Prospects of Using Temporal Logics for Knowledge Management

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Abstract. The paper concerns the possibility of using temporal logics for knowledge management. The idea of knowledge management is presented, along with the most typical computer solutions for this area. The temporal aspect of knowledge management is pointed out. Having in mind this temporal aspect, the paper presents possible advantages of extending knowledge representation for knowledge management with temporal formalisms.

Keywords: knowledge management, computer system, temporal logic, TAL language.

1 Introduction

Modern enterprises pay a lot of attention to the area of management that is called knowledge management. They understand, that employees' knowledge, or more generally speaking, the knowledge of organization, constitutes one of its key resources. Therefore basic management trends encompass not only managing quality or change, but also knowledge management. It is this area of activity that enables an enterprise to compete with its competitors on the more and more turbulent and dynamic markets.

It must be noted, at the same time, that the most of knowledge is of temporal character. Knowledge changes in time – for two basic reasons. The first is simply the flow of time, while the second – gathering of new information about objects, that knowledge concerns, objects that possess temporal characteristics [2]. Therefore omitting of a temporal dimension would lead to loosing of important knowledge elements. In this way, time becomes an important category for an enterprise in the area of knowledge management.

While analyzing current informatics solutions for knowledge management, it has to be noticed that time as a knowledge dimension is not noticed at all. Taking into account importance of a temporal aspect, it seems a major disadvantage. Therefore in this paper we propose extending of a knowledge representation in

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knowledge management systems by temporal formalization, and we consider advantages of the proposed solution.

The paper is organized as follows. In Section 2 the concept of knowledge management is presented. Section 3 concerns computer solutions in this area. The next point (Section 4) is devoted to the temporal aspect of knowledge, and to the advantages of using temporal formalization. In Section 5 a practical example of temporal knowledge management is presented. The last section of the paper contains conclusions.

2 Concepts and Models of Knowledge Management

Nowadays knowledge is perceived by modern enterprises as one of key resources that is equally (or more) important as such "classical" types of resources as land, capital or work. What make knowledge so important are its features. M. Grudzewski and I. Hejduk ([5] s. 48) point out the following knowledge's features:

- Domination – meaning, that knowledge is the most important resource of a firm;
- Inexhaustibleness – knowledge that is used, spread, moved does not diminish;
- While used, knowledge gathers value, not used, it disappears;
- Simultaneousity – knowledge may be used by many persons at the same time;
- Non-linearity – it is not possible to point out a direct relationship between the amount of knowledge possessed and the advantages of it.

The above mentioned knowledge features created (among other features) the management trend called knowledge management, because knowledge role as a resource has been noticed. It is a relatively young domain in management sciences, therefore does not exist a commonly accepted definition of knowledge management. The authors of [5], cited before, assume knowledge management as "the whole of processes enabling creating, spreading, and using knowledge for organization's purposes" (p. 47). This definitions links explicitly to the temporal dimension of knowledge, because it uses a definition of processes, which is linked with change. Modeling of processes is useful while describing continuous phenomena, as economic reality for example, therefore it is also useful for describing changes of knowledge treated as enterprise's resource. More on this topic may be found in [17].

Definitions of knowledge management are numerous, as are models of knowledge management. In the literature, the most important models are: the resource one, the Japanese one, and the process one.

The first one – the resource model – treats knowledge as a key resource of an enterprise. This resource comes both from the inside of an organization, as from its environment. In this model, the purpose of an enterprise is getting the strategic competitive advantage in the area of knowledge resource and its usefulness. More on this topic may be found in [3], and [16].

The name of the Japanese model comes from the nationality of its creators (I. Nonaka, and H. Takeuchi). They formalized Japanese firms' experience. The main accent in the model is put on knowledge creation.

Finally, a process model. It is based on previously cited definition of knowledge management as a set of processes, of which the most important are gathering and creating of knowledge, knowledge dividing, and transforming knowledge into decisions. The temporal character of the model (given *implicitly*), linked with the process description, has to be stressed here once more.

3 Computer Apparatus for Knowledge Management

Although in some definitions of knowledge management we may find some links to its temporal aspect (see Section 1), and although temporal dimension is present also in the definition of knowledge management system (see below), these systems do not possess ability to represent temporality explicitly.

As the author of [16] points out, knowledge management systems are "information systems that help workers in an enterprise with performing processes linked with knowledge management, such as location and acquisition of knowledge, its transfer, development and use" (p. 54). In the work cited, a schema of computer knowledge management system can also be found. It is presented in Fig. 1.

For the purposes of this paper, the application layer is meaningful, that is the layer consisting of knowledge management computer tools. On a general level, one can point out such systems, as ERP, CMS or search engines, while on a more detailed level, computer tools for knowledge management encompass for example:

- Document management systems,
- Competences management systems,
- Community management systems,
- Workflow systems
- Content management systems,
- E-learning systems,
- Searching systems,
- Groupware systems.

Applications for knowledge management are shown in Fig. 2; they will be also presented later on in a more detailed manner.

According to the elements of Fig. 2, the most popular and typical knowledge management systems are as follows:

- Documents management systems – which create, classify, create electronic archives of documents;
- Competences management systems – they create, write, publish, plan and analyze employees' competences;

- Workflow systems – automate processes of passing information, documents or tasks from one employee to another, according to a timetable;
- Community management systems – enable members of a "community" to communicate, where a "community" may be a group or groups of employees working on the same project;
- Content management systems – where "content" is understood as contents of web pages, intranets, multimedia etc.;

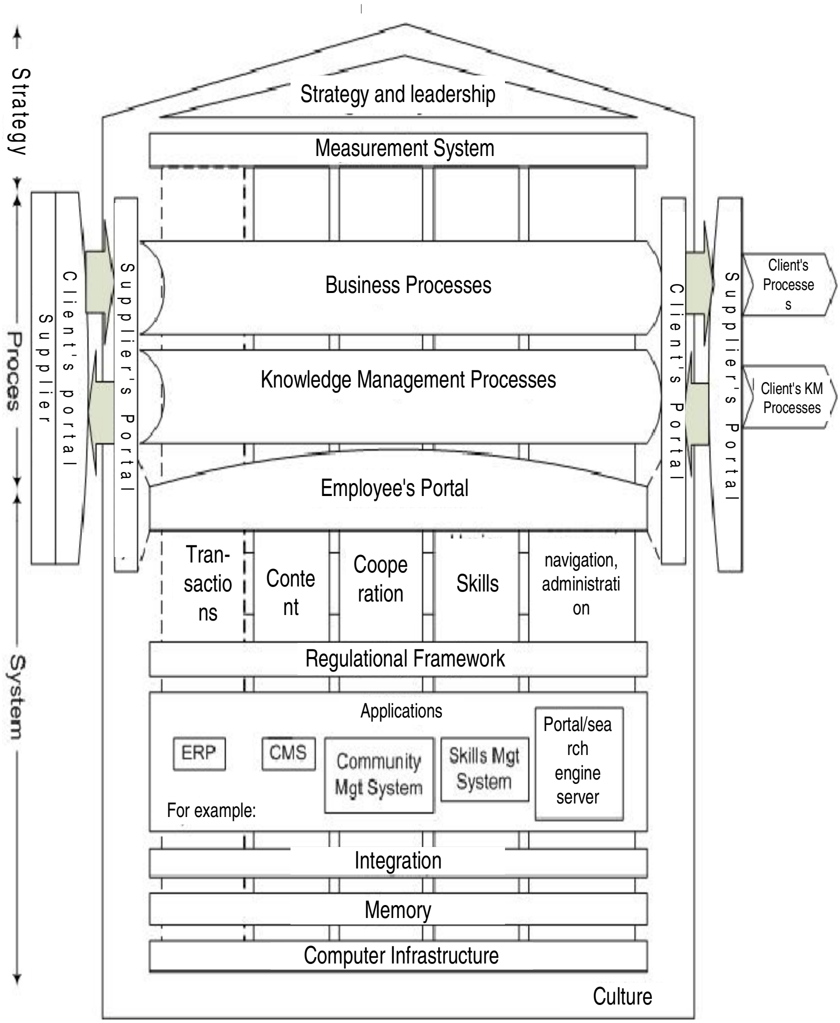

Fig. 1. Architecture of a knowledge management system. Source: [16] p. 55.

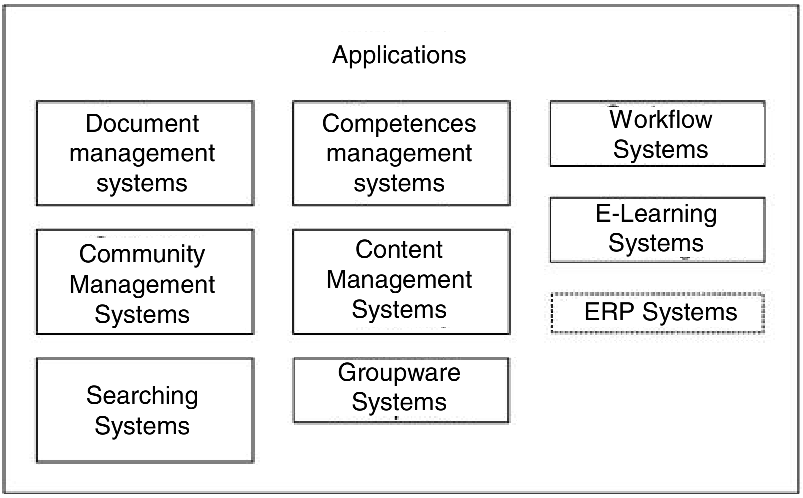

Fig. 2. Application layer of a knowledge management system. Source: [16] p. 56.

- E-learning systems – allow learning with the use of internet. Therefore their aim is to create and diffuse knowledge;
- Searching systems – aimed at a specific kind of classification, concerning search of documents, search of information inside documents, search of metadata on documents. Nowadays space the most frequently searched is www;
- Groupware systems – this term concerns software enabling exchange of information between members of the group working on the same task. It also enables – among others – planning of meetings (time management) or contacts management;
- ERP systems – systems that succor management in enterprises and institutions, with economic and planning functions. They enable to optimize internal and external processes of an enterprise. They encompass planning of all assets of an enterprise; therefore also knowledge perceived and treated as an asset.

As the above short survey of tools has shown, no one of them has implemented explicitly a possibility to handle temporal dimension of discourse. Some elements of activities linked with the notion of time are of course present. For example, archiving documents allows for tracing their changes, competence planning (e.g. training plan) is also settled in time, as well as task planning in groupware systems. It must be said that it is nevertheless the simplest kind of temporal dimension, linked with calendar time axis. No more advanced mechanisms can be found, that would enable for example analysis of reasons for knowledge changes, tracing knowledge evolution etc. Such possibilities are offered by systems based on temporal logics, which can perform temporal reasoning in an explicit and direct way (more on this topic can be found e.g. in [10]). It seems therefore that incorporating temporal formalisms into existing systems, or constructing new, fully temporal tools would constitute a great extension of possibilities in knowledge management. The next Section presents advantages of using temporal logics and formalisms.

4 Temporal Dimension of Knowledge Management

As it has been already pointed out in the Introduction, the knowledge in an organization is mostly temporal in characteristics. This means, that with the passing of time knowledge changes, new information comes on objects, that knowledge concerns, if these object poses temporal characteristics. It can be therefore said that this knowledge dimension, that is called "time" is in this case explicit. So omitting this dimension would lead to losing important elements of knowledge – temporal features. Having this in mind, time becomes for an enterprise a very important category in the area of knowledge management. It seems that enriching at least some of knowledge management systems with the possibility of explicit expression of temporal knowledge aspect would allow bettering managing this knowledge, even if taking into account its dynamics. The basic way of representing the temporal aspect of any phenomenon, including knowledge, is the use of temporal logics. Using this group of logic formalisms for knowledge management would lead to several advantages, coming from the advantages of temporal representation. Using temporal representation is well motivated, there are a lot of theoretic works on temporal formalisms and their features, also temporal formalisms have been used in many domains. It is certain, that temporal representation of a domain – including organizational knowledge – has many advantages. They can be divided into several groups:

1. Basic advantages – concerning temporal representation itself, independently from where it is used; these basic advantages also are the origin of advantages from other groups;
2. Advantages concerning representation of change;
3. Advantages concerning representation of causal relationships.

Time, as a dimension, is a basis for reasoning about action and change – only a proper use of temporal dimension allows for representation of change and its features, as e.g. its scope or interactions caused by change [15]. Such explicit temporal reference is possible through the use of a temporal formalism, where time is a basic variable.

Temporal logic allows encoding both qualitative and quantitative temporal information, as well as relationships among events, therefore it is easy to express such relations, as "shorter", "longer", "simultaneously", "earlier" etc. This in turn implies easiness of arranging phenomena in time, even if they overlap – Allen's interval algebra is an example of a formalism which allows such arrangements.

Temporal formalization makes possible to encode discrete and dense changes (according to a model of time adopted), allows for describing change as a process, and for reasoning about causes, effects and directions of change.

As time is the fourth dimension of the world, it may not be omitted during the reasoning process; otherwise the perspective of analysis would be too narrowed. The temporal dimension allows the system to "learn": the system collects cases concerning a phenomenon (or a subject domain) being represented, traces its evolution and thanks to this is able to generate new solutions [7].

It has been already said that temporal representation makes possible to represent change as a process. It is so, because with temporal logic, processes can be modeled explicitly – therefore knowledge on their temporal aspect, their interactions, on concurrent processes is easily expressed [1]. As Kania points out ([17], p. 60), models of processes are useful for describing dense phenomena, as for example economic ones.

Temporal logic gives us richer – temporal aspect included – formalization of domain knowledge, it also gives us "knowledge on knowledge": combining temporal operators with formal knowledge representation one can formulate assertions about knowledge evolution in a system [6]. Van Benthem presents an example of such combination, suggesting combining temporal and epistemic logic [2], p. 335. Placing knowledge in time treated as a basic dimension, one can add new knowledge to a base, not removing the "old" one, and with no risk of inconsistencies [8]. Temporal logic, as a knowledge representation language, should provide both explicit knowledge and access to tacit one ([12], p. 326). Temporal logic, which has reasoning rules built in, is able to provide this property.

Summing up, it should be pointed out that temporal formalisms meet the requirements of knowledge representation in artificial intelligence, such as:

- expressing imprecise and unsure knowledge,
- expressing "relations" of knowledge (e.g. A occurred before B", that very often have no explicit dates;
- different reasoning granulations,
- modeling of persistence.

The above postulates are met e.g. by Allen's interval algebra [1]. Therefore enriching the existing knowledge management systems with temporal formalisms, or building new systems, based on these formalisms, would allow for taking into account the temporal dimension of knowledge, its changes and evolution/ development. In this way knowledge may be managed more effectively.

5 Example of Temporal Knowledge Management

We will present a practical example of temporal knowledge management, concerning a problem of establishing, whether an unemployed person may be granted a benefit. The example chosen is very simple, to focus attention on a temporal languages approach. The temporal language chosen is TAL.

The TAL (Temporal Action Language) is derived from Sandewall's PMON logic [14]. Its main features as a language for describing temporal dependencies include: the notion of time independent from actions, the possibility of defining causal dependencies apart from actions' definitions, and the possibility of describing concurrent interactions.

The language consists of two levels (layers): the so-called surface language, which is used to describe narratives (for more information see [4], and the so-called base language, namely the logic of events, which is an ordered 1st order predicate logic. Any correct narrative description, after being transformed into the description in the base language constitutes a finite set of 1st order wffs.

The surface language layer consists of:

- temporal expressions,
- value expressions,
- atomic expressions,
- narrative statements,
- additional macro-operators and abbreviations (e.g. the durational reassignment operator, the reassignment operator, the occlusion operator etc.).

The base language layer (the logic of events) contains, among others, temporal predicates: HOLDS, OCCURS, OBSERVE, DUR, PER and others (the exact definitions of the predicates can be found e.g. in [4].

The surface language does not have formal semantics, although it has a formal syntax. The whole formal inference process is conducted after "translating" the description in the surface language into the description in the base language.

It is also worth mentioning here, that the description (specification) of a scenario in the TAL language consists of:

- type description,
- action definitions and descriptions,
- domain constraints specification,
- temporal dependencies specification.

To implement solutions encoded in the TAL language, one can choose the VITAL tool [9], developed at Linköping University, Sweden. The tool is very easy to use and automatically translates scenarios from the surface language (TAL) into the base language, therefore the person constructing a scenario does not have to be an expert in temporal predicate logic.

The example will be illustrated with Canadian unemployment law. The illustration comes from [13] and [11]. The authors present there a concrete decision problem, which in our opinion could be solved by using the TAL language. All the rules come directly, or after slight modifications, from Canadian unemployment law. The example to be discussed is presented in Fig. 3.

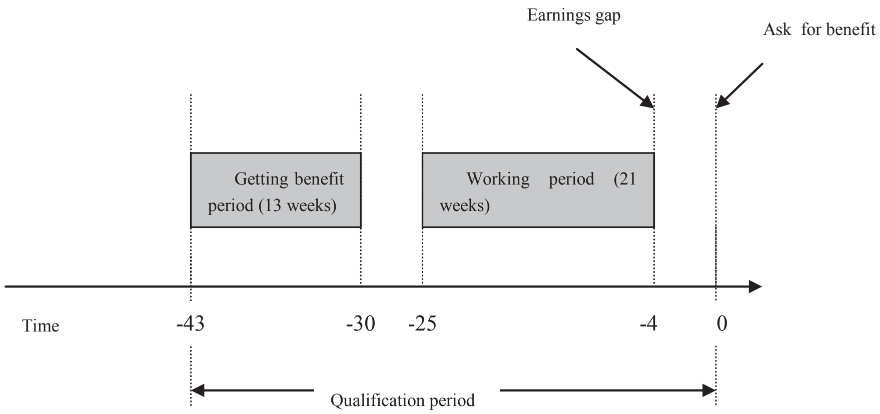

Fig. 3. Sample decision situation. Source: own elaboration based on [13].

As we can see in Fig. 3, a person asking for benefit lost work (in a week numbered with -4) and asked for benefit in a week numbered with 0. The former working period lasted for 21 weeks. The person had already been granted a benefit, and has been getting it for 13 weeks. For our purposes it is not important, what happened between weeks -25 and -30. We may assume that it was a working period or an unemployment period. The most important information concerning working period is that it lasted for minimum 21 weeks: on this basis we may establish, whether the person qualifies for a new benefit (this results from the Canadian law).

The basic problem (as in original works [13] and [11]) is to establish, whether the person has the right to the new benefit period. In our example the answer is yes, because the former working period was longer than 20 weeks (more details about the legal rules are to be found in [13], [11]. It is apparently a temporal information. Next we have to establish, how long a new benefit period is to be. This in turn depends on the information about the former benefit period, because the starting point of so-called qualification period is the point in which the former benefit period started. As it can be seen in the figure, the qualification period for the sample person is 43 weeks.

Summing up – the temporal aspect of the problem concerns establishing the longitude of qualification period and – in consequence – the new benefit period of an unemployed person.

The tool for the implementation of the problem is – as said before – the TAL language and its implementation named VITAL. The main task for VITAL was to calculate the longitude of qualification period, needed for establishing, whether a person will be granted a benefit, or not. As input data the following information has been provided:

- The fact, that the person has already been granted a benefit in the past (and for how many weeks),
- The former working period,
- A point time in which a person asked for the new benefit.

It should be pointed out here, that the assumed time granularity is one week, therefore time point is the number of a week.

We have encoded input data in a scenario written in the TAL language, in form of so-called occurrences. From these occurrences the VITAL tool was to infer the longitude of a qualification period. To enable this inference, we had also to encode a proper temporal dependency, linking input facts with the way of calculating the qualification period. The dependency has been taken from the Canadian unemployment law.

A key to success (that is to establish the longitude of qualification period) is a rule stating, that qualification period starts in the same time point as the former benefit period, and ends in the time point in which a person asks for a new benefit. Therefore, in terms of the TAL scenario, if we denote by *t1* the time point in which the variable *getting_benefit_1* becomes true, and by *t2* – the time point in which action *ask* (asking for new benefit) becomes active, then the variable *qual_period* (denoting the qualification period) should become true (the system should infer this value) over the interval [t1, t2). The discussed dependency, has the following form in the TAL language:

```
   dep forall t1, t2 [
      Ct([t1] getting_benefit_1) &
      Ct([t2] ask) &
            !exists t3 [t1 <= t3 & t3 < t2 & Ct([t3]
ask) ] ->
            I([t1, t2) qual_period) ]
```

where:
dep – dependency label,
t1, t2 – time points,
Ct – operator *changes to true*,
I – macrooperator, that assigns a new value to the default value of a feature, over a particular time interval ([4]).

The dependency stated as above will work also in a situation, when the same person will be hired again, then will get benefit again (*getting_benefit_1*), and then will again ask for benefit (*ask*). In such a situation the variable *qual_period* will be true from the first moment in which *getting_benefit_1* becomes true, up till the last action of asking for benefit. By formulating the dependency in the form presented above, we may check, whether *t2* is the shortest time point after *t1* such, that Ct([t2] ask).

The sample situation presented in Fig. 3 has been encoded in the VITAL tool. The only difference was that while numbering time points (weeks), positive numbers have been used. The result of temporal reasoning performed by the VITAL tool is presented in Fig. 4.

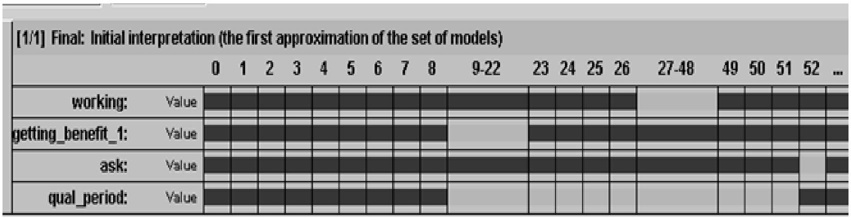

Fig. 4. The result of calculating the qualification period in the VITAL application. The lighter color on the timeline denotes the true value of a feature, while the darker one denotes the false value (in reality the drawings prepared by the VITAL tool are colorful). Source: own elaboration. Working - the time person has been working, other notations as in the text of the paragraph.

What is known after performing temporal reasoning by the VITAL tool? It is known for how many weeks the person has been getting the former benefit (if at all; in our example – for 13 weeks), for how long the person has been employed during the qualification period (from this information it will be possible to infer if the person may be granted the next benefit; in our example the working period is 21 weeks), how long is the qualification period (in our example – 43 weeks). All this information can be read from the above figure.

Moreover, we may assume that while asking for benefit, a person is obliged to provide some additional information, e.g. on family situation, education, additional skills etc., to enable decision on other forms of help. It makes no sense encoding this information in the VITAL tool, as it is not of temporal kind. Nevertheless the results of reasoning performed on temporal data, together with the additional information, may constitute an input for further, non-temporal reasoning.

6 Conclusions

Knowledge management is nowadays one of the most intensively developing trends in management. It is so because the growing role of knowledge in economic success and competitiveness is noticed and appreciated. At the same time it is important, that knowledge is mostly temporal in nature: knowledge changes in time. Therefore the temporal aspect of knowledge may not be omitted while managing this important asset of an enterprise.

In the existing computer systems for knowledge management the temporal aspect is present rarely and implicitly. Taking into account its importance, in the paper we proposed to use temporal logics to extend functionality of existing systems, or to build new computer tools for KM. It seems that the advantages of using temporal formalisms, presented in the paper, make this postulate fully justified.

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