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Calendars as Types

Data Modeling, Constraint Reasoning, and Type Checking with Calendars

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Introduction

"Dreifach kommt die Zeit:
Zögernd kommt die Zukunft herangezogen,
pfeilschnell ist das Jetzt entflogen,
ewig still steht die Vergangenheit."
(Friedrich von Schiller, 1759–1805)

Time and calendars play an important role in Artificial Intelligence, in Database Systems, and, in recent times, also in the Web and Semantic Web. Temporal reasoning is a major research field in Artificial Intelligence for applications such as time tabling, scheduling, and planning; in Database Systems for applications such as query answering and change detection and reaction. Many database and information systems as well as many advanced Web and Semantic Web applications and Web services like database updates, active systems, medical monitoring, information services, appointment scheduling, travel planning, Web trading and logistics, and so-called adaptive (or context-aware) applications and systems refer to temporal and calendric data. Most existing or foreseen mobile computing applications refer not only to locations but also to time [BLOS03]. For example, a mobile application listing pharmacies in the surrounding of a user will preferably only mention those that are currently open, i.e. it refers to rather sophisticated temporal and calendric data.

The temporal and calendric data involved in such applications and systems are most often rather complex, sometimes involving different calendars with various regulations and lots of irregularities (e.g. leap years). Calendars are arbitrary human abstractions of the physical time, enabling to measure and to refer to time in different units like "day", "week", "working day", and "teaching term". Examples of calendars are cultural calendars like the Gregorian, the Julian, the Hebrew, and the old and new Chinese calendars as well as professional calendars like the academic calendar of a university or the legal calendar used in some state including legal holidays, a specification of the legal working year, due dates

for taxes, etc. Hence, temporal and calendric data are not only irregular but they also depend on cultural, legal, professional, and/or locational contexts. For example the date "12/02/2005" is interpreted as 12^{th} February 2005 in France while it is interpreted as 2^{nd} December 2005 in the US. Time and calendar expressions like "month" or "teaching term" can be interpreted regarding different calendars. The specification of (religious) holidays depends on the calendar used such as "Christmas Day" which refers to 25^{th} December if the Gregorian calendar is used but to 7^{th} January if the Julian calendar is used to determine the date of Christmas on the Gregorian calendar. Several legal holidays are determined by regions such as "Epiphany" which is a legal holiday only in some German federal states. Beyond, calendric expressions such as "Friday evening" depend on some cultural interpretation: while Friday evening refers to the eve of Friday in most western countries, in some Islamic countries this expression refers to the eve of Thursday.

In fact, time and calendars seem to be fundamental issues associated with any time-dependent phenomenon in any dynamic system. These and further considerations gave birth to a large field of research in Artificial Intelligence and Database Systems that can be summarized to the effort of developing frameworks for temporal knowledge representation and reasoning. Such frameworks usually comprise a formalization of the aspects of time and calendars and means to temporal and calendric data representation and reasoning. Research in temporal knowledge representation and reasoning (in Artificial Intelligence and Database Systems) has mainly focused on set-theoretic and logic-based formalisms to time and calendars.

Recently, similar problems concerning time and calendars to those in Artificial Intelligence and/or in Database Systems appear in existing and emerging Web and Semantic Web applications and Web services. In fact, applications that involve arbitrary calendric data possibly referring to different calendars are typical for the Semantic Web: systems and applications in the Semantic Web cannot be considered being closed and they cannot demand uniform data modeling. Temporal and calendric data on the Web and the Semantic Web is extremely distributed and heterogenous. Furthermore, such data should support recent internationalization and localization efforts in the Web. Thus, existing and emerging Web and Semantic Web applications and Web services give rise to further considerations concerning time and calendar models and representation and reasoning approaches.

On the current Web, temporal and calendric data and expressions can hardly be interpreted by computers. The vision of the Semantic Web is to enrich the current Web with well-defined meaning and to enable computers to meaningfully process temporal and calendric data and expression. Nowadays research in the Semantic Web mainly focuses on *ontology-based* modeling (even of temporal and calendric data) using *generic* languages such as OWL or RDF which refer to *axiomatic reasoning* approaches designed for arbitrary Semantic Web applications.

The work reported about in this thesis claims that temporal data and calendars require *specific* modeling and processing tools, even in the Semantic Web, that goes far beyond ontology modeling and axiomatic reasoning approaches. This work is based on a programming language approach to data modeling and reasoning with calendars and calendric

and temporal data. This approach combines ideas and techniques developed for modern programming languages, in particular type checking approaches including subtyping (to relate different calendars and calendric types) with theory reasoning approaches, in particular constraint programming techniques. The application of choice is appointment scheduling involving arbitrary calendars, called *multi-calendar appointment scheduling*. Thus, this approach complements both research in the area of temporal knowledge representation and reasoning and research in the area of the Semantic Web with programming language approaches to conveniently express temporal and calendric data and expressions in a user-friendly calendar modeling language and with theory reasoning approaches to efficiently model and process problems *specific* to the particular application domain of calendars and time. The work's underlying thesis is twofold:

1. *"Calendar as Type":* calendars are more conveniently expressed with dedicated language constructs. Types and type checking are as useful and desirable with calendric data types as with whatever other data types. Types complement data with machine readable and processable semantics. Type checking is a very popular and well established "lightweight formal method" to ensure program and system behavior and to enforce high-level modularity properties yielding in abstraction. Types and type checking enhance efficiency and consistency of any language.

2. *"Theory Reasoning":* calendars are more efficiently processed with dedicated reasoning methods than with "axiomatic reasoning" of ontology languages like RDF and OWL. This makes search space restrictions possible that would not be possible if calendars and temporal notions would be specified in a generic formalism such as first-order logic and processed with generic reasoning methods such as first-order logic theorem provers.