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Towards a High Level Framework Model for the Description of Temporal Models in Healthcare Information Systems.

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Abstract

Time is intrinsically connected with medical knowledge and data, while medical temporal reasoning is directly relevant to almost every aspect of medical practice. Various medical information systems exploit temporal information and have developed specialized methods to address the unique storage and retrieval requirements of time-varying clinical data. The adopted approaches, being highly application-dependent, differ in a number of aspects such as the choice of ontological primitives, whether time is viewed as discrete or continuous, the modeling of uncertainty, incompleteness and impreciseness, the granularity of the time stamp chosen, etc. Information exchange between these systems, or integration in large scale healthcare information systems, will only be possible if a high level framework model, rich enough to express the properties of the various approaches in all its aspects, can be developed. Through a detailed review of the literature, this paper identifies the types of temporal information that have been shown to be relevant in medical applications, and as such defines part of the minimum requirements for the future framework model.

Introduction

Temporal representation and reasoning is necessary for the various tasks physicians have to perform when caring for their patients. During **history-taking**, they try to establish the time of onset, duration and chronology of the various symptoms and signs the patient may present or has shown recently, taking into account previous illnesses or concurrent diseases to detect recurrent manifestations. Patients may express temporal information very precisely, either in absolute terms (*I got a terrible headache yesterday at 5 o' clock*) or through relationships (*I started vomiting just after finishing my soup*). More often, patients are much more uncertain and not precise at all about their experiences: *the palpitations started a few minutes after I had been walking, or perhaps just before*.
Patients also tend to present their personal history as an *incomplete scenario*: they don't mention all relevant events, or omit certain parts of their story. By using intuitive causal-temporal reasoning mechanisms, physicians are able to think backward and forward in time, inferring events from state changes and state changes from events. They try to represent the temporal information in a structured way such that it is possible to *reason* from what the patient tells to what events and states must have existed as causes and effects of these states. It's up to the physician to *describe* the inferred cause and effect in an explanatory way.

Throughout the **diagnostic process**, physicians use temporal reasoning strategies in a number of ways. A causal diagnostic explanation, for example, must account for the temporal latency of observed manifestations given the hypothesized ethiological factor. Diagnostic decisions are also based on time-dependent constallations of symptoms and signs showing the physician similarities to previous courses or case descriptions in medical textbooks. As such, temporal constraints play a key part in the generation, elaboration and selection of hypotheses. Tests and technical investigations provide further clues towards a final diagnosis but it should not be forgotten that this new information relates to the time when the investigation was performed, and not to the time when the results are received.

Therapeutic actions and decisions rely heavily on notions such as the patient's past clinical course, current medical status and predicted future course. At the other hand, therapeutical interventions affect the temporal behaviour of manifestations considerably and even may invoke new ones, possibly side effects, leading to an adjustment of the therapeutic plan later on. In cancer chemotherapy planning for instance, temporal information is crucial for the generation of therapy plans responsive to the problems the patient may have encountered in the past.

Patient monitoring also involves analyzing the timing of changes in the patient's manifestations. When they are continuously monitored as in an intensive care unit, the exact time when a significant change occurs can be recorded. In other situations, this may not be the case and physicians will have to deal with various types and magnitudes of distortions in subjective time perception, possibly leading to ambiguities in the flow of events.

Temporal models in medical information systems

According to Shoham, a theory of time and change must first provide a language for describing what is true and false over time, and what changes and remains constant. Secondly, it must provide a way of defining and reasoning about rules of *lawful change* in the above language [1]. Through history, various temporal logics, aiming to resolve specific problems, have been developed. A rich and complete model of time is still unavailable, but such a model may prove to be computationally intractable. This is already the case for some models being not general at all, as for Allen's theory of action and time [2] which maintains only one view of the world and does not allow to deal with different hypothetical worlds nor in the past or the future [3], but for which it has been shown that answering many of the questions that physicians are dealing with is NP-complete, and thus almost assuredly intractable [4]. Nevertheless, variants of Allen's representation have been used in a number of systems, avoiding the intractability and other problems by imposing some restrictions on the language [5], assuming an equally distant basic scale instead of a continuous one [6], or introducing the notion of reference sets and hierarchical ordering using causal abstraction [7].

Long identifies at least seven tasks where temporal reasoning plays an important role in (table 1, [8]). In medical applications, some of these tasks have to be adressed at the same time. Patient monitoring for instance calls for planning, explanation and prediction. Numerous theoretical contributions and application-independent database- and expert system tools which *could* be useful for the management of temporal information have been proposed. This is in contrast with the paucity of practical applications, an overview of which is given in table 2. This may be due to the fact that basic research in this field aims at finding adequate solutions for specific problems, but makes too much abstraction of other important issues, possibly ignoring them at all.

Both formal theories and heuristic approaches have been applied to answer specific questions on temporal knowledge representation and temporal reasoning in medical applications. To mention only the most important ones: procedural logic implemented through horn clauses [9], syntactic pattern recognition [10], abductive reasoning [11], belief networks [12], event calculus and derivatives [13], reasoning by hindsight [14], interval calculus and related approaches such as Allen's temporal logic [5, 3] and Shoham's proposition type temporal logic

[15], the Time Line mathematical formalism [16], implementation of special operators [17, 18], production rules with fuzzy relational operators [19], statistical methods [20], not to mention the many combined approaches based on ad hoc considerations.

It has been stated that *a rich model of time is needed to capture the diverse aspects involved in medical problems* [21]. Though this is true from a theoretical point of view, it doesn't make sense to postpone our attempts concerning the exchange of data and knowledge between independent information systems containing temporal data until such a general model has been developed. A prerequisite however is the development of a high level framework model (HLFM), rich enough to **express and describe** the underlying structures of time, especially their semantics, that has been or will be adopted in these systems. Especially when object oriënted techniques are used to represent temporal ontologies, such a HLFM is mandatory in order to achieve maximal consistency and coherence. In the following paragraphs, we discuss the various issues concerning the structures that have been shown to be relevant in medical applications, and as such define the minimum requirements for the HLFM, the precise format of which will be discussed elsewhere. We do not discuss whether or not these structures reflect the absolute nature of time as this is a purely philosophical question, totally irrelevant in the light of our objectives, nor whether they are a good choice for their intended use within the applications under study.

Characteristics of temporal models

Medical applications dealing explicitly with temporal information must define a number of basic objects. Basic concepts commonly found throughout the literature are *intervals*, *instants* or *time points*, *properties*, *events*, *states*, *actions*, *occurences*, *processes*, *histories* and *facts*. The semantics of these concepts may vary considerably among the authors. There are a number of reasons for this.

Some applications are based on a specific temporal logic, and as such adopt the semantics of the underlying theoretical work. An important issue is the introduction of intervals and/or time points in the model. In Allen's original work for instance [2], which has been very influencial for later work in medical temporal reasoning, the notion of interval is the only primitive in the temporal ontology. Time points are excluded explicitly, but when they are needed conceptually, they may be viewed as very small intervals. Later, he introduces instants as constructs from special sets of intervals, each instant being identified with the set of intervals that either contain it or are bounded by it [22]. Finally, Galton proposed a further modification of the logic by introducing time points as a second primitive in the temporal ontology, being completely independent one from another [23]. Different views are found in McDermotts' logic in which a time point is the only temporal primitive, intervals not being defined at all [24], whereas Shoham also starts from time points, but defines intervals as a pair of time points [25].
In Kowalski's and Sergot's Event Calculus, developed as a framework for temporal databases, events are the basic primitives of the ontology. They are considered to be structureless points in time, but nevertheless not prevented from having duration [26]. This is in contrast with Donald Davidson's vision, where events are introduced not as time-points, nor intervals, but where they are causually individuated: two events are identical if and only if they have the same causes and effects [27]. Hayes, finally, questioned the classical approach of time, where states and situations are *snapshots* of the world at a given moment, actions and events being functions from one state to another. He introduced the concept of *histories*, being four-dimensional spatio-temporal entities just like objects. As such, time is intrinsically connected with space [28].

Secondly, it must be kept in mind that practical applications need to make some adjustments to the theory. By doing so, the semantics of their temporal and other primitives may vary considerably, even not reflecting the original ones. It has to be a point of research whether or not these differences should be accounted for in developing and using the HLFM, and how they are to be expressed.

Event concepts are a typical example of this. In general, an event is a *change in the state of the world*. This broad definition is usually narrowed in practical applications. Planning systems for instance tend to make a distinction

between events and actions, events being a *spontaneous* change in world state, triggered automatically because of natural or artificial mechanisms, and actions *being caused* by an agent. Agents cannot directly execute events, but can only take actions leading to world states that trigger the desired events [29]. A patient showing a rise in temperature (an event), may cause the physician (the agent) to administer some medication (an action), which may lead to a stabilisation of the patient's temperature (a second event).
The more a medical information system makes use of a specific formal representation, the less intuitive the semantics of the event concept may become. More striking, according to Allen's interval calculus, a rise in temperature as mentioned above isn't even an event, but rather a *process*, events being wholistic entities: when an event occured over an interval, it did not occur, by definition, over any subinterval of it. At the other hand, this is always the case for processes, as defined by Allen.

Things get even more complicated when adopting the viewpoints of linguists, which becomes mandatory for the design of Natural Language Processing applications for medical information systems. Whereas temporal models can be built using absolute time references for some events and relative references to express temporal relations between events, these two concepts alone cannot explain the collection of tenses in a natural language. At least three separate sense-semantic entities are required for this purpose: a point of speech, a point of event, and a point of reference [30]. For a linguist, the distinction between a process and an event is one of aspectual perspective [31], or as Comrie once stated: *The term process means a dynamic situation viewed imperfectively, and the term event means a dynamic situation viewed perfectively* [32]. Others however recognize processes as events with a certain temporal extension but no association with a consequent state [33].
It should be mentioned here that an even more exotic approach to tense is found in *narratology*, a sub-discipline of hermeneutics. The logic of story-telling requires a very specific and sophisticated logic of time: the way the story is told, is to be mapped on an objective time-scale, but the mapping must leave room for flash-backs, gaps in the story and different perspectives [34]. If we think of patients as narrators telling their story, the physician has to be in position to unravel the patients' story and to map in on such an objective time-scale, not forgetting however to incalculate the subjective qualifications the patient add to the time-scale: painful events seem to take a longer time than moments of pleasure. Here temporal logics meets hermeneutics. A temporal fuzzy-logic approach has been proposed for this by Nowakowska [35].
Linguistic aspects of temporal information in medical discharge summaries have been covered by Johnson [36], whereas temporal referencing in medical records is currently being studied by Ceusters et al [37].

Temporal models in medical applications also introduce high level concepts as aggregates or transformations of elementary temporal entities [6, 18, 38, 39, others]. These entities represent context-dependent temporal concepts used by physicians in a natural way: a patient's visit, a therapy cycle, an admission, periods of clinical exacerbations, etc. Such constructs can overcome the limitations of classical temporal databases as described in early database systems wherein only point-based events can directly be represented [40, 41]. It is obvious that it should be possible to represent these high level concepts, and the procedures by which they are defined, in the HLFM as well.

Besides the choice of ontological primitives, a number of other questions have to be answered before constructing a temporal model. The various possibilities are summarized in table 3. Throughout the literature, specific choices have been made in order to achieve the maximum performance for the application making use of the model. It doesn't make sense for instance to build a model with a temporal grain size of one second when only date-stamped facts are entered in the database. However, in the latter case, a rise in temperature can only be *deduced* after the results of two measurements, performed on different days, have been entered in the database. If one wants to represent a rise in temperature having occured within one single day, this information has to be represented as such, making use of a specific semantic construct.
When developing the HLFM, it should be kept in mind that data exchange between systems having adopted different basic assumptions will only be possible when transformation rules are available. So, the HLFM must not only be able to represent the choices made by the various systems, but should also provide *some strategy* to develop these transformation rules.

Impreciseness, incompleteness, uncertainty

Common-sense reasoning is tightly coupled with temporal reasoning. Reasoning with uncertain, imprecise and incomplete temporal information is for humans part of every day life, but automating common-sense is far more difficult than automating specialist knowledge.
Some medical information systems have tried to implement these issues in their temporal model.
Implementation of *uncertainty* impose a branching structure on time. Various approaches have been proved to be effective in practical applications, such as augmenting rule-based systems with certainty and necessity factors [19], Bayesian belief networks [12], and Assumption Based Truth Maintenance Systems [3]. In theoretical contributions, various kinds of modal temporal logic have been proposed.
Reasoning with *indefinite* and *incomplete* temporal information in medical applications has been implemented by using hindsight [14], and adapted versions of Allen's Interval Calculus [5, 6].
Impreciseness of temporal information is an important issue in systems dealing with linguistic variables. When information has to be exchanged between such systems, some mapping functions, taking into account the different time scales of the systems, have to be elaborated. This is especially the case when mapping clinical vocabularies by means of an interlingua, as has been proposed by Masarie [42]. Here again, we think, the HLFM may play an important role.

Conclusions

Time is intrinsically connected with medical knowledge and data, while medical temporal reasoning is directly relevant to almost every aspect of medical practice. Various medical information systems exploit temporal information and have developed various specialized methods to address the unique storage and retrieval requirements of time-varying clinical data.
Information exchange between these systems, or integration in large scale healthcare information systems, will only be possible if a high level framework model, rich enough to express the properties of the various approaches in all its aspects, can be developed.
It is our opinion that this work should begin with an in depth study of the *sublanguage* that is used by physicians when expressing temporal information, using various sources such as medical records, medical textbooks, classification and coding systems, as well as a thorough analysis of the temporal models used so far in medical information systems and relevant theoretical contributions. In this paper, we presented a general overview of the issues that have to be covered when performing the latter. From this work, we can conclude that the future HLFM should at least be able to provide the following:

1. an unambiguous way to define and/or describe the basic temporal entities used as ontological primitives in existing models. This may call for the definition of general concepts with precise semantics within the HLFM, from which the other entities may be derived in a formal way,

2. a structure (classification, taxonomy, framework, coding system,... ?) to describe the underlying nature of the temporal models (branching, granularity, discrete, ...),

3. procedures to map imprecise temporal information and relations upon one, common time line, without losing further information.

References

[1] SHOHAM Y. Reasoning about Change; Time and Causation from the Standpoint of Artificial Intelligence. The MIT Press, Cambridge, Massachusetts, London, England, 2nd ed. 1989.

[2] ALLEN JF. Towards a general theory of action and time. Artificial Intelligence 23, 123 - 154, 1984.

[3] HAMLET I, HUNTER J. A Representation of Time for Medical Expert Systems. In: Lecture Notes in Medical Informatics, Springer Berlin, 33, 112 - 119, 1987.

[4] VILAIN M, KAUTZ H. Constraint Propagation Algorithms for Temporal Reasoning. In: Proc. Fifth Nat. Conf. on Artificial Intelligence, Philadelphia, PA, 377 - 382, 1986.

[5] VAN BEEK P. Temporal Query Processing with Indefinite Information. Artificial Intelligence in Medicine 3, 325 - 339, 1991.

[6] TUSCH G. Tools for Modeling Time-oriented Concepts; Applications for Retrieval of Liver Transplantation Data. In Talmon JL, Fox J (Eds.) Knowledge Based Systems in Medicine: Methods, Applications and Evaluation; Proceedings of the workshop 'System Engineering in Medicine', Maastricht, 16-18/3/89, Springer-Verlag, 36 - 48, 1989.

[7] KOHANE IS. Temporal Reasoning in Medical Expert Systems. In Salomon R, Blum B, Jorgensen M (Eds.) MEDINFO '86, Elsevier Science Publishers North-Holland, 170 - 174, 1986.

[8] LONG D. A Review of Temporal Logics. The Knowledge Engineering Review, Vol. 4: 2, 141 - 162, 1989.

[9] DEKEYSER LJ, DE SCHREYE D, WILLEMS JL. An executable logic of time for medical expert systems. In: van Bemmel JH, Grémy F, Zvarova J (eds.) Medical Decision Making: Diagnostic Strategies and Expert Systems, Elsevier Science Publishers North-Holland, 34-37, 1985.

[10] TUSCH G, BERNAUER J, GUBERNATIS G, RADING M. Knowledge Acquisition using Syntactic Time Patterns. In Adlassnig KP, Grabner G, Berylsson B, Hansen R (eds.) MIE 91, Lecture Notes in Medical Informatics 45, Springer Verlag, 316 - 324, 1991.

[11] CONSOLE L, TORASSO P. On the co-operation between abductive and temporal reasoning in medical diagnosis. Artificial Intelligence in Medicine 3, 291 - 311, 1991.

[12] BERZUINI C, QUAGLINI S, BELLAZZI R. Belief Network Representations of Temporal Knowledge for Medical Expert Systems. In Talmon JL, Fox J (Eds.) Knowledge Based Systems in Medicine: Methods, Applications and Evaluation; Proceedings of the workshop 'System Engineering in Medicine', Maastricht, 16-18/3/89, Springer-Verlag, 49 - 67, 1989.

[13] KERAVNOU ET, WASHBROOK J. A Temporal Reasoning Framework used in the Diagnosis of Skeletal Dysplasias. Artificial Intelligence in Medicine 2, 239 - 265, 1990.

[14] RUSS TA. Using hindsight in medical decision making. Computer Methods and Programs in Biomedicine, 32: 81 - 90, 1990.

[15] BERNAUER J, RADING M, TUSCH M, REICHERTZ PL, GUBERNATIS G, PICHLMAYR R. Case Description and Case Retrieval on Time Oriented Patient Data. In: Rienhoff O, Piccolo U, Schneider B (eds.): Expert Systems and Decision Support in Medicine. Proceedings. Lecture Notes in Medical Informatics 36, Springer Berlin, Heidelberg New York, 308 - 313, 1988.

[16] COUSINS SB, KAHN MG. The Visual Display of Temporal Information. Artificial Intelligence in Medicine, 3: 341 - 357, 1991.

[17] de CHAMPEAUX D, DAVIDSON J, ROBERTS R. Medical Databases. Meth Inform Med 26: 69 - 77, 1987.

[18] DORDA WG. WAREL, A System for Retrieval of Clinical Data Considering the Course of Diseases. Meth Inform Med 28: 133 - 141, 1989.

[19] QIU D, DUDECK J. Temporal propositions in a HIS-oriented expert system shell. Med Inform vol 16, 1: 65 - 76, 1991.

[20] CEUSTERS W, DE WIELE L, VAN MOFFAERT M. Therapeutische meerwaarde van de FSL-1, een geautomatiseerde observatieschaal voor psychiatrische patienten. In: Hofdijk J, Beckers W (eds.), MIC '90 Proceedings, 212 - 223, 1990.

[21] KERAVNOU E. Medical Temporal Reasoning. Artificial Intelligence in Medicine 3, 289 - 290, 1991.

[22] ALLEN JF, HAYES PJ. A common-sense theory of time. In: Proceedings IJCAI-85, Los Angeles CA, 528 - 531, 1985.

[23] GALTON A. A Critical Examination of Allen's Theory of Action and Time. Artificial Intelligence 42: 159-188, 1990.

[24] McDERMOTT DV. A Temporal Logic for Reasoning about Processes and Plans. Cognitive Science 6: 101 - 155, 1982.

[25] SHOHAM Y. Temporal Logics in AI: Semantical and Ontological Considerations. Artificial Intelligence 33: 89 - 104, 1987.

[26] KOWALSKI R, SERGOT M. A Logic Based Calculus of Events. New Generation Computing 4: 67 - 95, 1986.

[27] DAVIDSON D. The Individuation of events, in ibid., Essays on Actiosn and Events, Oxford, 1980.

[28] HAYES PJ. The Naive physics Manifesto, in:Hobbs JR, Moore RC (eds.) Formal Theories of the Commonsense world, Ablex, Norwood, NJ, 1984.

[29] VERE S. Planning. In Shapiro (Ed.) Encyclopedia of Artificial Intelligence, Wiley, 748-758, 1990.

[30] REICHENBACH H. The Elements of Symbolic Logic. The Free Press, New York, 1947, reprint 1966.

[31] NAKHIMOVSKY A. Aspect, Aspectual Class, and the Temporal Structure of Narrative. Computational Linguistics, 14, 2: 29 - 43, 1988.

[32] COMRIE B. Aspect. Cambridge University Press, Cambridge England, 1976.

[33] MOENS M, STEEDMAN M. Temporal Ontology and Temporal Reference. Computational Linguistics, 14, 2: 15 - 28, 1988.

[34] RICOEUR P. Temps et Récit, Paris, 1976.

[35] NOWAKOWSKA M. Perception of Time: a New Theory. In Kohout L, Bandler W (eds) Knowledge Representation in Medicine and Clinical Behavioral Science. Abacus Press Cambridge Mass., Tunbridge Wells Kent, 95 - 104, 1986.

[36] JOHNSON S. Temporal Information in Medical Narrative. In Sager N, Friedman C, Lyman MS (Eds) Medical Language Processing: Computer Management of Narrative Data. Addison Wesley, Reading, Mass., 175 - 194, 1987.

[37] CEUSTERS W, BUEKENS P, DE BRUECKER G, DE RIJCK K. Temporal ontologies and temporal reference in medical records. In preparation.

[38] DEGOULET P, DEVRIES C, RIOUX P, CHANTALOU JP, KLINGER E, SAUQUET D, ZWEIGENBAUM P, AIME F. LIED: a Temporal Database Management System. In: Salomon R, Blum B, Jorgensen M (eds.) MEDINFO '86 Proceedings, Elsevier Science Publishers North-Holland, 532 - 536, 1986.

[39] KAHN MG, FERGUSON JC, SHORTLIFFE EH, FAGAN LM. Representation and Use of Temporal Information in ONCOCIN. In Ackerman MJ (ed.) SCAMC 85 Proceedings, IEEE Comput. Soc. Press, New York, 172-176, 1985.

[40] WIEDERHOLD G, FRIES JF, WEYL S. Structured Organisation of Clinical Databases. In Meier DA, Miller SW (eds.), AFIPS Conf Proc 44, AFIPS Press, 479 - 485, 1975.

[41] MARTIN JM, JABOT F, MARREL. How to Organize the Medical Data of Chronically Ill Patients in the Computer. Meth Inform Med 24: 5 - 12, 1985.

[42] MASARIE FE Jr, MILLER RA, BOUHADDOU O, GIUSE NB, WARNER HR. An Interlingua for Electronic Interchange of Medical Information: Using Frames to Map between Clinical Vocabularies. Computers and Biomedical Research 24, 379 - 400, 1991.

[43] BLUM RL. Discovery and Representation of Causal Relationships from a Large Time-Oriented Clinical Database: The RX-project. In: Lecture Notes in Medical Informatics 19, Springer Berlin, Heidelberg New York, 1982.

[44] FAGAN LM, KUNZ JC, FEIGENBAUM EA, OSBORN JJ. Extensions to the rule-based formalism for a monitoring task. In: Buchanan BG, Shortliffe EH (eds.) Rule-based expert systems: The MYCIN experiments of the Stanford Heuristic Programming Project. Reading MA: Addison-Wesley, 397-423, 1984.

[45] SAGER N, FRIEDMAN C, LYMAN MS. Medical Language Processing. Addison-Wesley 1987.

[46] KAHN MG, TU S, FAGAN LM. TQuery: A Context-Sensitive Temporal Query Language. Computers and Biomedical Research 24: 401 - 419, 1991.

[47] MITTAL S. Event-based organisation of temporal databases. In: Proc. 4th Nat. Conf. Canad. Soc. Computational Studies of Intelligence, 164 - 171, 1982.

[48] KAHN MG, FAGAN LM, SHEINER LB. Combining Physiologic Models and Symbolic Methods to Interpret Time-Varying Patient Data. Meth Inform Med 30: 167 - 78, 1991.

[49] KAHN MG, FAGAN LM, TU S. Extensions to the Time-Oriented Database Model to Support Temporal Reasoning in Medical Expert Systems. Meth Inform Med 30: 4 - 14, 1991.

[50] RUCKER DW, MARON DJ, SHORTLIFFE EH. Temporal Representation of Clinical Algorithms Using Expert-System and Database Tools. Computers and Biomedical Research 23: 222 - 239, 1990.

- Temporal Database Management
- Prediction
- Planning
- Explanation
- Learning new physics
- Natural Language Understanding
- Historical Reconstruction

Table 1: Tasks in which temporal reasoning may play an important role.

Patient Database management		
LTX - project	Retrieval of Liver Transplantation Data	Tusch, 1989 [6]
TIME - program	Temporal knowledge acquisition through the analysis of medical narrative	Sager et al., 1987 [45]
ONCOCIN - TQUERY	Context-Sensitive Temporal Query Language	Kahn MG,1991 [46]
PATREC	Management of event-based patient records	Mittal, 1982 [47]
Diagnosis and interpretation		
SDD	Diagnosis of Skeletal Dysplasias	Keravnou et Washbrook J, 1990 [13]
RX/RADIX	Derivation of simple structured disease episodes	Blum RL, 1982 [43]
Patient monitoring and therapy planning		
VM	Ventilator Management on an Intensive Care Unit	Fagan et al., 1984 [44]
ONCOCIN-TOPAZ	Detection of clinical events evolving over time in patients with bone-marrow diseases	Kahn MG et al., 1991 [48]
ONCOCIN-TNET/ETNET	Therapy advice in chemotherapy planning	Kahn MG et al., 1991 [49]
HYPERLIPID	Advisory system for the NIH-recommendations on lipid management	Rucker et al.,1990 [50]
TCS	Cardiac Intensive Care Acute Phase of Diabetic Keto-acidosis	Russ TA, 1990 [14]

Table 2: Some examples of MIS with temporal models

Is time in the model represented as continuous or discrete ?
Is time in the model taken to be a single time-line, a branching structure, parallel, circular, or a mixture of these structures ?
What ordering, if any, has been applied on the temporal primitives: a partial or complete one ?
What grain size has been chosen ?
Is time in the model considered infinite in either or both directions ?
If the temporal model includes the concept of an interval, are these defined as being open, closed or half-open, i.e. are the endpoints excluded or not from the interval itself ?

Table 3: The structure of time.