Proceedings of the International Multiconference on
Computer Science and Information Technology pp. 249–254
ISBN 978-83-60810-27-9
ISSN 1896-7094

Hybridization of Temporal Knowledge for Economic Environment Analysis

Maria Antonina Mach
University of Economics
Department of Knowledge and Information Management
53-345 Wroclaw, Poland
Email: maria.mach@ue.wroc.pl

***Abstract*—the paper is devoted to the concept of hybridization of temporal knowledge in an intelligent reasoning system. Hybridization is a special kind of integration, where heterogeneous knowledge is transformed in order to obtain a uniform one, but information on temporal characteristics and on core features of knowledge being transformed is preserved, and may be also used for reasoning. It may be said, that integration serves as means of hybridization, but only if at least two conditions are fulfilled: if integration is source-oriented, and the knowledge sources are kept autonomous.**

In the paper we present in detail the concept of integration, the conditions that are to be fulfilled if the integration is to serve as the means of temporal hybridization. We show an application area for a hybridized knowledge, namely the analysis of economic environment of an enterprise. We present an example of a hybridization procedure.

Keywords: integration, hybridization, temporal knowledge, temporal intelligent system.

I. Introduction

THE increasing complexity of an environment, in which modern enterprises operate, entails the more and more complex formal descriptions of this environment. This in turn leads very often to a problem of heterogeneous representations. Economic environment is of heterogeneous nature, so is its formal representation (based very often on different sources) and in order to perform a coherent reasoning by an intelligent system, all fragments of the representation must be unified.

In the paper we present the problem of using knowledge coming from different sources to perform an analysis of enterprise's environment. This environment changes in time, therefore we assume, that the analysis is performed by a temporal intelligent system that is a system, which explicitly and directly performs temporal reasoning. Such a system contains not only a fact base, a rule base and an inference engine – as any intelligent system – but also contains explicit time references both in representation and reasoning layers.

The reminder of the paper is organized as follows. In Section one we show how integration may be perceived as a mechanism of temporal knowledge hybridization. Section 2 is devoted to basic approaches to data and knowledge integration – they are very shortly presented and discussed in context of hybridization. In section 3 we present in detail the idea of temporal knowledge hybridization. In the same section we present an example of the integration process leading to a hybridized knowledge obtained from two temporal knowledge bases. The paper ends with a summary section. Some additional information, needed to make the example in Section 3 more readable, is presented in Appendix A and Appendix B.

II. Integration as Mechanism of Knowledge Hybridization

There can be several sources of knowledge about enterprise's environment: databases, data warehouses, Business Intelligence systems, or other information systems used by an enterprise, as well as text documents.

For an intelligent system to reason correctly, it is necessary that it reasons not only about economic environment as a whole, but also about its fragments – that is, about particular fragments of knowledge encoded in the representation layer. Therefore the integration process must preserve the original knowledge fragments. The process of transforming heterogeneous temporal knowledge, leading to a uniform representation, but at the same time preserving information on temporal characteristics and on core features of knowledge being transformed, is called a temporal hybridization. It can be therefore said that the integration process in a temporal intelligent system is a mechanism of knowledge hybridization, where knowledge concerns enterprise's environment.

III. Basic Approaches to Data and Knowledge Integration

Lawrence and Baker [LABA01] perceive integration as a process of merging notions and knowledge from single sources, resulting in a coherent view of the whole knowledge contained in these sources. It is a point of view of knowledge-based intelligent systems. It stresses a specific role of knowledge integration in management supporting intelligent systems. Generally speaking, by a heterogeneous knowledge base we mean a base of a diversified form, structure and origin [OWOC01].

The question of knowledge integration can be viewed from different perspectives and in different contexts. The problem is discussed in detail e.g. in [MAOW04], here we present a short summary in Table 1.

TABLE 1.
TYPES OF INTEGRATION. SOURCE: OWN ELABORATION.

CRITERION	TYPES OF INTEGRATION
Integrating system operations	virtual materialized
Direction of integration process	Source-oriented Client-oriented
Changes in sources being integrated	Domain integration Semantic integration
Aim of integration	Procedural integration Declarative integration
Objects being integrated	Mono-object integration Poli-object integration
Context of integration	Functional database text agent, other

In case of the task of temporal analysis of enterprise's environment, it seems that one should speak about the following types of integration:

a) virtual – because temporal representations of environment's elements are integrated before reasoning is proceeded, therefore there is a mediating system between knowledge sources and an user;
b) source-oriented – because the tasks of the systems are left unchanged, while changes appear in the sources, thus reflecting changes in the environment, and the system has to respect these changes;
c) semantic – while integrating knowledge before reasoning, a temporal intelligent system has to solve conflicts arising from e.g. different granulations of changes of elements in enterprise's environment;
d) declarative – the main aim of the integration process is to obtain an uniform representation for further reasoning, the tasks of the system remain unchanged during the integration process, while the system is not aimed at delivering the *at hoc* information;
e) integration that keeps the sources autonomous but at the same time integrates them (hybridization);
f) mono-object – the sources being integrated before the reasoning process starts are of the same type: temporal knowledge bases.

The most important question in the process of hybridization of temporal knowledge is to respect changes in knowledge sources and to keep the sources autonomous. Only in such case information on temporal characteristics and on crucial features of knowledge being integrated is preserved. Therefore if the integration is to be used as a mechanism of hybridization, should be, first of all, source-oriented (b), and should keep the sources autonomous (e) – these are the two basic conditions of a temporal hybridization.

IV. TEMPORAL HYBRIDIZATION PROCESS

A temporal intelligent system, aimed at analyzing changes in enterprise's environment, uses many different kinds of knowledge, because the environment is heterogeneous, complex and dynamic. Elements of enterprise's environment may be of qualitative, quantitative or mixed nature. To represent them in a temporal intelligent system, one has to use also qualitative, quantitative and mixed temporal formalisms. Moreover, the system should be able to reason both about each group of elements (a so-called detailed view), and about all the elements treated as a whole (a so-called general view). To obtain a coherent view of all the elements, the hybridization of temporal knowledge about particular elements of the environment has to be done.

From the economic point of view, the heterogeneity of knowledge in the system may be perceived as:

a) heterogeneity of sources: knowledge can be gained from different sources – see introduction;
b) heterogeneity of features: because elements of the environment can be viewed as different features to be represented in a different way.

From the computer science point of view, in a temporal intelligent system we may find the following types of heterogeneity:

a) logical heterogeneity – because we assume, that elements of the environment are represented by means of logical formalisms;
b) temporal heterogeneity – because the above formalisms are temporal logics, as the features represented have an explicit temporal aspect to be captured;
c) reasoning heterogeneity – because for each group of environment's elements a different inference mechanism is needed. Each group of elements is represented in a separate knowledge base, each of which has a separate inference mechanism linked with it. Moreover, taking into account different characteristics of environment's elements, the inference mechanisms do not need to use the same inference strategy.

In our opinion there is no need to develop a new particular technique for integration of representations. The integration itself serves only as a mechanism of hybridization of knowledge about enterprise's environment. Any integration tool or technique may be used, if only it fulfills the two main conditions, pointed out in Section 2 (namely the condition <b> and <e>). Of course, the more conditions (formulated in section 2) fulfilled by the integration tool/technique, the more useful it is for a temporal intelligent system.

Consider a simple example of an integration procedure, leading to hybridization of temporal knowledge. Assume there is an enterprise that wishes to start a TV channel. The enterprise has two knowledge bases:

a) a base of legal knowledge concerning licenses – as a license is required to start a TV channel;
b) a base of knowledge concerning the influence of dollar's exchange rate on capital barriers to entry to a mass-media market (knowledge gained from an expert).

The knowledge bases are of the following form (simplified to make the example clear):

a) legal knowledge base – formalized in the LTR language[1]

```
if TT1: license(issuing authority, enterprise)
    TT2: is_issued(TT1)
    Occurs(TT2)
Then occurs(valid(TT1), instant(TT2))

If  TT2: valid(TT1)
     Occurs(TT2)
Then Holds_on(valid(TT1), period(TT3))
Period(TT3) Equals(5y, 50y)
```

b) knowledge base on capital barriers to entry – formalized in the Prolog+CG language [KABB00], designed to formalize conceptual graphs[2]. As the knowledge base is temporal, the original conceptual graphs notation has been augmented with fuzzy temporal references, taken from [KALC05].

```
[CRB] - actn -> [change] - manr -> [proportionally] :-
  [sit = [fluctuations] - attr -> [frequent],
  - ptnt -> [DER] ] <- tref - [TR = [[GCGty: #ctx] - TAgo -> [month: {}@3]] <- TOvr].
  (if during the past 3 months frequent fluctuations of DER has been observed, then CRB changes proportionally)

[CRB] - actn -> [lower] :-
   [sit = [decrease] - ptnt -> [DER]] <- tref - [TR = [Year: 2004] - Tsnc -> [GCGty: #end]].
  (if since the end of 2004 the decrease of DER has been observed, then CRB lowers)
```

where: CRB – capital barriers to entry, DER – dollar exchange rate.

In this example we observe the problem of the logical heterogeneity (two different representation formalisms), the heterogeneity of features being represented (two different kinds of barriers to entry – legal and capital ones), and the heterogeneity of temporal granulation – for the legal knowledge, the granulation may be established for one year, while for the knowledge about DER the more accurate granulation is one day (this is so because of a different pace of changes in the case of law and in the case of DER).

A sample procedure of integration of the above knowledge bases may be as follows:

a) transformation of granulations to obtain an uniform one;
b) establishing a reference time point;
c) choosing a final representation formalism;
d) transformation of time ontologies to obtain an uniform one;
e) conversion onto the final formalism and merging of the two knowledge bases.

Ad a)

It seems natural that a common granulation for both knowledge bases should be one day. It is so because it is easier to present years in terms of days than inversely. Under such circumstances the knowledge base about the DER remains unchanged, while the second rule in the legal knowledge base is transformed according to the new granulation:

```
If  TT2: valid(TT1)
     Occurs(TT2)
Then Holds_on(valid(TT1), period(TT3))
Period(TT3) Equals(1825d, 18250d)
```

We assumed, for simplicity, that each year equals 365 days.

Ad b)

A reference time point is needed for further ontology standardization. We propose that the reference point be a day on which integration is done, e.g. r_0 = 07/09/2006.

Ad c)

The choice of the final temporal representation formalism depends on time ontology and on the integration technique. In our example we deal mainly with time intervals (validity period of a license, a period in which changes of DER are observed). Therefore one of the possible common formalisms may be Allen's interval algebra [ALLE81], [ALLE83]. There are several reasons that justify this choice:

- the LTR theory (used to formalize the legal knowledge base) is partly based on Allen's algebra,
- Allen's algebra in turn derives from the first order predicate calculus,
- the conceptual graphs (used to formalize the second knowledge base) are easy to convert on 1st order predicate calculus – see Appendix B.

Ad d)

Ontology standardization means establishing, what temporal objects are in both knowledge bases, and converting them onto the final temporal formalism. In the example there are the following temporal objects:

- event: license issuing, proportional change of a barrier, lowering of a barrier, lowering of DER, fluctuations of DER,
- fact: validity of a license;
- agent: issuing authority,
- constant: interval [1825d, 18250d] – to be denoted as t_2,
- variable: enterprise, license,
- interval: 3 months before the reference point r_0 – to be denoted as t_3, an interval from the end of 2004 to the reference point r_0 – to be denoted as t_5.

Ad e)

[1] The basic concepts of the LTR theory are explained in Appendix A.
[2] A short explanation on conceptual graphs is given in Appendix B.

To convert both knowledge bases onto Allen's interval algebra, we introduce two predicates: HAS(what, who) and DURATION (interval, length). After conversion all the rules (both bases merged together), using the time ontology established in step d) are of the following form:

OCCURS(ACAUSE(issuing_authority, license_issuing), t_1) ⇒ OCCURS(license_issuing, t_1)

OCCURS(license_issuing, t_1) ⇒ HOLDS(license_validity, t_2) ∧ HAS(license, enterprise) ∧ MEETS(t_1, t_2) ∨ BEFORE(t_1, t_2) ∧ DURATION(t_2, [1825, 18250])

OCCURRING(frequent_fluctuations_DER, t_3) ⇒ OCCURS(change_CRB, t_4) ∧ DURATION(t_3, 90) ∧ BEFORE(t_3, t_4) ∨ MEETS(t_3, t_4)

OCCURS(decrease_DER, t_5) ∧ ECAUSE(decrease_DER, t_5, lower_CRB, t_6) ⇒ OCCURS(lower_CRB, t_6) ∧ BEFORE(t_5, t_6) ∨ MEETS(t_5, t_6) ∨ OVERLAPS(t_5, t_6) ∧ DURATION(t_5, [(2004 12 31), r_0])

The main advantages of the above sample integration procedure are standardization of formalisms and preserving temporal information. The main disadvantage, on the other hand, is that in the final knowledge base there is no possibility to encode fuzzy temporal references. This means that we have lost a part of information. This disadvantage is due partly to the choice of Allen's algebra, partly to the problems with formalizing fuzzy intervals, and partly to simplification of the procedure, to make the example clear.

What needs to be stressed is that after the above integration procedure both original knowledge bases remain unchanged, the third knowledge base is added to them, and therefore the two basic conditions of temporal hybridization are fulfilled.

V. Conclusions

In practice the most popular and the most widely used are the tools and techniques of semantic integration. If it is assumed that the main aim of integration is to create a coherent representation of information from different sources, and to enable reasoning based on heterogeneous sources, it becomes obvious that semantic, conceptual integration is indispensable.

There are many advantages of using hybridized knowledge in enterprise's intelligent systems. Let us point out the following ones (see also [IWFA95], [OWOC03]):

- "openness" of knowledge – caused by its variety – allows for a more accurate reflection of a domain being analyzed;
- a model of hybrid knowledge makes analysis and prediction of domain's behavior easier. This has been proven in the context of hybrid systems [IWFA95], but is valid also in context of hybrid knowledge;
- knowledge built upon independent sources is more unquestionable, reliable and trustworthy than knowledge built upon a single source.

The other advantages of using hybridized knowledge and maintaining heterogeneous knowledge bases in the reasoning system are as follows:

- each element of the economic environment is represented in a separate knowledge base (knowledge "openness") which leads to a precise representation of elements having different characteristics;
- easy analysis of economic elements – when elements are represented separately, the system can easily capture their features and take them into account during the reasoning process;
- reliability of knowledge about economic environment – using several knowledge sources before integration, if these sources concern the same economic element, allows to improve the level of knowledge reliability. Of course it is assumed that in case of any contradictions there is a method of eliminating them, but this question is beyond the scope of this paper.

We do not address in the paper problems concerning maintaining hybridized knowledge bases, such as problems of knowledge coherence or knowledge validation. The detailed discussion on these problems can be found e.g. in [OWOC01] or [MAOW04] – the procedures used to ensure knowledge coherence, and the procedures of knowledge validation and verification are similar to those used in the case of typical, non-hybridized knowledge bases.

Appendix A. Basic Concepts of the LTR Theory

The detailed description of the theory can be found in [VIYO98]. Table 2 contains a summarization of the most important LTR features.

Table 2.
Basic features of the LTR theory. Source: [VIYO98].

Legal Temporal Representation (LTR)	
Time ontology	Elements: points, intervals, durations, clock-calendar constants Relations: <, *begin, end, next, previous, ImmediateBefore, ImmediateAfter*
Time theory	IP theory axioms + discreteness axioms + „immediateness" axioms
Temporal constraints	Qualitative point-point, metric over points, qualitative interval-interval, qualitative point-interval, unary over durations
Temporal qualification	Temporal tokens
Incidence theory	Predicates: holds, occurs, holds_at, holds_on Axioms: *holds* and *holds_on* homogeneity

Some features in the above table need a few words of commentary.

a) IP theory – point-interval time theory by Vila and Schwalb [VISC96];
b) Discreteness axioms – the authors of the LTR theory assume time to be discrete, although not always discrete time is sufficient. In our example however we can have discrete time, as law does not change in a continuous way (or at least we may assume it doesn't);
c) Predicates – based on Allen's time theory. The Holds predicate is used both for points and intervals. The holds_on predicate concerns holding of a feature over an interval, and holds_at – holding of a feature in a time point. It may be disputable, whether there really is a need for multiplying the variants of the Holds predicate.

The most important feature of the LTR theory, that needs more explanation here, concerns the so-called temporal tokens. They are used to link propositions with their times, which means a temporal qualification of propositions. Tokens may also be predicates' arguments. The method comes from a temporal arguments method (see e.g. [HAUG87]), where time is introduced as one or more additional arguments, for example:

Valid(act, t1, t2)

Tokens, instead, link propositions with the time of occurrence, e.g.:

Valid(act, tt1)

Which allows for the following interpretations: begin(tt1) = 01/01/1990 – the starting point for token tt1; or period(tt1) = [01/01/1990; 31/12/1990] – an interval over which a token tt1 is valid. It can be therefore said that a token represents a special temporal case of a temporal proposition.

A law article is formalised in the LTR theory as a rule or rules that express relations between the occurrences of events (under certain conditions) and their effects, being the holding of certain features. The LTR language is a rule one, and does not need any assumption on reasoning method.

Appendix B. Some Remarks on the Conceptual Graphs

The conceptual graphs notation has been originally introduced by Sowa [SOWA00]. A conceptual graph is a bipartite, directed graph with two kinds of nodes: notions and relations. It may be encoded graphically, with rectangles representing notions and ovals representing relations; or as text, where notions are in square brackets and relations are in parenthesis. The formalism derives from semantic networks. We have chosen this notation because conceptual graphs have some advantages, such as:

- they are legible, easy to understand, and at the same time it is a strictly formal notation,
- they are useful for representing AI problems, e.g. formalizing natural language sentences,
- they are easily expressed in KIF and first order logic, which allows using CG rules in many types of reasoning systems.

The version based on conceptual graphs needed slight modifications in relation to widely accepted CG notation, because of Prolog+CG language's particular requirements. They are as follows:

a) we could not use the AGNT relation, because, according to formal requirements, only a living being may be an agent. Therefore, instead of writing e.g. [remain] – AGNT -> [OP], we used to write: [OP] – ACTN -> [REMAIN], where ACTN stands for action;
b) the premises are time-stamped (relation Tref, graph name: TR), while conclusions are not – there are only general references such as "past", "future", linked with the CRB variable by a PTIM relation. This is so, because the validity period of conclusions is not always the same as the validity period of premises. In our opinion, there is no justification for using the same time reference in premises and conclusions;
c) according to the Prolog+CG notation, relations' names are given without parenthesis;
d) according to the Prolog+CG notation, if the graph has several branches, they are separated by commas.

As we stated earlier, the original Sowa's notation was augmented with fuzzy temporal references.

References

[ALLE81] Allen J. F., *An Interval-Based Representation of Temporal Knowledge*. Proc. IJCAI-81 – 7th International Joint Conference on Artificial Intelligence, Morgan Kaufmann 1981.

[ALLE83] Allen J. F., *Maintaining Knowledge about Temporal Intervals*. „Communications of the ACM", Vol. 26 No. 11, November 1983.

[HAUG87] Haugh B. A., *Non-standard semantics for the method of temporal arguments*. Proc. IJCAI-87: 10th International Joint Conference on Artificial Intelligence. Morgan Kaufmann Publishers, 1987, pp. 449-455.

[IWFA95] Iwasaki Y., Farquhar A., Saraswat V., Bobrow D., Gupta V., *Modeling Time in Hybrid Systems: How Fast is „Instantaneous"?* Proc. IJCAI-95: 14th International Joint Conference on Artificial Intelligence, Montreal, Canada, Vol. 2, pp. 1773-1780, Morgan Kaufmann.

[KABB00] Kabbaj A., *Prolog+CG User's Manual. Version 2.0., 01-12-2000.* www.insea.ac.ma/CG-Tools/PROLOG+CG.htm downloaded July 30, 2005.

[KALC05] Kalczynski P., *Temporal Semantic Networks for Business News*, University of Toledo Research Paper 2005.

[LABA01] Lawrence R., Barker K. *Integrating data sources using a standarized global dictionary*. W: Abramowicz W., Zurada J. (Eds.), *Knowledge discovery for business information systems*. Kluwer Academic Publishers, USA, 2001. pp. 153-172.

[MAOW04] Mach M., Owoc M. L., *Integracja wiedzy ze źródeł heterogenicznych*. Wydawnictwo BEL, Warszawa 2004 [*Integrating knowledge from heterogeneous sources*].

[OWOC01] Owoc M. L., *Podejścia do weryfikacji heterogenicznych baz wiedzy*. In: Baborski A. (red.), *Pozyskiwanie wiedzy z baz danych.* Prace naukowe AE Wrocław nr 891, Wrocław 2001. [*Approaches to heterogeneous knowledge bases verification*].

[OWOC03] Owoc M. L., *Knowledgebases: A Management Context and Development Determinants*. Proc. IS-2003: Informing Science Conference, Pori, Finland, June 2003, pp. 1193-1199.

[SOWA00] Sowa J. F., *Knowledge representation*. Brooks/Cole, Pacific Grove, CA, 2000.

[VISC96] Vila L., Schwalb E., *A Theory of Time and Temporal Incidence based on Instants and Periods*. TIME-96: Third International Workshop on Temporal Representation and Reasoning. Key West, Florida, USA, May 19-20, 1996.

[VIYO98] Vila L., Yoshino H., *Time in automated legal reasoning*, w: Martino A., Nissan E. (eds.), "Information and Communications Technology Law", Special issue on formal models of legal time. Vol. 7 No. 3, 1998.