ARTES Project Extension Application: Simulation Concepts to Model Real-Time Properties of Symmetric Multiprocessor Systems

Lars Albertsson
Computer and Network Architectures Laboratory
Swedish Institute of Computer Science
lalle@sics.se

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1 Introduction

This is a request for a two-year extension of the funding for the ARTES project "Simulation Concepts to Model Real-Time Properties of Symmetric Multiprocessor Systems". The project has previously been granted funding for two years, ending 2001-04-30. We therefore apply for a retroactive extension, starting 2001-05-01.

The research within the project is focused on exploring how complete system simulators can be used for building, testing, and debugging real-time applications in general-purpose symmetric multiprocessor systems. A complete system simulator is basically an entire computer implemented only in software. It provides an effective platform for observing temporal behaviour of computer systems; execution in the simulator is deterministic, and application time flow can be observed, replayed, and analysed without intrusion.

During the first phase of the project we have developed tools for temporal debugging of real-time applications and performed case studies of real-time system debugging on the Linux kernel and on a multimedia application. We have also explored a novel technique for explaining deadline misses in real-time applications: correlating deadline misses with system events and measurements. The results indicate that this technique is effective for real-time system performance analysis, and we therefore wish to continue constructing simulation-based profiling tools for real-time systems.

We also aim to develop tools for debugging and finding race conditions. Race conditions is also an example of a time-dependent and non-deterministic problem that appears in multiprocessor-based real-time systems. The deterministic debugging environment that we have developed is therefore a suitable tool for replaying and debugging race conditions. We will continue by developing a tool for both finding race conditions in concurrent software by manipulating the simulator to trigger unlikely, but possible, interleavings of events in the system.

2 Problem Statement

Emerging information technology applications such as information servers, multimedia servers and telecommunications systems, are characterised by requiring both high throughput performance and predictable service. Due to economical and performance requirements, such applications are often developed on commodity symmetric multiprocessor platforms. Unfortunately, developing correct concurrent real-time software is difficult. This difficulty is compounded by a lack of tools to aid the developers.

Simulation methodologies are an effective approach in the analysis of functional and performance behaviour of a complete computer system. The major advantage is that hardware/software interactions can be studied in a deterministic manner. The functional and timing specification of the hardware platform is implemented in a software simulation model which makes the interaction of the complete software system, encompassing application and system software, with the hardware platform visible. Therefore, such a simulation system provides a powerful environment to verify function as well as tracking performance bottlenecks. It also allows manipulation of the simulated system in order to check software robustness under stressful conditions which can be very difficult to obtain on real systems.

The simulator used in this project, Simics [1], is a complete system simulator [1, 2]. It provides an accurate functional model of a modern workstation, allowing operating systems and applications to run without modification. Because the simulator is implemented in software, the execution can be observed and replayed. The simulator itself, however, provides a low-level interface, and is not immediately useful as a tool for real-time or concurrent application developers. In this project, we therefore explore and construct new types of tools using Simics as a basic building block. The research is performed in collaboration with Virtutech, manufacturer of Simics.

3 Project plan and expected results

The project is performed by Lars Albertsson, supervised by Erik Hagersten, Uppsala University, and Peter Magnusson, SICS/Virtutech.

Month 1-6 A performance profiling tool for real-time applications. The tool should support correlation between system metrics and missed deadlines as well as user-defined comparisons between periods where deadlines are met and periods where deadlines are missed. The profiling tool will be implemented as an extension to a standard symbolic debugger.

Month 7-12 Initial work on race condition detection. We will evaluate our proposed race condition detection method by using it on programs with known bugs. We will also explore how efficiency can be improved by cutting down the search space.

Month 13-18 Implementation of race condition detection tool, including support for guiding race condition search to recently developed or error-prone

code sections. We will also develop an aid tool for bug tracking, which operates by comparing simulation to reference executions.

Month 19-24 Thesis work. Publication of a journal article.

4 Industrial relevance

Assuring that concurrent software with real-time requirements is correct and provides reliable performance is a very difficult task. Today, there are no good methods and few tools to aid software developers to detect problems specific to such software. This is an important issue for companies whose products require reliable service, such as manufacturers of telecommunication and financial systems, as well as for the computer system vendors themselves. In order to obtain industrial experience in the field, I will visit Sun Microsystems during the project duration to work with multiprocessor system testing. This work will be performed with the aid of complete system simulation, but it is yet unclear how closely it will fit with the project plan.

Appendices

1. Second year report for the project
2. CV for Lars Albertsson

References

[1] Peter S. Magnusson, Fredrik Dahlgren, Håkan Grahn, Magnus Karlsson, Fredrik Larsson, Fredrik Lundholm, Andreas Moestedt, Jim Nilsson, Per Stenström, and Bengt Werner. SimICS/sun4m: A Virtual Workstation. In *Proceedings of the 1998 USENIX Annual Technical Conference*, 1998.

[2] Mendel Rosenblum, Stephen A. Herrod, Emmett Witchel, and Anoop Gupta. Complete computer system simulation: The SimOS approach. *IEEE parallel and distributed technology: systems and applications*, 3(4):34–43, Winter 1995.

Simulation Concepts to Model Real-Time Properties of Symmetric Multiprocessor Systems Second Year Report

Lars Albertsson
Computer and Network Architectures Laboratory
Swedish Institute of Computer Science
lalle@sics.se

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Introduction

Within the research project "Simulation Concepts to Model Real-Time Properties of Symmetric Multiprocessor Systems" we explore the use of complete system simulation for analysing high performance systems with quality of service requirements. By using Simics, a system-level instruction set simulator, operating systems and time sensitive applications may be analysed without intrusion. Our goal is to develop tools and methods for performance analysis and debugging of complex, multiprocessor based real-time systems, using simulation as a building block.

The project plan mentions three main objectives:

- Development of tools for analysing quality of service sensitive applications within simulation models of multiprocessor systems.
- Development of environments for feeding modelled user input to simulation of interactive applications.
- Evaluation of proposed modifications to make conventional SMP capable operating systems support QoS guarantees.

Results

The activity under the first two years have concentrated on the first objective, building tools based on simulation. After obtaining experience with the research field, we think that the most interesting results will be produced by investigating how new types of tools can be built. The research will therefore continue in this direction, by exploring other types of tools for time-sensitive programs.

These specific accomplishments have been made during the first two years:

- Design and prototype of a simulation based "temporal debugger", capable of analysis of operating system execution time flow. As a case study, we have used the temporal debugger to analyse short time critical sequences in Linux. These results were presented at MASCOTS [5] and the Real-Time Linux Workshop [4].
- Detailed design of a temporal debugger for analysis of user applications. The key component of the debugger is a technique for mapping low-level data, provided by the simulator, to application level data useful to the debugger. The debugger was presented briefly at RTAS [2]. A more detailed presentation has been submitted for consideration [3].
- Demonstration of the temporal debugger by analysing missed deadlines of an MPEG video decoder. It is also demonstrated how the debugger environment can be used to measure performance statistics in the simulated system, and how these statistics are useful for profiling real-time applications and explain missed deadlines [3].
- A support meta-tool (tool to build tools) for probing of a simulated system. This meta-tool has been essential in the construction of the temporal debugger, and facilitates building other tools for probing programs in the simulated system. It is also useful for building other types of support software, such as models for application input.
- A study in related research regarding practical methods for constructing, validating, and predicting real-time system behaviour [1].

Industrial participation

The project is based on the use of Simics, developed by Virtutech, which is a spin-off company from SICS. As the project represents a novel use of Simics, it exposes services the simulator may need to support. It is therefore a source of input to discussions on future directions of Simics. Peter Magnusson, assistant supervisor, is the creator of Simics as well as the manager of Virtutech. He is familiar with the issues involved in complete system simulation, and plays a key role in the education.

Publications

[1] Lars Albertsson. An overview of practical research approaches to real-time system engineering. Technical report, Swedish Institute of Computer Science, 2001.

[2] Lars Albertsson. Simulation-based debugging of soft real-time applications. In *Proceedings of the Real-Time Application Symposium*. IEEE Computer Society, IEEE Computer Society Press, May 2001.

[3] Lars Albertsson. Temporal debugging and profiling of multimedia applications. Submitted for Multimedia Computing and Networking, 2002.

[4] Lars Albertsson and Peter S. Magnusson. Simulation-based temporal debugging of Linux. In *Proceedings of the Second Real-Time Linux Workshop*, December 2000.

[5] Lars Albertsson and Peter S. Magnusson. Using complete system simulation for temporal debugging of general purpose operating systems and workloads. In *Proceedings of MASCOTS 2000*. IEEE Computer Society, IEEE Computer Society Press, August 2000.

virtutech

Tuesday, June 05, 2001

ARTES
Box 325
SE-751 05 Uppsala
Sweden

Attn: Roland Grönroos

To Whom It May Concern:

Virtutech hereby wishes to declare it's continued endorsement and support of project no P1-9805 "Simulation Concepts to Model Real-Time and Dependability Properties of Symmetric Multiprocessor Systems" within the PAMP programme.

The use of complete system simulation to analyze high performance systems with quality of service requirements is of general industrial interest, and is of particular interest to Virtutech.

The use of simulation to support the design and implementation of high performance systems is well established, and Virtutech is having great success marketing Simics™ for such applications. The use within any real-time domain raises difficult issues where input from research projects is highly valuable.

The potential is very large indeed. Today quality of service requirements on high performance systems are slowly but steadily increasing. There simply do not exist adequate tools and methods to handle the requirements that this blend causes to arise. And this at a time when such systems are becoming the default compute/communication platform across industry.

We're very impressed by the work done to date by the principal investigator, Lars Albertsson at the Swedish Institute of Computer Science (SICS). Virtutech is happy to continue supporting this project with access to Simics engineers and technology.

Sincerely,

Peter S. Magnusson
Chairman and CEO
Virtutech AB

WWW.VIRTUTECH.SE
NORRTULLSGATAN 15, 1 TR • SE-113 27 STOCKHOLM • SWEDEN
PHONE: +46 8 690 07 20 • FAX: +46 8 690 07 29

Curriculum Vitae

Lars Albertsson
Computer and Network Architectures Laboratory
Swedish Institute of Computer Science
Box 1263, SE-164 29 Kista, Sweden
lalle@sics.se, www.sics.se/~lalle

Employment

Since 1997, I am a member of the Computer and Network Architectures Laboratory at the Swedish Institute of Computer Science. My research is focused on the construction of profiling and debugging tools for real-time and multi-threaded software. The work is based on Simics, a simulator modelling an entire computer system.

I have previously worked with network protocol implementation, including IPv6 development for HP-UX and IP multicast for the Nemesis operating system.

Education

Master of Science in Electrical Engineering 1999 from the Royal Institute of Technology, Stockholm. Thesis title: "Interactive Visualisation Using Parallel Computers".

Publications

[1] Lars Albertsson. Simulation-based debugging of soft real-time applications. In *Proceedings of the Real-Time Application Symposium*. IEEE Computer Society, IEEE Computer Society Press, May 2001.

[2] Lars Albertsson and Peter S. Magnusson. Simulation-based temporal debugging of Linux. In *Proceedings of the Second Real-Time Linux Workshop*, December 2000.

[3] Lars Albertsson and Peter S. Magnusson. Using complete system simulation for temporal debugging of general purpose operating systems and workloads. In *Proceedings of MASCOTS 2000*. IEEE Computer Society, IEEE Computer Society Press, August 2000.