Temporal extension of an object-oriented information system about hospitals

Frédéric Weymann [a,1], Christa Weßel [a], Cord Spreckelsen [a]
[a]*Department for Medical Informatics, RWTH Aachen University, Aachen, Germany*

Abstract. Access to historical data is the key to the in-depth analysis of a hospital. Therefore, support for efficient temporal storage and query mechanisms by database management systems is highly desirable. While a lot of research has been conducted in the context of temporal relational databases, there is a lack of equivalent work concerning object-oriented databases. Currently, no temporal object-oriented database system is publicly available. This paper presents CHRONOS, a temporal extension to the object-oriented database system FastObjects tailored to the needs of the CERES project. The CERES research project aims to develop a free web-based and object-oriented information system about German hospitals. By intentionally restricting the system to the actual need of the users, CHRONOS avoids the pitfalls of the general case and the risk of becoming a bloated system that is almost unusable by the average user because of its extremely high complexity. Instead, CHRONOS provides an efficient, comfortable and easy to use way to manage and retrieve historical data about hospitals.
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1. Introduction

In general, it is impossible to evaluate the medical and economical performance of a hospital solely by looking at its most recent key data. A comparison with other hospitals but also with historical data is required to reach an adequate judgment. For example identifying trends enables to determine whether the performance of a hospital is improving or is in decline. The experience of the hospital's staff in treating a specific disease can be estimated through analysis of the number of treated patients in the past years and the date of the first treatment.

Currently, interested user groups like potential patients or healthcare professionals aren't able to access concise historical information about all hospitals in Germany. German health carriers have started to publish structured quality reports [1, 2] but the data is limited to the year 2004 at the moment. Furthermore, the reports of most hospitals are only available as PDF files which turns finding and comparing interesting information into a tedious task.

The CERES research project at the Department for Medical Informatics at Aachen University aims to develop a free web-based and object-oriented information system

[1] Corresponding Author: Frédéric Weymann, Department of Medical Informatics, RWTH Aachen University, Pauwelsstraße 30, 52074 Aachen, Germany, E-mail: fweymann@mi.rwth-aachen.de

that will empower the user to select and compare historical data of all German hospitals in an comfortable and unified way.

The CERES information system is developed as a JAVA Web Application and uses the object-oriented database management system FastObjects from Versant [3]. The schema of the database – called MINERVA – is modelled using a subset of the Unified Modelling Language [4] and represents information about the hospital's structure and selected outcome criteria [5].

However, MINERVA does intentionally not model temporal aspects in order to simplify the modelling process and to create an intuitively understandable schema. Therefore, a concise temporal snapshot can be represented by the schema but no historical data can be stored unless a temporal DBMS is used. This modelling approach is based on the assumption that although the object-oriented data model is expressive enough to allow a direct representation of temporal data, it is still advantageous to leave the organization of data evolution to the employed database management system to keep the complexity of the overall system small.

A lot of research has been conducted in the field of relational temporal databases [6] and there exists several implementations of temporal relational DBMS [7]. Unfortunately, no comparable amount of work has been conducted in the framework of object-oriented databases. There also exists only very few implementations of temporal OODMBS and these are either not distributed or no longer maintained.

In any case, database management systems that aim to solve the general problem of managing any kind of temporal data are highly complex systems with a multitude of new concepts and features. This is problematic because CERES intends to provide a comfortable and intuitive way of accessing information about hospital to the general public. Therefore, most potential users do not have extensive technical knowledge and require a lean and easy to understand system that isn't cluttered up with functions they will never use or even need.

Furthermore, there are several technical pitfalls when adding a temporal dimension to a database system like inefficient query evaluations or an explosion of the space occupied by the database.

In order to avoid all these problems, CHRONOS does not try to provide a solution to the general case of temporal databases. Instead, the database system is tailor-made to the actual needs of the potential user groups of an web-based information system about hospitals.

2. Material and Methods

As the main approach in the development of CHRONOS is to tailor the system precisely to the needs of potential users, a considerable effort is devoted to the requirement analysis. There are no existing web-based information systems that offer freely available, historical data about German hospitals so CERES has to construct a new niche for itself [8]. It is unknown when and in which way users will utilize CERES and how the system will change their approach to the evaluation and selection of hospitals. This complicates the requirement analysis for CRONOS and CERES in general as the analysis cannot be based on the experiences with existing systems.

To guarantee that the requirement engineering process is open to new and unexpected aspects and ideas, the actual analysis phase is preceded by an exploration phase [9]. The exploration phase utilizes methods from the empirical social research

and consists of preparation, conduction and analysis of semi-structured interviews with representatives of potential user groups. These include patients, doctors, medical controllers and economists working in the healthcare sector.

All interviews are transcribed and analysed using qualitative data analysis methods and methods that are employed in goal-oriented design approaches, e.g. personas, goals and scenarios [10, 11].

CHRONOS is not a DBMS developed from scratch but it extends the commercial OODBMS FastObjects with temporal functionality. The new functions include the storage of time-stamped objects and object properties, a temporal query language and a snapshot view for non-temporal applications to ease migration.

Storage of historical data is realized by automatically adding new classes and attributes to MINVERA during the database generation process. These changes are not visible to external applications or to the modellers, they are only used internally to store and retrieve historical data. Based on the hypothesis that all elements of a hospital are dynamic and can change anytime in any way, all objects and all object properties are time-stamped. The modellers do not have to decide whether a class, an attribute or an association is temporal or static. Only valid time information are stored because information about the transaction time are of no interest to all identified user groups.

The temporal query language provided by CHRONOS is called CHRONOQL and is an extension of FastObject's version of OQL[2]. Theoretically, there exists a large amount of possible temporal language extension.

Temporal constraints can be formulated using Allen's temporal logic [12]. A temporal extension, i.e. the set of all objects of a specific class that are valid at a specific time, can be used as base of a query in place of the usual extensions [13]. The query language can offer two different access modes to the values of an attribute: Access at a specific date or access to the whole history, for example to calculate the average value over a given period [14].

However, several of these extensions pose the risk of turning the query evaluation intractable. Due to this, it is imperative to determine whether an extension is really needed by the users or can be dropped without losing essential functionality.

Applications using CHRONOS can access the objects stored in the database in two different ways. The snapshot view presents the data at a specific date and completely hides the temporal dimension. The CERES team has already developed several non-temporal applications that require this view to stay operational when the switch from a non-temporal to a temporal OODMBS is done. Since snapshots at any date can be requested, this view also offers an easy way to implement applications with simple temporal support by offering the user the choice to pick a date and then present the data at the selected date. This view does not allow updates. Translating updates of data at a single point of time into valid time intervals is complicated and there is actually no need for this feature because virtually all CERES application only retrieve data but do not change them.

The temporal view allows full access to the history of all objects. Applications can see all objects that ever existed and area allowed to retrieve when and how their properties have changed. This view can be used to update the data and is useful for developing more complex temporal applications.

[2] FastObjects only implements a limited subset of the OQL standard

3. Results

The analysis of the semi-structured interviews reveals that potential CERES users only require very basic temporal selections. For example, there are simply no realistic scenarios that would require the formulation of interval relations as described in Allen's temporal logic [12]. There is also no need to provide features that allow to restructure or aggregate the base data as most data provided by CERES is already summarized and there is a view manager that provides these features [15]. Most queries focus on the current data or select objects that satisfied a condition at some point in the past..

The exploration phase provides both new ideas and impulses for CHRONOS and the CERES project as whole. One suggestion is a new front-end that offers an easy way to select objects and time periods and arranges the selected data freely in a table that can be also be exported to external application if desired.

Another idea is the support of "Since when"-queries, i.e. queries that determine when an object satisfied a given condition for the first time[3].

Using these results, CHRONOQL can be designed as a very lean and efficiently evaluable query language that is still able to satisfy the needs of the user groups targeted by the CERES project.

Thanks to the structure of the CERES development platform, CHRONOS easily integrates into the existing system. The database schema MINERVA is modelled using the proprietary UML editor ZEUS. ZEUS has an integrated module which generates JAVA classes from the modelled class diagram. These classes are used by FastObjects to create the database schema. By extending the module, CHRONOS can silently enhance the schema as required without the need of further interaction from the developers.

CERES applications do not access the database directly but are required to use an additional access layer called the "CERES Toolkit". As all data exchanged between the database and the applications pass through the Toolkit, CHRONOS can easily control what information are visible to the applications. This allows a very natural and robust implementation of both the snapshot and the temporal view. By default, a snapshot view of the current system time is provided, so all non-temporal applications continue to work properly after the switch to a temporal database is done. Newly developed and reengineered applications that are aware of the temporal dimension can easily enable access to the temporal view or move the focus of the snapshot view by using a set of new methods added to the CERES Toolkit.

Since FastObjects is a closed-source system and therefore no access to the internal data or indexing structures is possible, all CHRONOQL queries are rewritten as standard OQL queries by the CHRONOS query optimizer and passed on to FastObjects. Using this approach, CHRONOS is able to efficiently determine the result set of a query without having to maintain indices or create a evaluation plan.

4. Discussion

Adding temporal support to database management systems in order to overcome the problem of increasing data and program complexity is a widely accepted approach and

[3] For example "Since when does this hospital treat herniated discs?"

has been extensively researched for over two decades, although mostly in the context of relational databases [16].

There exist few approaches for temporal object-oriented databases [13, 14, 17]. However, these works try to create general-purpose systems which results in very complex systems that are hard to implement and maintain. They require the user to invest a lot of time into understanding the various temporal concepts and provided features before the system can be used properly. This isn't a realistic option for a web-based information system which is open to the general public and has to be usable by the average internet user without special training.

CHRONOS follows a new approach by intentionally leaving out all features that may be interesting in the general case but are of no use for the CERES project. The resulting temporal framework is lean and easy to understand and to use.

Since tailoring the system precisely to the users' needs is crucial, the utilized analysis methods need to be selected with much care. Several methods like personas or use cases were developed in the field of requirements engineering and are very helpful in preparing the design phase. However, these methods often concentrate on technical aspects and their openness to completely new aspects and ideas is limited.

That's why a preliminary explorative phase is beneficial. The employed subjective research methods are well established in empiric social studies and provide the means to create a holistic image of potential users and their personal goals [10, 5].

5. Conclusion

This paper presented CHRONOS, a temporal object-oriented database management system built on top of an existing OODBMS.

The system provides a unified way to store historical data of all parts of a hospital and therefore frees the CERES modelling team from the need to represent temporal aspects in the database schema.

By centralizing the management of the historical data, CHRONOS also helps to prevent all CERES applications from becoming more and more complex because they have to deal directly with the representation and processing of historical data. This reduces the development time and improves the overall software quality. A special snapshot view even allows non-temporal applications to continue their proper functionality without the need of any reengineering.

CHRONOS is a back-end application and therefore concentrates on how historical data is stored and made accessible to the different applications in the CERES projects. It does not deal with the problem how to present the data to the user. To fully profit from the benefits of a temporal database, the CERES project has to upgrade the existing front-end tools and to develop new temporal applications. CHRONOS supports these steps by providing a lean and robust temporal framework and an efficient implementation of temporal aspects.

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