Proposal to ARTES
Flexible Reliable Timing Constraints

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Updated version; acoording to evaluator comments

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1 Summary

The goal of the proposed research is to develop methods for the derivation, specification, and run-time execution of activities with timing constraints, which exploit inherent flexibility in temporal demands, e.g., on application level, instead of *overconstraining* specifications. We propose to use *flexible timing constraints,* which express feasibility information of activities rather than numbers demanded by common system models and scheduling algorithms. These will be scheduled by *novel offline algorithms*, which are capable of exploiting the expressed flexibility, while maintaining *reliability* requirements.

2 Problem Statement

The main concern with respect to temporal behavior of a real-time system is meeting the timing relations between input and output from and to the environment, respectively. Timing constraints such as period and deadline meet demands of system models and in particular scheduling algorithms rather than application level requirements. Instead of focussing on application demands, timing constraints are determined to suit task models mandated by system operation.

Many real-world industrial applications, e.g., automotive and control applications, have timing requirements which cannot be expressed by deadlines and periods or which restrict the system if expressed by standard timing constraints. Only few tasks have “natural” periods and deadlines. Most are only derived during system design in an iterative process: they are artifacts. Often, several settings for deadline and period may be feasible, but only one can be selected: the specification becomes *overconstrained.* In addition, the knowledge about original requirements and their inherent flexibility is abandoned and no longer available to subsequent design and runtime phases. The decomposition of end-to-end deadlines in distributed systems, for example, results in constraints for tasks on individual nodes with no information about other tasks and overall deadlines. Only when the entire design is completed, can an incorrect selection be detected, e.g., by a failed scheduling attempt. Adaptive fault-tolerance methods allow for the choice of fault-tolerance methods, task ensembles, redundancy levels, etc., provided the required reliability is achieved. Again, the designer has to select one out of several feasible choices, with different impact on timing constraints and schedulability.

While the knowledge of several options and choices may exist during design, the lack of appropriate representation leads to its abandoning. The design ends with numbers for, e.g., deadlines and periods, providing no further information about the options that existed. When redesign is necessary, this information has to be derived again or recollected by the designer without support. Rather, the feasibility information, if accessible to the designer in the process, is of interest. It can be used to instantiate or select timing constraints repeatedly should the redesign be carried out.

Most current scheduling techniques are designed to handle constraints expressed on the level of periods and deadlines. Consequently, they cannot exploit extra flexibility in temporal demands efficiently. One particular restriction is the assumption of timing constraints being *static*, i.e., they are the same and stay fixed for all instances of an activity. This prevents solving timing problems by changing the set of timing constraints for single instances, e.g., to avoid collisions with other periodic or aperiodic activities, or rearranging subtask deadlines.

No temporal guarantees can be given if the system does not provide certain reliability: deadlines are at risk if simple faults cannot be tolerated and lead to failures. Special attention has to be given to the impact of increased temporal flexibility on reliability, e.g., with respect to fault-tolerance methods such as replica determinism. Reliability demands, possibly adapting during a system lifetime, are key criteria for selection of timing constraints.

3 Main Ideas

3.1 Technical proposal

We propose to investigate into *flexible timing constraints*, which help to overcome the above stated problems. Instead of using numbers to constrain tasks, such as for period and deadline, these represent information about the *feasibility* of system activities: *Timing entities*, i.e., functional units whose execution is temporally constrained, are given *feasibility functions* describing the temporal relations on the unit's input and output. Given a set of timing constraints, the feasibility function determines whether the temporal requirements on the timing entity are met by these constraints. This may include reliability requirements and instantiation of timing constraints. In the case of repeating or periodic entities, the derived constraints can either be constant for all instances or varying with each instance.

We envision *decomposition* of the proposed flexible timing constraints: Given a timing entity composed of subentities and a feasibility function, a set of feasible timing constraints for the subentities can be instantiated, keeping information about flexibility. Starting from application level demands on input and output of system services, an iterative design process refines until a scheduling algorithm can process the timing constraints.

While knowledge of flexibility in temporal constraints facilitates the design process, it can be fully exploited when taken into account during *scheduling*: Artifacts created during design can be changed, e.g., to change subtask deadlines, within the flexibility provided during scheduling, instead of requiring redesign and rescheduling. New scheduling methods will have impact on runtime complexity and system reliability. We will investigate into several directions for scheduling of timing entities and flexible timing constraints and analyze each for such tradeoffs.

In systems where standard scheduling algorithms with standard timing constraints are mandated, the scheduler can use the knowledge about artifacts, their constraints, and alternatives to pinpoint candidates for change, instead of a "blind" redesign. Another direction will be to develop algorithms which work without the "bottleneck" of standard constraints by directly scheduling timing entities with full exploitation of their flexibility. These will allow for varying constraints for different instances. As mentioned above, we will study the effect of added flexibility on system properties, in particular on reliability for each of the new scheduling methods.

3.2 Research Methods

Our research will study data from real-world industrial applications in the automotive domain, as well as other areas, e.g., control theory, non periodic task scheduling, end-to-end deadlines, in a first step. The information gathered together with the researchers and engineers of the industrial partner will be analyzed for overconstrained specifications. Such specifications will be studied for their underlying, "natural" constraints and derivation process. The information gathered will form a basis for development of flexible timing constraints and their composition. The proposed flexible constraints will be applied to the data for validation and compared to standard methods. In a next step, we will analyze existing scheduling algorithm for applicability with flexible timing constraints. We envision 4 tracks: (1) Standard off-line algorithms, with the addition of changing timing constraints in the infeasible case; (2) modified off-line algorithms, capable of modifying constraints during schedule construction; (3) combined off-line and online algorithms, and (4) online algorithms. (3) and (4) will require the development of new scheduling methods. The results from this analysis and the new algorithms will provide for a scheduling framework of flexible timing constraints: guidelines for standard algorithms, and newly developed ones. Checking back with real-world data and industrial partner, we will tune the methods to provide a set of methods and tools.

4 Expected Results and Impact

The results of our research will be methods for derivation, specification and scheduling to exploit temporal flexibility in real-time systems while maintaining demands on reliability.

Mecel has expressed demand for the proposed research and will provide applications to be studied for their temporal constraints and flexibility. As a case study, a specification method will be provided and an appropriate scheduler selected and modified to suit the BASEMENT architecture.

5 Project Plan

5.1 Personnel

This project will be conducted by one Ph.D. students with 20% of department duties and supervised by Gerhard Fohler and Krithi Ramamritham. The project will span over a period of 2.5+2.5 years.

5.2 Activities

A. Case studies, current practice, and state-of-the-art

  A.1. Case studies of overconstrained specifications and derivation of constraints; quantitative and qualitative assessment

    A.1.1. Automotive application – main focus
    A.1.2. Control theory
    A.1.3. Real-time system design, e.g., non periodic tasks, end-to-end deadlines, distribution, subtask deadline assignment

  A.2. State-of-the-art literature

  A.3. Current industrial practice of timing constraints and derivation in automotive application

Deliverables A:

- Report on constraints and overconstrained specification in case studies
- Report on state-of-the-art

B. Definition of requirements on methods

  B.1. Specify "natural constraints" of case studies
  B.2. Evaluation criteria and methods, e.g., utilization, reliability
  B.3. Identify shortcomings of current practice
  B.4. Identify requirements for appropriate methods

Deliverable B: Report on shortcomings and requirements

C. Analysis of scheduling methods and state-of-the-art

  C.1. Offline scheduling
  C.2. Online scheduling
  C.3. Combined offline – online scheduling

Deliverables C:

- Report on state-of-the-art, adequateness and shortcomings of scheduling methods
- Licentiate Thesis

D. Development of specification method and design process

  D.1. State-of-the-art specification
  D.2. Expression and specification of flexible timing constraints, including composability, evaluation methods

Deliverable D: Proposal for flexible timing constraints

E. Modifications to existing and development of new scheduling algorithms

  E.1. Standard offline scheduling
  E.2. Offline scheduling with modifications to change TC during construction
  E.3. Combined offline and online scheduling
  E.4. Online scheduling

Deliverables E:

- Scheduling framework: Guidelines for modification of existing methods
- Proposals new methods
- Prototype implementations

F. Implementation of tool support

Deliverables F: Tools

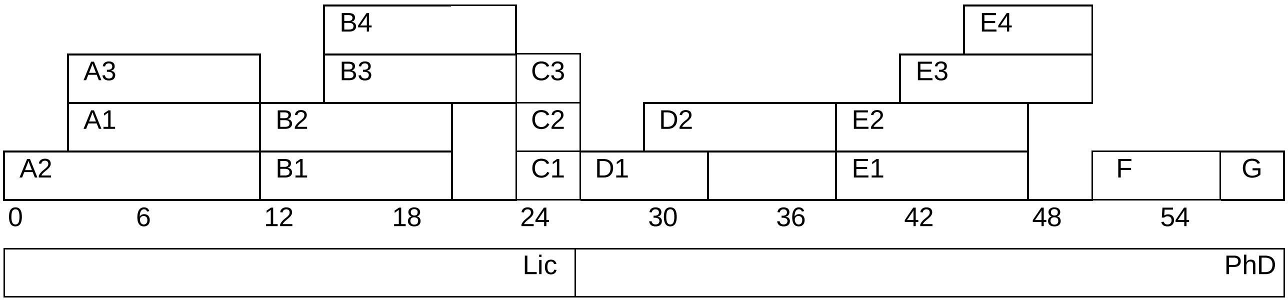
G. Analysis and tuning of methods

Deliverables G:

- Tools
- Ph.D. thesis

5.3 Time plan

This schedule will include a 2-3 months research stay at a highly ranked international research institution.



6 Preliminary Budget

We project the total project budget to be comprised of funding for

- Ph.D. student salary for 2.5 + 2.5 years, considering departmental duties
- supervision cost
  - Gerhard Fohler, salary, 20%
  - Prof. Ramamritham, mobility, salary, 2 weeks/year
- research stays for Ph.D. students at international institution (2-3 months)
- conference travel for presentation of results
- a 20% department overhead is added to the above listed items

7 Related Research

The issue of timing constraints, their origins and use has been discussed in [Ramamritham:]. The creation of artifacts and constraints in the design process with respect to predictability was addressed in [Stankovic:90].

Early versions of flexible timing constraints have been proposed in [Fohler:97].

Gerber et. al. have studied relative timing constrains [Gerber:95b] and design based on end-to-end deadlines [Gerber:95]. Cheng and Agrawala [Cheng:97] developed a scheduling algorithm for relative timing constraints.

[Seto:97] presented a method to derive periods for rate monotonic scheduling from a control application.

[Fohler:94] presented the modification of a static scheduler to include constraints specified in RTL [Jah86:].

Issues of incremental schedule construction and offline scheduling to meet general requirements are currently studied in the ARTES projects “Incremental, iterative schedule construction”, and “Identification of Complexity-Reduction Techniques for Optimal Scheduling in Embedded Distributed Real-Time Systems”.

8 Relation to Profile and Industry

Our proposed research aims at solving real-time problems meeting industrial demands. It will be carried out in co-operation with the industrial partner. The process will provide us with insights in concrete, application specific, real-time engineering practices and broaden the scientific foundation for industry.

We expect to learn how to specify and design real-world real-time systems by analyzing the actual problems, their requirements and used industrial practice, and by providing solutions and research to meet the encountered demands.

The use of flexible timing constraints acknowledges the need of specifications meeting industrial application demand rather than that of target system and scheduling algorithm. It will enable designers to focus on application constraints and design, reduce design cycles, and provide more general and efficient scheduling methods.

In heterogeneous systems, information about feasibility may be expressed by different types of timing constraints, representing the same demand: Suppose a system applies rate monotonic scheduling on one node, and earliest deadline first on another, both have to execute a task within a certain time window. This can be expressed directly via starttime and deadline in the EDF based node and has to be translated into period only for the RM node. Flexible timing constraints allow the designer to express the execution window, and only later deal with the actual node, its scheduling paradigm, and fitting translation. In a similar way, flexible timing constraints aid the construction of composable systems.

9 Context

9.1 The research group

The proposed research will be carried out at the Computer Engineering Department (IDt) at Mälardalen University, Västeras in co-operation with Mecel AB, Gothenburg as industrial partner and Prof. Ramamritham, University of Massachusetts/IIT Bombay as cooperator and external supervisor.

Real-time systems research was established at MdH around 1990 by three persons as a glue between academia and industry. It has since then been the most active and fast growing research area, as well as a strong educational profile, at MdH. The real-time research at MdH is supported by a number of regional and national authorities, foundations and companies. As a result, real-time systems has been identified (by the university board) as the research area of highest priority at MdH. It has grown to approximately 40 persons providing 500 full time student equivalents.

9.2 Complimentary activities

The SALSART tool suite for distributed schedule design and analysis, currently being developed, will be used to assist the development of the proposed research and methods. A number of master thesis projects both at IDt and Mecel will help with implementations.

The ARTES funded project, “Incremental, iterative schedule construction”, currently carried out at IDt will provide help for the development of schedules and constraints.

Our project will interact closely with the ARTES funded project, “Identification of Complexity-Reduction Techniques for Optimal Scheduling in Embedded Distributed Real-Time Systems”, currently carried out at Chalmers University under supervision of Jan Jonsson in cooperation with Mecel AB.

9.3 International academic co-operation

Prof. Krithi Ramamritham from University of Massachusetts/ IIT Bombay will be academic partner in the project. He will work on the project for 2 weeks/year during visits, consult throughout the project, and act as student co-supervisor.

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9.4 Industrial co-operation

Mecel AB has a group consisting of around 10 persons working with the design of distributed real-time system in automotive applications. Mikael Strömberg leads this group. The group is developing design support for real-time systems, including scheduling and allocation tools. Currently, timing constraints are expressed in standard ways.

Mecel AB will provide real-world data, techniques, and specification from the automotive domain. Researchers and engineers of the group, together with the academic partners, will analyze these data for overconstrained specifications. Such specifications will be studied for their underlying, "natural" constraints and derivation process. The information gathered will form a basis for development of flexible timing constraints, their composition, and scheduling. Prototype implementations of the developed methods will be applied at Mecel AB for validation and further use.

A number of student projects both at IDt and Mecel AB will help with implementations.

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11 Appendices

Appendix A: C.V. of Gerhard Fohler

Appendix B: Support letter Prof Ramamritham

Appendix B: Support letter Mecel

Appendix A

C.V. of Gerhard Fohler

Appendix B

Support letter Prof Ramamritham

Appendix C
Support letter Mecel