# Data Management in Vehicle Control-Systems*

**- A Doctoral Thesis Proposal. -**

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# 1 Project Description

The COMET-project, which is a joint project between Mälardalen University and Linköping University, officially started in December 2000. Two doctoral students are currently working in the project, Dag Nyström, Mälardalen University, and Aleksandra Tešanović, Linköping University. The project is supervised by Christer Norström and Mikael Nolin, Mälardalen University, and Jörgen Hansson, Linköping University.

The area of interest for the project is data management in embedded real-time systems. Specific questions span from "How are data managed today?" and "What are the current and future requirements on data management?" to "Is it possible to lift the level of abstraction for data management in such systems without jeopardizing performance and predictability?" and "To what extent can flexibility with respect to data management be introduced these systems?". Our research, which focus on systems in the automotive domain, include work done in areas such as (i) real-time database management systems, (ii) component-based software development, (iii) aspect-oriented software development, and (iv) automotive software development.

The research performed in the project focuses around our experimental real-time database management (RTDBMS) platform, entitled COMET. The properties of this platform are derived from data management requirements found in a case-study [9] performed at Volvo Construction Equipment Components AB, Eskilstuna, Sweden. The major properties of COMET include:

1. a highly configurable architecture, created using a development process method, denoted ACCORD [15], developed within the project.

2. a database access method, denoted database pointers [8], which allow the application to efficiently access individual data elements within the database.

3. a concurrency control algorithm, 2-version database pointer concurrency control (2V-DBP) [7], that allow hard and soft database transactions to co-exist in the system. The algorithm prevents hard transactions to be blocked by less important soft transactions, while still allowing these soft transactions to execute without being aborted by hard transactions.

4. different implemented instances of COMET, which include:

   - COMET BaseLine, a flexible, relational RTDBMS, that allow ad hoc database queries, as well as database pointer transactions to be issued.
   - COMET ConcurrentLine, a variant of COMET BaseLine which allow multiple database transactions to be executed concurrently.
   - COMET QoSLine, a quality of service aware instance of COMET, which can execute transactions on different quality levels.
   - COMET MiniLine (currently being implemented), a slimmed down, static version of COMET which minimizes the run-time part, allowing a large part of the functionality to be handled by off-line configuration and analysis tools.

The project follows two separate tracks, one per university. The first track, which focuses on the data management issues, and real-time database management issues, is performed at Mälardalen University. This Ph.D. thesis proposal will focus on this track. The second track, performed at Linköping University, focus more on the

architectural issues of COMET, including component-models, aspect-oriented issues and software engineering issues.

The achievements within the project so far include:

| | |
|---|---|
| Technical Reports | 2 |
| Workshop Papers | 4 |
| Conference Papers | 6 |
| Journal Papers | 1 |
| Licentiate Theses | 2 |
| Masters Theses | 12 (Among 16 students) |

The expected time of defense of the Ph.D. thesis is October 2005.

## 2 Problem Formulation

In recent years, automotive control systems have evolved from simple single processor systems to complex distributed systems. At the same time, the amount of data that needs to be managed by these systems is increasing dramatically; data volume managed by automotive systems is predicted to increase 7-10% per year [4]. Current techniques for storing and manipulating data objects in automotive systems are ad hoc in the sense that they normally manipulate data objects as internal data structures. This lack of a structured approach to data management results in a costly development process with respect to design, implementation, and verification of the system [9]. It also makes the system difficult to maintain and develop while preserving consistency with the environment, e.g., maintaining temporal properties of data. As data complexity is growing the need for a uniform, efficient, and persistent way to store data is becoming increasingly important. Using a real-time database management system (RTDBMS) as a tightly integrated part of an automotive control system has the potential to solve many of the problems that application designers have to consider with respect to data management, e.g., locking of the data, persistency and deadlock situations. More importantly, incorporating an RTDBMS into an automotive control system can reduce development costs, result in higher quality of the design of the systems, and consequently yield higher reliability [5].

The variability of data management requirements in different automotive control systems requires distinct RTDBMS configurations specially suited for the particular system [14]. Since an automotive control system is heterogeneous, consisting of several nodes (called electronic control units, ECUs), the ability to configure the RTDBMS to suit the requirements of an individual node is crucial. For instance, an automotive system could consist of a small number of resource adequate ECUs responsible for the overall performance of the vehicle, e.g., 32bit CPUs with a few MB of RAM, and a large number of ECUs responsible for controlling specific subsystems in the vehicle, which are significantly resource-constrained, e.g., an 8bit micro-controller and a few KB of RAM [9]. ECUs with greater amount of resources usually have real-time operating systems support, which is not affordable in small resource-constrained ECUs. Although different in their characteristics and available resources, all nodes in an automotive control system are exchanging, sharing and manipulating data, thereby requiring a uniform way of data management, e.g., via a RTDBMS.

The heterogeneous characteristics of nodes in an automotive control system result in a need to have distinct RTDBMS configurations suited for a particular node [9]. In

safety-critical nodes, tasks are often non-preemptive and scheduled off-line, implying that a RTDBMS configuration for that node could be made small in size and provided functionality, since the majority of the RTDBMS's functionality, such as synchronization and concurrency-control, could be handled off-line. Less critical and larger nodes have preemptable tasks, requiring a RTDBMS configuration with run-time concurrency control mechanisms, and support for database queries formulated during run-time (ad-hoc queries). A configurable RTDBMS supporting different types of nodes would, from the application's point of view, provide uniform access to the data regardless of the size and characteristics of an ECU.

Today, there exists a number of commercial databases suitable for embedded systems, e.g., Pervasive.SQL [10], Polyhedra [11], Berkeley DB [12], and TimesTen [16]. Although small in size and therefore suitable for resource-constrained automotive control systems, these databases do not incorporate real-time behavior. This in turn implies that their behavior cannot be analyzed, which makes them unsuitable for deployment in an automotive system. Research projects that are building real-time database platforms, such as DeeDS [3], RODAIN [6], STRIP [2], and BeeHIVE [13], mainly address real-time requirements, are monolithic, and targeted towards a larger-scale real-time application, which makes them unsuitable for use in embedded resource-constrained environments.

## 3 Contributions

The contributions of this thesis are:

- Identification of the industrial requirements on data management issues in automotive systems. This is done in an industrial case-study (Paper A) performed at Volvo Construction Equipment Components AB, Eskilstuna, Sweden. The paper identifies how data currently is managed in their system (through shared data structures scattered throughout the system), and points out some shortcomings and problems that was discovered during the industrial stay.

- Development of a concept entitled COMET (Paper B), which provides a framework to manage data in automotive systems. The framework include the COMET RTDBMS, that is a database management system suited for the Volvo System presented in paper A. Key concepts in this work is the provided tool support, the highly configurable RTDBMS, and analysis tools.

- Development of a concept called database pointers, which together with a concurrency control algorithm entitled 2V-DBP (Paper C), allow real-time systems to have both a soft and a hard real-time part. The hard real-time part, which is responsible for the critical controlling of the vehicle (or other environment), is of a static nature (periodic execution). The soft part one the other hand handles management and diagnostics, activities that typically require a more flexible and dynamic approach. 2V-DBP enables the hard and the soft parts to execute totally separated from each other, even if both parts access mutual data. 2V-DBP enforces this using a combination of pessimistic concurrency control (for the soft part), and a limited form of versioning (for the hard part). The algorithm is then further developed in the proposed algorithm, entitled 2V-DBP-SNAP (Paper D), in which the current limitation of one data access per hard transaction is removed. In 2V-DBP-SNAP, hard transactions could access any number of data elements in one atomic operation, without causing database inconsistency problem.

- The final part of the thesis (Paper E) tries to point forward, opening up new threads of research to follow. By integrating the RTDBMS into a component framework, enabling components to specify their required and provided data, components can be constructed without any knowledge of whereabouts of the database. Components could be migrated freely (either at compile time or at run time) around in a distributed system, letting the component framework ensure that the correct data is transported to the correct component in a timely manner.

## 4 Outline of the Doctoral Thesis

The doctoral thesis will be a collection of five articles described in section 5, i.e., paper A-E. These will be glued together using an introductionary "coat" that will present the background of the work.

The outline of the thesis will be as follows:

Introductionary coat which will describe the background, motivation, problem description, and contributions of the thesis.

Paper A The Volvo case-study in which an industrial study show the motivations, requirements and possibilities with the work.

Paper B In which the overall concept of COMET is presented, it is put in context with the requirements presented in paper A.

Paper C which presents 2V-DBP and motivates why this is a crucial part of a RT-DBMS in an automotive application.

Paper D The extension to paper C which introduces 2V-DBP-SNAP.

Paper E Which points the finger on where the future might go. The closure of COMET. Integration of COMET as a part of the component framework.

# 5 Published Papers as a Part of the Doctoral Thesis

## Paper A

Dag Nyström, Aleksandra Tešanović,
Christer Norström, Jörgen Hansson & Nils-Erik Bånkestad
***Data Management Issues in Vehicle Control Systems: a Case Study***
In Proceedings of the 14th Euromicro Conference on Real-Time Systems
June 2002, Vienna, Austria

*This conference paper investigates the requirement on a real-time database residing in a safety-critical real-time embedded control-system. It is based on a case study performed at Volvo Construction Equipment Components AB, Eskilstuna.*

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|---|---|---|
| Contributing authors: | Dag Nyström | Main (joint) author of paper |
| | Aleksandra Tešanović | Main (joint) author of paper |

## Paper B

Dag Nyström, Aleksandra Tešanović, Mikael Nolin, Christer Norström & Jörgen Hansson
***COMET: A Component-Based Real-Time Database for Automotive Systems***
In Proceedings of the Workshop on Software Engineering for Automotive Systems
May 2004, Edinburgh, Scotland (satellite event to ICSE 2004)

*This paper introduce a software engineering approach for generating RTDBMS configurations suitable for resource-constrained automotive control systems, denoted the COMET development suit. Using software engineering tools to assist developers with design and analysis of the system under development, different database configurations can be generated from pre-fabricated components.*

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| Contributing authors: | Dag Nyström | Main (joint) author of paper<br>RTDBMS technical ideas |
| | Aleksandra Tešanović | Main (joint) author of paper<br>Aspect + ACCORD ideas |

### Paper C

Dag Nyström, Mikael Nolin, Aleksandra Tešanović, Christer Norström & Jörgen Hansson

***Pessimistic Concurrency Control and Versioning to Support Database Pointers in Real-Time Databases***

In Proceedings of the 16th Euromicro Conference on Real-Time Systems
June 2004, Catania, Sicily, Italy

*This paper proposes a concurrency control algorithm suited for system consisting of both hard and soft transactions. The algorithm, which combines pessimistic concurrency control [1] and a limited form of versioning, allow hard transactions to execute independently of any soft transactions, and vice versa. Hard transactions will never be blocked by soft transactions, and soft transactions will never be aborted or blocked by hard transactions.*

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| Contributing authors: | Dag Nyström | Main author of paper<br>Main ideas of contribution |
| | Mikael Nolin | Main co author and<br>technical advisor |
| | Aleksandra Tešanović | Co author of paper |

## 6 Remaining Papers for Doctoral Thesis

Titles of papers in this section are to be considered working titles, and might be subject to changes.

### Paper D

Dag Nyström, Mikael Nolin, Aleksandra Tešanović, Christer Norström & Jörgen Hansson

***Adding Snapshot properties to Database Pointer Transactions***

To be submitted to the 16th Euromicro Conference on Real-Time Systems

*This paper is intended to be the final paper on database pointers and 2V-DBP. The contribution of this paper will be to remove a limitation in the current version of 2V-DBP. The proposed concept of the paper, entitled 2V-DBP-SNAP, will enable database pointer transactions to contain multiple data accesses, while still retaining atomicity and serializability.*

### Paper E

Dag Nyström, Aleksandra Tešanović, Mikael Nolin, Christer Norström & Jörgen Hansson

***Using a Real-Time Database as a Part of a Component Framework***

To be submitted to 8th International SIGSOFT Symposium on Component-Based Software Engineering

*This paper is intended to show how a RTDBMS can be used as a part of a component framework. A possible implementation into the SAVEComp would enable for data requirements/provisions for components. The components should then be possible to deploy in any system. The framework would ensure the data is transported to/from the component.*

# 7 Additional Publications

**Paper F:** Aleksandra Tešanović, Dag Nyström, Jörgen Hansson & Christer Norström
*Embedded Databases for Embedded Real-Time Systems: A Component-Based Approach*
Tech. Report #43, Mälardalen Real-Time Research Centre, Mälardalen University

**Paper G:** Dag Nyström, Aleksandra Tešanović, Christer Norström & Jörgen Hansson
*Database Pointers: a Predictable Way of Manipulating Hot Data in Hard Real-Time Systems*
In Proceedings of the 9th International Conference on Real-Time and Embedded Computing systems and Applications, February 2003, Tainan, Taiwan.

**Paper H:** Dag Nyström, Aleksandra Tešanović, Christer Norström & Jörgen Hansson
*The COMET BaseLine Database Management System*
MRTC Report 98/2003, ISSN 1404-3041 ISRN MDH-MRTC-98/2003-1-SE
Mälardalen Real-Time Research Centre, Mälardalen University, April 2003.

**Paper I:** Aleksandra Tešanović, Dag Nyström, Jörgen Hansson & Christer Norström
*Integrating Symbolic Worst-Case Execution Time Analysis with Aspect-Oriented System Development*
In Proceedings of the OOPSLA 2002 Workshop on Tools for Aspect-Oriented Software Development, Seattle, USA. November 2002

**Paper J:** Aleksandra Tešanović, Dag Nyström, Jörgen Hansson & Christer Norström
*Towards Aspectual Component-Based Development of Real-Time Systems*
In Proceedings of the 9th International Conference on Real-Time and Embedded Computing systems and Applications, Tainan, Taiwan. February 2003.

**Paper K:** Aleksandra Tešanović, Dag Nyström, Jörgen Hansson & Christer Norström
*Aspect-Level Worst-Case Execution Time Analysis of Real-Time Systems Compositioned Using Aspects and Components*
In Proceedings of the 27th IFAC/IFIP/IEEE Workshop on Real-Time Programming, Poland. May 2003.

**Paper L:** Aleksandra Tešanović, Jörgen Hansson, Dag Nyström, Christer Norström & Pernilla Uhlin
*Aspect-Level WCET Analyzer: a Tool for Automated WCET Analysis of a Real-Time Software Composed Using Aspects and Components*
In Proceedings of the 3rd International Workshop on Worst-Case Execution Time Analysis, Porto, Portugal. July 2003.

**Paper M:** Aleksandra Tešanović, Dag Nyström, Jörgen Hansson & Christer Norström
*Aspects and Components in Real-Time System Development: Towards Reconfigurable and Reusable Software*
In Journal of Embedded Computing, July 2004.

## 8 Future Work and Time-Plan

The research work to perform up until the defense of the thesis can be divided into three distinct tasks, namely, (i) completion of the work on 2V-DBP-SNAP. This work is in its initial stage, but a good candidate idea is ready, (ii) Integration of COMET into SAVEComp to provide COMET as a part of the component framework, and (iii) wrapping up the introduction of the thesis.

In parallel to this, ongoing work on a journal publication is conducted. The paper will merge the results from paper C and F and present the concept in an extensive way. If this paper is accepted for submission prior to the printing of the doctoral thesis, this paper will replace paper F.

The following activities, their deadlines and their respective deliverables are expected to be finished by the end of October 2005:

| **Activity** | **Deadline** | **Deliverable** |
|---|---|---|
| Completion and submission of paper D | December 13 -04 | Submitted paper |
| Completion and evaluation of the COMET MiniLine implementation. | February -05 | Implementation |
| Completion and submission of paper E | January 7 -05 | Submitted paper |
| Completion of doctoral thesis | August -05 | Thesis |
| Doctoral thesis defense | October -05 | Doctoral degree |

## 9 Graduate Courses

| **Course** | **Credits** | **Status** |
|---|---|---|
| Real-Time systems, advanced course | 5p | Completed |
| Science Methodology | 5p | Completed |
| Parallel Systems | 5p | Completed |
| Safety-Critical Real-Time Systems | 5p | Completed |
| Real-Time Databases | 5p | Completed |
| Design of Real-Time Systems | 5p | Completed |
| Software Architecture | 3p | Completed |
| SAVE Component course | 5p | Completed |
| Formal methods for Real-Time Systems | 5p | Completed |
| ARTIST Summer-School on Real-Time Systems | 1p | Completed |
| Concurrency Theory and Time | 3p | Near completion |
| Case-Study Research | 3p | Ongoing |
| Pedagogic Course | 3p | Completed |
| **Total credits** | 53p | |

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