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# Design Strategies for Real-Time High-Performance Multimedia Applications on Multiprocessors

## Second Year Report

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## 1. Summary of Project

According to the original project proposal, the goal of this project is to develop concepts in terms of (i) *quality-of-service negotiating scheduling algorithms* that adjust the quality-of-service (QoS) level dynamically and (ii) *worst-case performance analysis and improvement techniques* to reduce the gap between average and worst-case performance for virtual-reality applications on multiprocessor systems. The developed concepts shall make it possible to design parallel programs that can achieve high performance on a wide range of multiprocessors under real-time requirements.

The project goals will be achieved through two Ph.D. student projects carried out by Jonas Lext and Björn Andersson whose detailed plans are available from <http://www.ce.chalmers.se/pamp/utv/jonas.pdf> and <http://www.ce.chalmers.se/pamp/utv/bjorn.pdf>, respectively. The focus of the first Ph. D. subproject is real-time rendering algorithms and their efficient implementations on multiprocessors. Key research issues are to find efficient parallelization strategies to address the performance and real-time goals of real-time rendering algorithms. The focus of the second Ph. D. subproject is to develop principles for QoS negotiation in adaptive real-time multiprocessor systems. Here, we want to devise run-time scheduling heuristics that can adapt their behavior dynamically in accordance with available resource capacity and designer specifications.

Apart from the two Ph. D. students directly financed by ARTES/PAMP, the project also involves an industrial Ph. D. student (Ulf Assarsson) whose project focus is on real-time rendering algorithms for multiprocessor systems. In addition, apart from the two senior researchers Per Stenström and Jan Jonsson, a third senior scientist, Tomas Akenine-Möller, is associated with the project. He acts as co-supervisor for Jonas Lext and Ulf Assarsson.

Ulf Assarsson's involvement in this project also constitutes the industrial link to ABB Robotics Products who uses the technology developed in the project in a CAD application taking the form as tools for real-time 3D simulation of industrial robots in automated workshops.

In this second-year project report, we briefly overview the original plans, the achieved results, and the deviation from the original plan for each of the two projects financed by ARTES/PAMP in Sections 2 and 3, respectively. Finally, we comment on the industrial role of the projects in relation to the collaboration with ABB Robotics Products in Section 4.

## 2. Project status “Parallelization of VR algorithms”

### 2.1 Original plan

In the original plan, the following milestones and deliverables were specified:

- **Activity 9807-9809:** ARTES/PAMP student recruitment.
- **Activity 9809-9909:** First phase of project. In this phase the application requirements will be analyzed by selecting study objects in terms of parallel visualization algorithms to identify performance and real-time issues. **Deliverable 9909:** Selection of study objects in terms of parallel implementations of visualization algorithms. State-of-the-art report on performance and real-time issues based on preliminary evaluations. Refined specifications of the Licentiate project topics and project plans.

The project formally started in January 1999 because the student recruitment took a little longer than expected. In August 1999, a first revision of the original project plan was done motivated from an evaluation of all ARTES projects that took place during the ARTES/PAMP summer school in Linköping in August 1999. In the revised study plan, the following concrete project goals were specified:

- **Study 1: Design and compilation of a benchmark for dynamic scenes**

This study aims at identifying suitable performance and real-time metrics to evaluate real-time rendering algorithms. The key result of this study is a methodology to evaluate properties of real-time rendering algorithms along with a benchmark suite that allows for objective comparisons between different algorithms. The anticipated deadline for completion of this project phase was 9912.

- **Study 2: Evaluation of new acceleration methods for real-time ray tracing**

This study aims at evaluating two new ideas regarding the intersection tests in ray tracing that often is a performance bottleneck in this application. The intersection tests to be evaluated are not only expected to perform better than previously proposed methods but are also expected to lend themselves better for animation in that they take advantage of scene geometries and frame-to-frame coherency to speed up the computation. Thus, they are good candidates for meeting the real-time constraints for rendering in real-time. The evaluation will be based on the methodology developed in Study 1. The anticipated deadline for the completion of this project phase is 0009.

### 2.2 Project results and deviation from original plan

Study 1 has been completed. The results from this project phase has been reported in a paper entitled “A Benchmark for Animated Ray Tracing”, which has been published by IEEE Computer Graphics & Applications, March/April 2001. With the exception of that the project has been delayed due to that implementations took longer than expected, this project has followed the plan and no deviation from the original plans has occurred.

During study 2, a method has been developed that allows the ray tracing process to be parallelized by about a factor 10 in comparison to not using the developed method. The idea is to reduce the work done in the parts of the algorithm that is very hard to parallelize. The work was presented at the largest computer graphics conference in Europe, called EuroGraphics, this autumn. Also, as a side effect, another article which determines rapidly whether a triangle overlaps a box has been developed, and this algorithm has been published in Journal of Graphics Tools. This algorithm was needed in order to complete the study 2 as well. This is also according to the plan (except for the delay).

Ulf Assarsson has been working on parallelization of tree traversal algorithms with focus on computer graphics algorithms, such as view frustum culling and collision detection. This extensive work has been presented at EuroPar, also this autumn. Ulf has also written and defended his licentiate thesis this year.

### 3. Project status “Real-time scheduling algorithms for QoS negotiations”

#### 3.1 Original plan

In the original plan, the following milestones and deliverables were specified:

- **Activity 9807-9809:** ARTES/PAMP student recruitment.
- **Activity 9809-9909:** First phase of project. In this phase the different task dispatching methods will be analysed and their performance assessed. **Deliverable 9909:** State-of-the-art report on properties and other issues based on preliminary evaluations. Refined specifications of the Licentiate project topics and project plans.

The project formally started in January 1999 because the student recruitment took a little longer than expected. In August 1999, a first revision of the original project plan was done motivated from an evaluation of all ARTES projects that took place during the ARTES/PAMP summer school in Linköping in August 1999. In the revised study plan, the following concrete project goal was specified:

- **Study 1: Analysis of real-time multiprocessor task dispatching methods**

This study aims at analysing the properties and performance of two different task dispatching methods for shared-memory multiprocessor systems, namely the partitioned approach (where each task always execute on the same processor) and the non-partitioned approach (where a tasks can execute on an arbitrary processor). The purpose of the study is to determine which of these methods are most suitable for an adaptive real-time system where task sets may change during the course of the system’s mission. The key results of this study are (i) an in-depth understanding of mechanisms of the different dispatching methods including identification of possible scheduling anomalies, and (ii) how the temporal behaviour of the methods can be predicted in advance. The anticipated deadline for completion of this project phase was 9908.

- **Study 2: Analysis of bus contention on schedulability for shared-memory multiprocessors**

This study aims at analysing the impact of bus operations in a shared-memory multiprocessor on the schedulability of a set of real-time tasks. The main focus of the study is to analyse whether it is possible to determine a worst-case scenario for memory references in a shared-memory architecture with a round-robin-based bus arbitration policy. Since memory references typically are a function of local cache contents, all bus operations do not occur in reality. We intend to analyse and evaluate the overhead as caused by bus operations for the task dispatching methods in Study 1. The anticipated deadline for completion of this project phase was 0006.

#### 3.2 Project results and deviation from original plan

Study 1 has been very successful and has revealed several new research problems, and has therefore been extended to also encompass spring/fall 2001. The results from Study 1 has been reported in several papers.

The first paper, entitled "Some Insights on Fixed-Priority Preemptive Non-Partitioned Multiprocessor Scheduling," was presented in a preliminary form at a Work-in-Progress session at the *IEEE Real-Time Systems Symposium* in December 2000. This paper reports on several observations regarding non-partitioned multiprocessor scheduling, most notably issues relating to scheduling anomalies, schedulability testing and priority assignment. In particular, the paper explains why the transition from the uniprocessor to the multiprocessor case is not an easy one. An extended and highly revised version of this paper was submitted to the *IEEE Transactions on Computers* in March 2001.

The second paper, entitled “Fixed-Priority Preemptive Multiprocessor Scheduling: To Partition or Not to Partition”, was presented at the *IEEE Int’l Conf. on Real-Time Computing Systems and Applications* in December 2000. The main results in that paper are all aimed at refuting the common belief that the non-partitioned method is inferior to the partitioned method for real-time scheduling. To this end, we have made the following contributions: (i) identified important scheduling anomalies and limitations for the non-partitioned method and pinpointed fundamental differences between the schedulability conditions in multi- and uniprocessor systems; (ii) proposed a new priority-assignment policy for the non-partitioned method that circumvents many of the identified anomalies and limitations; and, by simulation experiments,

we have shown that the new policy increases the system's ability to meet deadlines to levels above that of the partitioning method; (iii) proposed a new dispatching algorithm for the non-partitioned method that reduces the number of task preemptions to levels below that of the partitioning method.

The third paper, entitled "Static-Priority Scheduling on Multiprocessors", will be presented at the *IEEE Real-Time Systems Symposium* in December 2001. The main result from this paper is a new static-priority assignment scheme for non-partitioned multiprocessor scheduling that circumvent several performance bottlenecks that have plagued traditional assignment schemes. The paper contains formal derivation and proofs of a scheduling-related performance guarantee bound for the new scheme, as well as an experimental evaluation of its actual run-time performance.

The fourth paper, entitled "Preemptive Multiprocessor Scheduling Anomalies", was recently submitted for possible publication at the *IEEE Int'l Parallel and Distributed Processing Symposium*. This paper shows that scheduling anomalies can in fact occur in all forms of multiprocessor scheduling, not only non-partitioned but also partitioned and time-table-driven systems. The paper also presents methods for avoiding scheduling anomalies in a partitioned system.

The first three papers resulting from Study 1 constitute the licentiate dissertation of Björn Andersson which was presented in June 2001. Because Study 1 was found to trigger further research issues, Study 2 was never initiated.

#### 4. Statement from participating industry

ABB Robotics Products develops tools for real-time 3D simulation of industrial robotics in automated workshops. There are two characteristic performance bottlenecks in the software that implements this application: (1) real-time simulation of the control equipment of the robotics and (2) real-time rendering in 3D for detailed CAD models of the robot cells. High detailness is often needed for correct placement of e.g. the welding points and collision detection. The project focus on real-time 3D graphics in this project provides important input to advance the state of the products in this application domain.

#### List of references

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ABB is the leading supplier of industrial robots with 100,000 robots installed world-wide. ABB Automation Technology AB has 2000 employees in Sweden and develops and manufactures robots. An essential part of the robot is the software, where efficient methods to support the programming of the robot is key. One way to improve the programming aspect is to use VR models. Programming is then performed by e.g. pointing out the route of the robot in a virtual reality model of the factory. Because many programming tasks, such as pointing out welding points, involve very detailed models of the factory, a key challenge for such tools is the availability of high-resolution real-time VR models that can be run on cost-effective platforms. The focus on real-time rendering algorithms in this project is clearly an important asset to the technology used in the tools developed at ABB. Also, the focus on investigation of design principles of such algorithms on multiprocessors is interesting owing to the fact that multiprocessors are likely to become the de-facto platform even for low-end PC machines.

A handwritten signature in black ink, appearing to read 'Robert Busk', written over a horizontal line.

Robert Busk, ABB Robotics

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