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TEMPORAL KNOWLEDGE AND TEMPORAL REASONING SYSTEMS

Abstract: The paper is devoted to a problem of temporal reasoning for (among others) managerial tasks. It shows the complexity of economic environment, which leads to representational problems. Next the features of a temporal reasoning systems are pointed out, and finally one of such systems – a PROTON one – is presented and critically discussed.

Keywords: temporal reasoning, time, temporal intelligent systems, economic environment.

1. Introduction

A modern economic domain may be called – after Ansoff – a turbulent one. Changes appear very quickly, and it is difficult to take them all into account. At the same time, if managerial decisions are to be correct, it is absolutely necessary to use knowledge about these changes. This in turn brings the need of using the temporal aspects of the environment, as changes occur in time. Therefore, economic knowledge is of temporal character, and reasoning about it also is temporal. Time becomes a crucial dimension of economic analysis.

The economic decisions are nowadays so complex that they have to be supported by intelligent tools. Many authors have dealt already with the problem, even the whole branch of science emerged, called business intelligence. It deals with using intelligent computer analyses to support business decisions. Nevertheless, although BI tools are complex and advanced, not many of them take the temporal dimension into account.

The goal of the paper is to present a survey of questions linked with dynamic analysis of enterprise's economic environment. Therefore, we first discuss how time is dealt with in economics and in artificial intelligence (see Section 2). In Section 3 we present temporal systems and temporal knowledge together with their characteristics. Section 4 is devoted to so-called temporal reasoners, and the solution proposed by the authors of the PROTON reasoned is critically discussed.

2. Time management and artificial intelligence

If today enterprises operating on a free market want to survive, become successful and develop themselves, they have to react to changes in the economic environment quickly and properly [Nowak 1998]. This concerns past, present and anticipated changes. The analysis of past changes may form a basis for prediction, present changes affect current activity, and anticipated changes allow formulating strategic plans for the future. Perceiving changes in this way is connected with a modern trend in strategic management, according to which enterprises treat analysis of anticipated changes and the reaction to present changes as equally important; very often the first type of analysis becomes more important (see e.g. [Stanek, Michalik, Twardowski 2000]).

At the same time, as Ansoff claims, in the environment of an enterprise there can appear bigger and bigger turbulences, resulting from – among other factors – four processes: newness of change increase, pace of change increase, environment complexity increase, and environment intensity increase [Kaleta 1999, 2000].

If we point out the above three types of change – past, present and future ones – as well as the increase of their pace, it becomes obvious that in the strategic analysis we have to consider the time factor, being a key one. There exist many theories putting emphasis on time in strategic analysis. Here we will recall two of them, namely: a concept of time-based competition and a concept called “economy of speed”.

In the first theory “overtaking” the competitors in time is perceived as the main factor in enterprise’s success. To do so, an enterprise needs research concerning the dynamics of phenomena and of processes in its economic environment as well as inside the firm [Gierszewska, Romanowska 1999]. The second theory stresses the need for real-time management, which allows starting strategic operations before competitors start them, gaining in this way a so-called first-mover advantage [Tvede, Ohnemus 2001].

Summing up, a good strategy has to be based on knowledge on environment’s dynamics. Such knowledge is gained through continuous process of collecting information on the environment and interpreting it [Przybyłowski et al. 1998]. The pace of changes may be so great that it may cause problems to be solved in *ad hoc* manner [Stanek, Michalik, Twardowski 2000]. If the problems are to be solved by an intelligent system, also the system’s knowledge has to be placed in temporal context, as it has to be always up to date. And one of the main reasons for knowledge changes is the passage of time [van Benthem 1995].

All that has been said above leads to a simple conclusion: a good representation of economic knowledge should be a time-based one.

It is commonly known and accepted that time representation and temporal reasoning are necessary in many AI systems [Vila 1994], as time is the basis for reasoning about action and change. Many AI systems concern enterprise’s environment which is constantly changing (see e.g. [Mach 2003]). Therefore, if decisions made on the basis of such systems' advice are to be correct, the system has to deal with temporal dimension of information, changes of information in time as well as it should "possess" knowledge of the nature of those changes [Vila 1994]. That is why the need of representing temporal knowledge in AI systems seems nowadays obvious. And the tasks for such temporal AI system encompass among others [Vila 1994]:

- maintaining temporal coherence,
- answering temporal queries,
- explanations,
- prediction, etc.

A temporal intelligent system is a system that performs temporal reasoning explicitly. That is, the system not only contains e.g. fact base, a rule base, and an inference engine, but also deals with the question of time directly. Such a system allows inference about changes of phenomena in time, historical analysis of phenomena, prediction and – generally speaking –a dynamic analysis of reality depicted.

The most common way of representing temporal knowledge is to use notations based on logic. Many authors have been dealing with this question and there are several temporal logic systems, which can be roughly divided into: logics of time intervals, logics of time points and logics of time points and intervals (see e.g. [Hajnicz 1996]).

The artificial intelligence systems, which – according to the most popular definition – need and should simulate intelligent behavior, should be able to gain new knowledge, act successfully depending on the state of their knowledge and adapt fast to new situations or changes. In many situations there is also a need for tracing the evolution of knowledge.

One can see a real need for constructing temporal intelligent systems in areas of economy and management. As the examples of such areas one could point out:

- adaptive formulation of marketing strategy, depending on changes in competitive environment conditions,
- adapting investing strategy to economic and/or legal conditions,
- adapting development strategy of an enterprise to entry barriers on a relevant market, etc.

Researchers have proposed in the literature several solutions to adaptive temporal intelligent systems, which encompass, among others, the use of temporal logic, dynamic models (the ones based on states and predicative ones). Reiter [1995, 2000] proposed to use situation calculus.

3. Temporal systems and temporal knowledge

By a temporal intelligent system we understand an artificial intelligence system that explicitly and directly performs temporal reasoning (see Section 2 for definition). For an intelligent system to be considered temporal, explicit time references should be found at least in the representation and reasoning layers. A sample structure of a temporal intelligent system is presented in Figure 1.

A temporal intelligent system may be considered a decision support system in a sense that its purpose is to support e.g. decisions that need an advanced temporal analysis of the economic environment. Taking into account the temporal features of the environment, we may see the tasks of the system from two different perspectives.

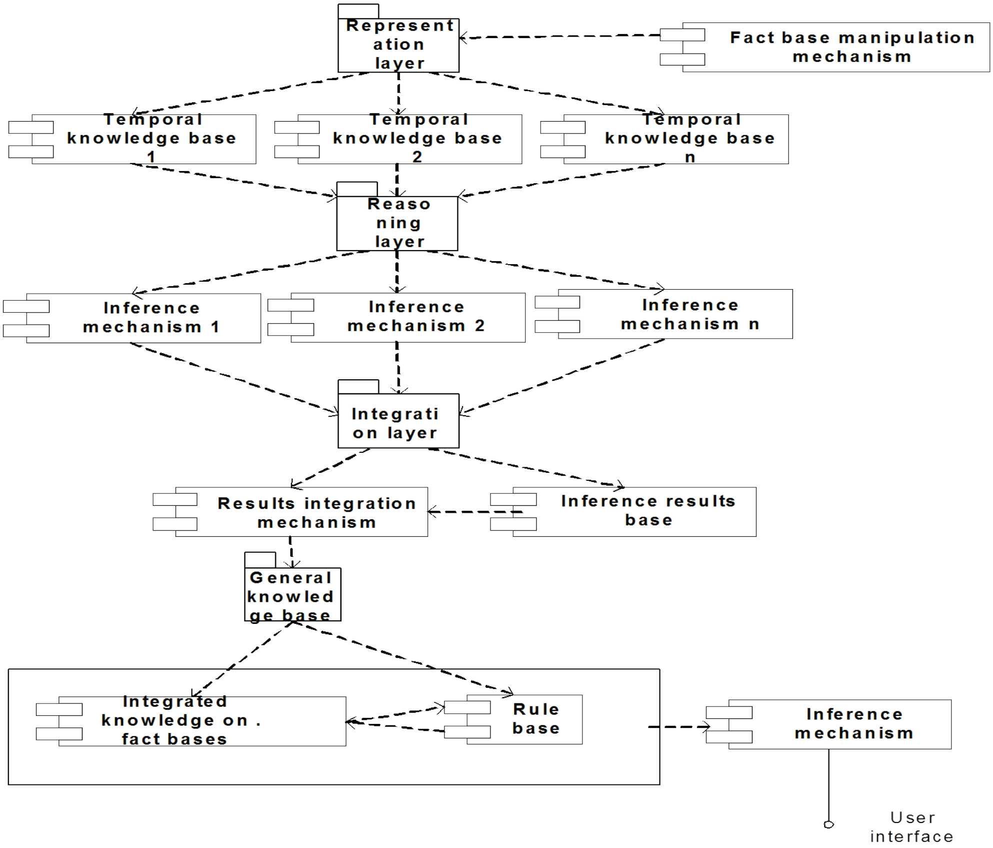

Figure 1. A structure of a sample temporal intelligent system

Source: own elaboration.

In an economic-managerial perspective, the intelligent analysis of changes encompasses:

1) a proper representation of phenomena in the economic environment and of their changes in time,

2) representation of both qualitative and quantitative phenomena,

3) analysis of the current state of the environment,

4) historical analysis of changes in the environment (tracing changes' evolution),

5) expression of causal relationships,

6) analysis of future changes in the environment.

A tool for performing the above tasks should be able to (instrumental perspective):

1) represent time – discrete and/or dense one, depending on the needs and on the nature of phenomena being analyzed,

2) represent causal relationships between actions and/or phenomena in the environment, represent conditions to perform an action,

3) represent processes, among which are conditional and concurrent ones,

4) analyze future changes.

What are the advantages of using temporal formalisms? First of all, they allow representing changes and reasoning about causes, effects and directions of these changes. Next, with causal relationships, temporal formalisms may be used for "if-then" analysis. These formalisms provide representation for qualitative and quantitative temporal information as well as temporal relations. It is possible to perform qualitative reasoning and simulate human commonsense reasoning. With temporal formalisms it is possible to differ reasoning granulations and model processes in an explicit way.

Temporal knowledge is a special kind of knowledge. It is distinguished by the following properties:

- time-dependent,
- changing,
- encompassing changes and actions,
- encompassing causal relationships.

A temporal knowledge may be used in a temporal intelligent system. A system possessing such a knowledge is capable of gaining new knowledge, providing up-to-date knowledge, and dealing with new information. As a result, it is possible in such a system to represent changing domains, fit into changes in system's environment and reason about changing domains.

The temporal knowledge is not homogeneous. One can distinguish several types of it, depending on the scope of temporal assignments:

- static knowledge: "An enterprise has to conform to legal rules";
- sequences: passing a law à signing the law by the President à publishing the law;
- wiedza znakowana czasowo: application for concession à decision à valid period of concession;
- fully temporal knowledge: varying prices of shares.

In the next section we present and discuss one of temporal intelligent systems (temporal reasoners), called PROTON.

4. Temporal Reasoners – reasoners for temporal ontologies/ knowledge bases: PROTON

In Sections 2 and 3 we defined a temporal intelligent system. To the best of our knowledge, there are no functioning systems of that kind. Instead, there are implemented systems for managing temporal information which use single temporal or semi-temporal formalisms. One of them is a tool called PROTON − a reasoner acting over temporal ontologies. We will briefly discuss it here, on the basis of [Papadakis et al. 2011].

PROTON stands for "Prolog Reasoner for Temporal Ontologies in OWL". It is a reasoning system for managing temporal information over OWL ontologies. The construction of the tool adopts a 4d-fluent approach to representing temporal information in ontologies. It is possible to represent time points or time intervals and also events occurring in these time points or intervals.

Behind the construction of PROTON, there are some observations and assumptions. First observation is that such representation languages, as OWL and RDF, are based on binary relations. The temporal information, that is an information with explicit temporal aspects, may be represented in ontologies, but its changes cannot be represented in neither OWL nor RDF. As a consequence, while performing reasoning over information represented in OWL or in RDF, one cannot take the temporal aspect of information into account.

PROTON is dedicated to reasoning about temporal ontologies in OWL and is capable of handling queries concerning events changing in time. It starts with a temporal ontology in OWL, then transforms it into triplets of the form (subject predicate subject). Finally, these triplets are transformed into Prolog clauses. PROTON is implemented in so-called temporal situation calculus, thus it can make use of Prolog mechanisms for implementing the reasoning component.

The main formalisms for reasoning about actions and change are: situation calculus, fluent calculus, event calculus, action languages, action calculus [Levesque, Pirri, Reiter 1998; Pinto, Reiter 1995; Thielscher 1998; Kowalski, Sergot 1986, 1989; Baral, Tran 1998; Gelfond, Lifschitz 1998] and temporal action logic (TAL). Situation calculus is the most popular of them, a second order language aimed at representing changes of the world. In SC all changes result from performing some actions. The world itself is depicted using so-called fluents (which may be predicates or functions). A probable evolution of the world (domain) is a sequence of actions represented with situations.

It is worth annotating the use of temporal situation calculus. The original SC is a typical action language, capable of expressing temporal aspects of the domain in an implicit way [Levesque, Pirri, Reiter 1998; Pinto, Reiter 1995]. Probably this implicitness forced some authors to develop a more temporally oriented version of SC, namely the temporal situation calculus. One of those authors is Raymond Reiter (works such as: [Reiter 1996, 1998], and others). Nevertheless, one immediately notices that the "temporal" SC is an only slight modification of the classic one. As Reiter points out, these modifications encompass adding a temporal argument to all instantaneous actions as well as adding one new axiom. In this way a kind of hybrid representation language is obtained, the one combining implicit and explicit time expressions.

The only reason for using temporal situation calculus in PROTON is – in our opinion – the need for using Prolog reasoning, with which SC is strictly connected. Nevertheless, the authors of PROTON propose their own extension to classic SC in order to incorporate time notion explicitly. Their modifications are as follows [Papadakis et al. 2011]:

- For each fluent f, an argument L is added, where L is a list of time intervals $[a; b]; a < b$.
- Each $[a; b]$ represents time points x: $\{x\{a < x < b\}\}$.
- Fluent f is true over all intervals from list L.
- Two new functions have been defined: *start*(a) and *end*(a), where a is an event (action).
- Events are ordered: $a1 < a2$, where *start*($a1$) < *start*($a2$).
- Predicate *eventHappen*($a; t$) means, that action a is executed at time moment t.
- A so-called "temporal situation" is defined as a situation with a list of time intervals, over which fluents are true.
- Function *Holding*($S; t$) returns all fluents true at time t. For a functional fluent, *Holding*($S; t$) returns a value of the function in point t. Situation S is a temporal one.
- Passing from situation to situation is possible when *Holding*($S; t$) returns different sets.

What is immediately visible after this short list, is a strange way of representing time points. In our opinion a point should be represented as an interval $\{a, b\}$ where $a = b$. This is the way Allen represents time points (see [Allen 1983, 1984]). This is the more justified that the authors of PROTON later on adopt Allen's interval calculus for manipulating time intervals.

Next, in our opinion the authors needlessly multiply temporal entities, introducing both time points and time moments. Time points would be quite enough. Obviously, one may suppose that for the authors time points and time moments mean the same, but this is not stated anywhere in the paper cited.

PROTON is based on the idea of transforming representation in temporal ontology into a set of Prolog predicates. After such transformation, temporal queries may be asked against Prolog database. Thanks to the temporal extension of the situation calculus, PROTON is able to manipulate relationships among time points or intervals and reason temporally.

PROTON tool is composed of several modules: SWI-Prolog, which converts OWL concepts into Prolog clauses, a module for calculating interval relations, a set of functions for calculating property values in points of time, a set of predicates establishing, when an event takes place, and finally, a set of rule executing predicates, which operate when an event or a change in feature value occurs.

OWL concepts are transformed into facts of the form "predicate(subject, object)". Before this can be done, the OWL ontology is converted into triplets (subject predicate object) with SWI-Prolog. After transforming all OWL objects into facts it is possible to use Prolog reasoning for implementing the reasoner.

PROTON's knowledge base consists of automatically created predicates, concerning the domain of application. Some of them are common for all ontologies, while others are domain-specific. Also implemented are Allen's temporal relations (before, equals, meets, overlaps, during, starts, finishes). There are some additional predicates in the knowledge base – two predicates for time handling, two predicates for calculating feature values – domain dependent, and some other predicates, among which there are those responsible for solving the frame problem.

There are some questions arising while analyzing PROTON's structure and knowledge base. First, it seems strange to put predicates into the KB, while at the same time these predicates "scan" the KB and establish some values. It seems that these are functions, not predicates, the question is why the authors of [Papadakis et al. 2011] call them predicates.

Second, in our opinion there is no need to introduce both time points and time intervals if the relations in the KB are those introduced by Allen (as commonly known, he introduced only interval relations and showed how to define time points in terms of intervals). It would be quite enough then to introduce only intervals of time into PROTON's knowledge base.

The authors do not explain, how past events are handled and how the KB is actualized. And last but not least, they write about a knowledge base in one place, while about a database in another. In this way the reader does not finally know, whether PROTON contains a KB or a DB or both.

Summing up, PROTON is one of the first attempts to implementation of a temporal reasoner over OWL ontologies, not free from weaknesses.

Some other interesting temporal reasoners are e.g. SOWL [Batsakis, Petrakis 2011], FuzzyTIME temporal reasoner [Juarez 2010] and others.

5. Conclusions

The domain of temporal reasoning used for economic and managerial problems is vast and it is not possible to cover all the questions in one paper. The temporal economic knowledge is a specific one; therefore, it needs a specific treatment. The solutions presented in the paper do not account for a so-called commonsense reasoning, which may be very useful for formalizing economic decisions and/or economic expertise. Therefore, we also plan to present a survey of commonsense reasoning solutions which may be applied to economic and managerial problems.

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WIEDZA TEMPORALNA I TEMPORALNE SYSTEMY WNIOSKUJĄCE

Streszczenie: Artykuł poświęcony jest problemowi wnioskowania temporalnego m.in. w zadaniach menedżerskich. Wskazuje na złożoność otoczenia ekonomicznego, która prowadzi do problemów z reprezentacją wiedzy o nim, następnie przedstawia cechy, jakie powinien mieć temporalny system inteligentny, wreszcie jeden z takich systemów – PROTON – zostaje krytycznie przeanalizowany.

Słowa kluczowe: wnioskowanie temporalne, czas, temporalne systemy inteligentne, otoczenie ekonomiczne.