations. Designed and implemented communication software. Operated electronic mail gateway to CSNET/Internet and redesigned electronic mail software. Sep. 1993 - Nov. 1984.

System D: Developed a distributed transaction processing system, consisting of a set of servers connected by a high-speed local network. Designed the system architecture and created the communication subsystem. Oct. 1979 - Jun. 1981.

Xerox Palo Alto Research Center (PARC), Palo Alto, California.
May 1977 - Aug. 1977, Research Intern.

Modularized an interactive graphics editor, and then added a communications module to allow collaboration between any number of users on an Internet (containing both Ethernets and slow telephone lines). The design was a simple distributed database, where the requirements were to maintain consistent copies of a small fast-changing data base at nodes of a minimally connected network of virtual circuits. Updates could occur at any node, and nodes or groups of nodes could leave and enter the collaboration network.

Carnegie Mellon University, Dept. of Comp. Sci., Pittsburgh, Pennsylvania.
Aug. 1975 - Aug. 1979, Graduate Assistant.

Research on synchronization mechanisms, in particular, the specification, implementation, and verification properties of Predicate Path Expressions. Designed and implemented Predicate Path Expressions and a data abstraction mechanism as an Algol 68 preprocessor. Designed and implemented an experimental programming language using the CDL-2 compiler-compiler.

Chalmers University of Technology, Göteborg, Sweden.
Feb. 1972 - Aug. 1975, Teaching/Research Assistant.

Analyzed and simulated cyclic storage media, especially the interference between input-output processes and the effect of buffering.

Designed microprogramming support to implement a control structure for small computers.

Degrees

Ph.D. in Computer Science, Chalmers University of Technology, Göteborg, Sweden. Dec. 1979.

Ph.D. in Computer Science, Carnegie Mellon University, Pittsburgh, Pennsylvania. Aug. 1979.

M.S. in Computer Science, Carnegie Mellon University, Pittsburgh, Pennsylvania. May 1976.

M.S. in Engineering, Chalmers University of Technology, Göteborg, Sweden. Feb. 1972.

Teaching Experience

University of Skövde, Dept. of Computer Science, Skövde, Sweden.
Apr. 1993 - present, Professor of Computer Science (bitr. prof. i datalogi)

IBM Research Division, Almaden Research Center, San Jose, California.

University of California at Berkeley, Berkeley, California.
Spring 1984, Visiting Professor of Computer Science.

Carnegie Mellon University, Dept. of Comp. Sci., Pittsburgh, Pennsylvania.
1975 - 1979, Graduate Assistant.

Chalmers University of Technology, Göteborg, Sweden.
Fall 1976, Teaching assistant.
1972 - 1975, Instructor and Teaching Assistant.

Honors and Awards

Research Division Technical Group Award, IBM Almaden Research Center, Dec. 1993. For "contributions to the development of the Hourglass language and image processing software for use with printers and displays."

External Recognition Award (Secretary/Treasurer to ACM SIGOPS), IBM Almaden Research Center, Nov. 1988.

Research Informal Award (Hosted First Corporate Datastream Architecture Meeting), IBM Almaden Research Center, Jan 1987.

Research Division Award (Developed electronic mail software and a gateway to CSNET/Internet), IBM Research Division, May 1983.

Graduate Stipend, Carnegie Mellon University, Aug. 1975 - Aug. 1979.

Doctoral Scholarship, Chalmers University of Technology, 1975 - 1979.

Travel Fellowship (for studies in the USA), The Swedish Government, 1975.

ASEA Scholarship (for studies in the USA), The Sweden-America Foundation, 1975.

Professional Activities

Member of the Editorial Board of the IEEE Press Series on Engineering of Complex Computer Systems

Member of the Executive Committee of the IEEE Technical Committee on Complexity in Computing (TCCX)

Program Co-Chair of the Fourth International Conference on Engineering of Complex Systems (ICECCS '98), Monterey, California.

Publicity co-chair of the Real-Time Technology and Applications Symposium (RTAS '98).

Member of the Program Committee of the Third International Conference on Engineering of Complex Systems (ICECCS '97), Como, Italy.

Co-Chair of the Complex Database Systems and Data Management Track of the Second International Conference on Engineering of Complex Systems (ICECCS '96), Montreal, Canada.

Member of the Program Committee of the Second International Conference on Engineering of Complex Systems (ICECCS '97), Montreal, Canada.

Member of the Program Committee of Real-Time Database Workshop RTDB '96, USA.

Program Co-Chair of the International Workshop on Active and Real-Time Database Systems (ARTDB-95), Skövde, June 1995. The workshop was co-sponsored by ACM and ACT-NET, the European Research Network for Active Databases.

Member of Program Committee, International Workshop on Raster Imaging and Digital Typography (RIDT'89), Lausanne, Switzerland, Oct. 12-13, 1989.

Secretary/Treasurer to ACM SIGOPS for two years.

Memberships in Professional Organizations

Association for Computing Machinery (ACM)

IEEE Computer Society

Publications

1. S.F. Andler, J. Eriksson, and M. Lundin, Distributing Control Systems Using Active Rules, In Proc Jt 24th IFAC/IFIP Workshop Real Time Programming (WRTP'99) & 3rd Int'l Workshop Active and Real-Time Database Systems (ARTDB-99), Schloss Dagstuhl, May-June 1999.

2. S.F. Andler and J. Hansson (eds.), Active, Real-Time, and Temporal Database Systems: Proc 2nd Int'l Workshop (ARTDB-97), Springer LNCS, 1998.

3. S.F. Andler, J. Hansson, J. Eriksson J. Mellin, and B. Eftring, Overview of the DeeDS Architecture, In Proc Workshop Parallel and Distributed Real-Time Systems (WPDRTS'98), Orlando, Florida, 1998.

4. J. Hansson, S.H. Son, J.A. Stankovic and S.F. Andler, Dynamic Transaction Scheduling and Reallocation in Overloaded Real-Time Database Systems, In Proc 5th Int'l Conf Real-Time Computing Systems and Applications (RTCSA'98), Hiroshima, Japan, IEEE Computer Society Press, 1998.

5. J. Mellin, J. Hansson, and S.F. Andler, Refining Design Constraints of Applications in DeeDS, In Real-Time Database Systems, A. Bestavros, K-J Lin, and S.H. Son (eds.), Kluwer, May 1997.

6. ¨DeeDS Towards a Distributed Active and Real-Time Database System," with Jörgen Hansson, Joakim Eriksson, Jonas Mellin, Mikael Berndtsson and Bengt Eftring. ACM SIGMOD Record, Special Section on Advances in Real-Time Database Systems, 25, 1 (March 1996), pp. 38-40.

7. ¨Refining Design Constraints from a System Services Model of a Real-Time DBMS," with J. Mellin, J. Hansson. In Proc. 1st Int'l Workshop on Real-Time Databases: Issues and Applications, March 1996.

8. ¨Automatic Generation of Gridfitting Hints for Rasterization of Outline Fonts and Graphics." In EP90: Proc. Int'l Conf. Electronic Publishing, Document Manipulation & Typography, R. Furuta (ed.), Cambridge University Press, 1990, pp. 221-234.

9. ¨The COSIE Communication Subsystem: Support for Distributed 0ffice Applications," with D. B. Terry. ACM Trans. Office Information Systems (TOOIS) 2, 2(Apr. 1984), pp. 79-95.

10. ¨Experience with Measuring Performance of Local Network Communications," with D. B. Terry. In Proc. 26th IEEE Computer Society Int'l Conf. (COMPCON), Feb. - Mar. 1981, pp. 203-205.

11. ¨System D: A Distributed System for Availability," with I. Ding, K. Eswaran, C. Hauser, W. Kim, J. Mehl, and R. Williams. In Proc. 8th Int'l Conf. Very Large Data Bases (VLDB), Mexico City, Sep. 1982, pp. 33-44.

12. ¨On Enhancing Local Network Communication Devices," with D. Daniels and A. Spector. In Local Networks for Computer Communications, A. West and P. Janson (eds.). North-Holland Publishing Company, 1981, pp. 191-205.

13. ¨Predicate Path Expressions: A High-Level Synchronization Mechanism." Ph.D. Thesis, Carnegie Mellon University, Pittsburgh, Pennsylvania, Aug. 1979.

14. ¨Predicate Path Expressions." In Conf. Record 6th ACM Symposium on Principles of Programming Languages (POPL), San Antonio, Texas, Jan. 1979, pp. 226-236.

15. ¨Synchronization Primitives and the Verification of Concurrent Programs." In Operating Systems: Theory and Practice, D. Lanciaux (ed.). North-Holland Publishing Company, 1979, pp. 67-99.

16. ¨Types in Algol 68," with Peter Hibbard. In Proc. 5th Annual III Conf. on the Implementation and Design of Algorithmic Languages, IRIA, Guidel, France, May 1977, pp. 124-144.

Technical Reports

1. R. Birgisson, J. Mellin, and S.F. Andler, Bounds on Test Effort for Event-Triggered Systems, Tech Report HS-IDA-TR-99-001, Dept Comp Sci, U Skövde, 1999. (Submitted for publication.)

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Ph.Lic. Predictable Event Monitoring, University of Linköping, 1998.
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Research Interests

Research interests are mainly multi-purpose timely event monitoring and its uses. Further, interests are in software engineering, requirements engineering (elicitation, negotiation, and validation), distributed systems, databases, object-orientation, software architecture, testing, debugging, and programming methodology.

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A.3. Brief Curriculum Vitae for Mats Grindal

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