A Survey on Temporal Reasoning and Temporal Maintenance Systems

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***Abstract*— The research in temporal databases is going to complete its third decade. From time to time various researches have been carried out in this direction leaving its impact on almost every area, such as record keeping applications, clinical application, scientific application, financial applications and project management. The researches in the field of temporal data mining can be divided into two areas. One is related to temporal maintenance while another deals with the task of temporal reasoning. The integration of these two tasks forms the architecture of temporal mediator, which now a days are used for the designing of management information systems. The paper is based on the survey of temporal maintenance and temporal reasoning systems developed so far.**

Keywords*— temporal reasoning; temporal maintenance; temporal mediator.

I. INTRODUCTION

Now a day's many database application manage time varying data. Temporal database incorporates the concept of time to create high level abstractions useful in database applications. Analyzing large sequential data streams to unearth any hidden regularities is important in many applications ranging from finance to manufacturing processes to bioinformatics. Temporal data mining methods must be capable of analysing data sets that are prohibitively large for conventional time series modeling techniques to handle efficiently.

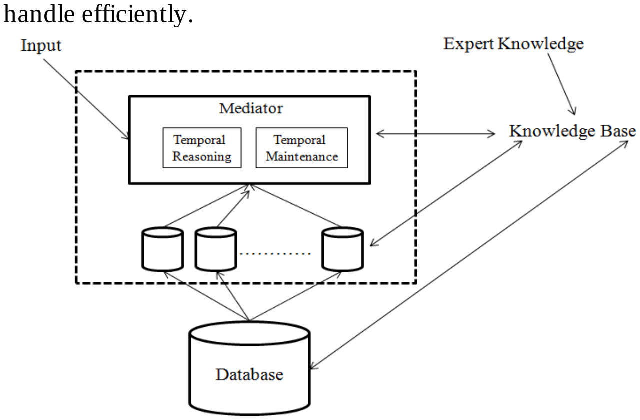

Figure 1. Temporal mediator architecture

II. RELATED WORK

For better decision making one cannot ignore the chronological order and the time stamp associated with each data set. The field of temporal data mining is concerned with mining large sequential dataset. The dataset should be ordered by some index value. As in case of time series analysis each record is ordered by time.

Following researchers illustrated the limitations associated relational model and other database models:
Codd (1990) predicted the fact that in the relational model the temporal nature of data has been largely ignored, being reflected only through updates while ignoring the past states [1]. The knowledge discovered from conventional database has limited value since the temporal nature of data is not taken into account but only the current or latest snapshot Saraee, et al. (1995) [2].

Temporal data management can be very difficult using conventional (non temporal) data models and query languages. So time has been added to many data models, including the entity-relationship model, semantic data models, knowledge-based data models, and deductive databases. However, by far the majority of work in temporal databases is based on the relational and object-oriented data models. Various temporal data models were proposed based on temporal dimensions. Some models are defined over valid time or transaction time others are defined over both. The valid time of a fact is the collected times-possibly spanning the past, present and future when the fact is true in mini world. The transaction time of the database fact is the time when the fact is current in the database, Thompson (1991) [3]. The various temporal models proposed are given in Table I.

Table I. Temporal Data Models

Model Name	Temporal Dimension(s) & Identifier	Citation
Accounting Data Model	(both / both) & (Thompson)	[3]
Temporally Oriented Data Model	(both / both) & (Ariva / Bhargava, et al.)	[4] / [5]
Time Relational Model	both & Ben-Zvi	[6]
Temporal Oriented Data Bank Model	(valid / both) & (Wiederhold, et al. / Yau, et al.)	[7] / [8]
Historical Relational Data Model	(valid / valid / transaction) & (Clifford, et al. / Jones, et al. /	[9] / [10] /

	Lomet, et al.)	[11]
Bitemporal Conceptual Data Model	(Jensen, et al. & both)	[12]
Heterogeneous Relational Data Model	(Gadia, et al.) & (valid)	[13]

Dey, et al. (1996) [14] proposed temporal relational algebra based on multidimensional tuple time stamping to capture the temporal behavior of data. The concept of Coalescence operation and Value equivalent tuples are introduced. A new operation temporal projection was proposed in this algebra. For e.g. the tuples ⟨6017, [1,5], 20K⟩ and ⟨6071, [4,7], 20K⟩ are value equivalent. If they are coalesced, the resulting tuple will be ⟨6071, [1,7], 20K⟩.

III. Temporal Maintenance Systems

For managing and maintaining temporal databases many temporal query languages were proposed.

A. *TQuel (Temporal QUEry Language)*

Snodgrass (1987) [15] developed TQuel language and was designed to be a minimal extension, both syntactically and semantically, of Quel (query language in the Ingres relational database management system).

B. *TQuery*

Fagan, et al.(1991) [16] developed a context-sensitive temporal query language.

C. *TSQL2 (Temporal Structured Query Language)*

Snodgrass, et al.(1995) [17] have developed temporal query language known as TSQL2 to query and manipulate time varying information data stored in a relational database. It is an extension of SQL-92.

Now a day's many commercial database systems support temporal dimensions. Oracle 9i included support for transaction time. The Oracle 10g includes the period data type, valid-time support, transaction-time support, support for bitemporal tables, and support for sequenced primary keys, sequenced uniqueness, sequenced referential integrity, and sequenced selection and projection, in a manner quite similar to that proposed in SQL/Temporal. In addition to oracle, there are also other products which provide temporal support. LogExplorer, aTempo's Time Navigator, IBM's DataPropagator, MarkLogic's and MarkLogic Server are some of them.

TQuel, TQuey and TSQL2 are the various temporal query languages and they falls in the category of temporal-maintenance systems.

O'Connor, et al. (2002) [18] developed a temporal maintenance system for clinical domain known as Chronus II. It extends the standard relational model and the SQL query language to support valid-time temporal queries. Its design was influenced by the original Chronus query system and by TSQL2. The system was developed in Java and it operates as a layer above existing relational database and interacts with the database through a JDBC interface.

IV. Temporal Reasoning Systems

For any realistic decision support system, it is not sufficient to able to effectively and efficiently store and retrieve the time-oriented data but it is also necessary to be capable of reasoning about time-oriented medical data. Temporal reasoning in clinical domain has made considerable progress.

Fagan (1980) [19], designed Ventilator Manager (VM) program is designed to interpret on-line physiological data in the intensive care unit.

Blum (1982) [20], developed Rx system for knowledge-discovery from time-oriented clinical databases.

Summarization program for medical records was designed by Downs, et al. (1986) [21] for summarizing major events in time-oriented medical records of systemic lupus erythematosus patients.

Temporal utility package (TUP) was the temporal reasoning system (domain independent) proposed by Kohane (1987) [22]. The system can be used for wide variety of knowledge bases and represents various types of abstractions and contexts.

IDEFIX is a knowledge-based system that produces intelligent summaries from a time-oriented database of patients who have systemic lupus erythematosus designed by Zegher-Geets (1988) [23].

Russ (1989) [24] presented a data-dependency system, the temporal control structure (TCS), designed to support reasoning with data changing over time and show how it can be used to implement reasoning by hindsight.

Kahn (1991) [25] implemented a program, called TOPAZ that generates a narrative summary of the temporal events found in the electronic medical record of patients receiving cancer chemotherapy.

Guardian is composed of a variety of software modules organized in two levels. At the lower level, Guardian has modules which perform data reduction and abstraction tasks. At the higher level, various reasoning skills exist and cooperate under the guidance of BB1 (Blackboard Control Architecture) designed by Hayes-Roth, et al. (1992) [26].

TrenDx system proposed by Haimowitz, et al. (1993) [27] to match clinical data efficiently against a set of predefined patterns.

Shahar, et al. (1993) [28, 29, 30] designed temporal reasoning system for clinical domain. It is a computer program, developed in CLIPS (a shell for knowledge-based systems, developed by NASA Software Technology Branch) and runs on wide variety of hardware platforms. It consists of three modules; temporal-reasoning module, a static domain knowledge base and a dynamic temporal fact base. RÉSUMÉ was tested in several clinical domains: protocol-based care, monitoring of children's growth and therapy of insulin-dependent diabetes patients.

V. MEDIATOR SYSTEMS

The research in the field of temporal databases has two directions. One of which was based on temporal-reasoning and other was based on temporal-maintenance. Temporal-reasoning supports inference tasks involving time oriented data; often connected with artificial intelligence methods. Temporal-maintenance deals with storage and retrieval of data that has multiple temporal dimensions, often connected with database community.

Real decision support applications that involve time-oriented data require to some extent both maintenance of the data and reasoning about them. Now a day's the major research issues in this area are related to integration of above two tasks by using Mediator (Figure 1).

Wiederhold (1992) [31] has proposed the important concept of a mediator which can be regarded as a framework for performing semantic integration over multiple data sources and reasoning systems.

Subrahmanian, et al. (1995) [32] developed a mediator known as HERMES- A Heterogeneous Reasoning and Mediator System. HERMES is a system based on the HKB theory (Hybrid Knowledge Bases). The system currently runs on Sun Sparc stations (under UNIX), as well as on the IBM-PC platform under DOS/Windows 3.1.

Tzolkin was a temporal mediator based on clinical guidelines, proposed by Shahar, et al. (1999) [36]. In the mediator architecture, the temporal-reasoning modules uses RÉSUMÉ system and temporal-maintenance module uses Chronus system as implementation. It allows clinicians to use SQL-like temporal queries to retrieve both raw, time-oriented data and dynamically generated summaries of those data.

Idan is a distributed temporal-abstraction mediator for medical databases proposed by Boaz, et al. (2003) [44]. The mediator was based on the theory of knowledge based temporal abstraction. Idan integrates a set of time-oriented data sources, domain specific knowledge sources, vocabulary servers, a computational process specific to the task of abstraction of time oriented data using domain specific knowledge, and a controller that integrates all services. Idan was implemented using several environments. The medical vocabularies are stored in an MSSQL server. The rest of the services, including the controller, were implemented in the Microsoft .Net environment, written in the C# programming language. All communication is performed using XML documents. Table II illustrates the various mediators proposed so far.

Table II. Mediators

Mediator	Developer and Year	Remarks	Citation
Active Object-Relational Mediators	Kudrass, et al., 1996	Object oriented mediator	[33]
Distributed Mediator Integrating Many Data Sources	Josifovski, et al., 1999	Based on mediator-wrapper approach	[37]
Oo Mediator	Lin, et al., 2000	Querying XML data through such an Object-Oriented (OO) mediator system using an OO query language	[38]
E-Xmlmedia Mediator	Gardarin, et al., 2002	Integrating and querying disparate heterogeneous Information as unified XML views	[41]
Finder	Alvarez, et al., 2002	For building several real world data integration applications, both in the Internet and Intranet domains	[42]
Intelligent Mediator	Ricci, et al., 2002	Query management	[43]
Xml Mediator	Mathkour, et al., 2003	Mediator based on XML technology	[44]
Hierarchical Markov Model Mediator (HMMM)	Zhao, et al., 2006	Based on video objects to facilitate temporal pattern retrieval	[46]

VI. CONCLUSION AND FUTURE DIRECTIONS

In this paper we discussed on temporal maintenance and temporal reasoning systems developed so far related to medical domain. Further we illustrated some of the mediator systems in various domains designed by integrating the tasks of temporal reasoning and temporal maintenance. The future research in the field of temporal data mining can be carried by developing temporal mediator system for designing management information systems [51-59].

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