NONLINEAR TIME ONTOLOGY FOR ECONOMIC REALITY DESCRIPTION

Maria Mach-Król

University of Economics
Katowice, Poland
maria.mach-krol@ue.katowice.pl

Abstract

The paper deals with the problem of representing time while reasoning about changing economic domain. The modification of Hobbs&Pan time ontology is proposed and formalized. Also the resulting ontology is augmented with proposal of Hajnicz and McDermott to provide basis for representing both abstract branching time as well as the calendar one.

***Keywords* –** economic environment, time, temporal ontology, temporal reasoning

INTRODUCTION

The environment in which modern enterprises operate is used to be called turbulent [WIHE11]. This word exactly mirrors features of enterprises' environment: discontinuity, changeability, heterogeneity. Because of these features it is very difficult to percept changes in the environment, to define their causes, effects and directions, and how they affect enterprises' operations. The impact of these changes on enterprise's strategy is also seen.

The analysis of changes may not be performed apart from the aspect of temporality, because time is strictly connected with the notion of change. The temporal aspect is important, because in modern enterprises knowledge becomes a valuable asset. And a great part of knowledge is temporal. Therefore time becomes an important category for enterprises.

All the above leads to a simple conclusion: a complete representation of economic knowledge must be a temporal one. As Sowa claims [SOWA00], [CHST12]the knowledge representation consists of three elements: ontology, logic, and computational procedures. Every logic assumes an ontology of the domain being depicted. Therefore the representation of knowledge about dynamic economic environment should be composed of ontology of time and domain, temporal logic and computational procedures (reasoning). From the other side, the ontology of time concerns basic temporal entities and time structure. If we assume that the choice of proper temporal entities is strictly dependent on time structure, it becomes obvious that the question of time structure is fundamental. And so is the question of temporal ontology.

1. ONTOLOGY

As it has been pointed out in the Introduction, one of the main elements of knowledge representation is ontology, because every logic – including temporal ones – assumes an domain ontology. Many authors defined ontology. Here we cite only a few definitions.

Eder iKoncilia [EDKO05] define ontology as a conceptualization of a domain. It describes domain notions, their properties and relations. A similar view of the ontology is presented bySalguero et al. [SAAR08], who describe it as a specification of knowledge domain conceptualization. A controlled dictionary depicting formally objects and relations between them, and has a grammar (p. 126).

Grenon [GREN03] writes that formal ontology is a branch of philosophy, that analyses and creates theories at the highest level of generality.

Perry et al. [PEHA06] add to the above that ontology assures the context or domain semantics (p. 147).

It seems that for time ontology the best definitions are these by [EDKO05] and [SAAR08]. It is because time ontology has to encompass time elements – points or intervals or both – and their relations. Moreover, it has to contain a „way" to manipulate these elements, so they become meaningful. The detailed description of time ontology adopted in the economic analysis is presented in Section 3.

2. LEFT LINEAR TIME (TIME BRANCHING INTO THE FUTURE)

In the economic analysis of enterprise's environment we assume the model of time branching into the future (left linear one). The motivation for this choice is as follows. The environment of an enterprise is non-deterministic, while assuming linear time needs it to be deterministic. Only with time branching into the future we can assume that the enterprise's environment is non-deterministic. Moreover, the structure of left linear time allows for "what-if" analysis of the environment.

It is not the only possible structure. For example, if we take into account the temporal differences between markets, we may think about parallel time structure, which allows to perform analysis on many markets at the same time. We may also think about time branching into the past – to perform analysis on how changes on different markets in the past affect the present situation of an enterprise. However, as we said above, in the paper we assume left linear time.

The formal definition is as follows ([KLIM99], p. 21nn):

A time structure *T* is called branching into the future (left linear) if

$$\forall t_1, t_2, t_3 \in T\ (t_2 < t_1 \wedge t_3 < t_1) \Rightarrow (t_2 < t_3) \vee (t_2 = t_3) \vee (t_3 < t_2). \quad (1)$$

We assume point structure of time as the basic one. Generally, in the ontology of time one may assume points, intervals or both as basic temporal entities. Different authors force different solutions to this question (see e.g. [VILA94]). In the paper we will assume point time. The reason for this choice is the application domain – the economic one. In practice, many elements of the economic environment change in a continuous manner, it is even suggested to continuously monitor the environment [PRHA98], but also many elements change in a discrete manner. Moreover, if we assumed a continuous time, we should introduce a second order axiomatization ([BEGA04] p. 36), while in the paper we want to restrict ourselves to first order formalisms.

Formally:

Time is composed of points and a precedence relation <, therefore a point structure *T* is an ordered pair $\langle T, < \rangle$, where T – a nonempty set of points, < the precedence relation.

The axiom of time discreteness is formulated as:

$$\forall x, y\ (x < y \rightarrow \exists z\ (x < z \ \&\ \neg\exists u\ (x < u \ \&\ u < z)))$$

$$\forall x, y\ (x < y \rightarrow \exists z\ (z < y \ \&\ \neg\exists u\ (z < u \ \&\ u < y))) \quad (2)$$

This structure has the following properties:

a) transitivity $\forall x, y\ (x < y \ \&\ y < z \rightarrow x < z)$
b) anti-reflexivity $\forall x\ \neg(x < x)$
c) antisymmetry $\forall x, y\ (x < y \rightarrow \neg\ (x < y))$

Moreover, because we deal with time branching into the future (left/backward linear one), we add an axiom of back linearity:

d) back linearity $\forall x, y\ (x < z \ \&\ y < z \rightarrow X < y \vee x = y \vee y < x)$.

3. THE ONTOLOGY OF POINT TIME

The point time ontology presented in this section extends and modifies the ontology by Hobbs and Pan [HOPA04], also adding time properties from [HAJN96], because of economic application domain, presented in the Introduction and in Section 2.

Topological temporal relations.

Time points are a subclass of temporal entities:

$$Instant(t) \rightarrow TemporalEntity(t)$$

$$\forall (T)\ TemporalEntity(T) \rightarrow Instant(T) \quad (3)$$

Predicates *begins* and *ends* are the relations between points and temporal entities:

$$begins(t,T) \rightarrow Instant(t) \wedge TemporalEntity(T)$$

$$ends(t,T) \rightarrow Instant(t) \wedge TemporalEntity(T) \quad (4)$$

Moreover

$$Instant(t) \equiv begins(t,t)$$
$$Instant(t) \equiv ends(t,t). \quad (5)$$

If exists a beginning and an end of a temporal being, it is unique:

$$TemporalEntity(T) \wedge begins(t_1, T) \wedge begins(t_2, T) \rightarrow t_1 = t_2$$
$$TemporalEntity(T) \wedge ends(t_1, T) \wedge ends(t_2, T) \rightarrow t_1 = t_2 \quad (6)$$

Predicate *TimeBetween*is a relations between a temporal being and two points:

$$TimeBetween(T, t_1, t_2) \rightarrow TemporalEntity(T) \wedge Instant(t_1) \wedge Instant(t_2) \wedge (Instant(t_1) < Instant(t_2) \vee Instant(t_2) < Instant(t_1) \vee Instant(t_1) = Instant(t_2)) \quad (7)$$

The condition in the above expression - $(Instant(t_1) < Instant(t_2) \vee Instant(t_2) < Instant(t_1) \vee Instant(t_1) = Instant(t_2))$ – means that time points lie on the same time branch. It is necessary to add this condition, because only on the same time branch (time axis) the condition of strict linear order is fulfilled, which allows to compute the value of *TimeBetween* predicate. It is not possible to compare distances between points on different time branches.

4. COMBINING TIME AND EVENTS

After presenting the basic ontology of left linear time it should be discussed how time is linked to events in the world. Hobbs and Pan propose to use 4 predicates:*atTime, during, holds, timeSpan* [HOPA04] p. 70.We extend here the notion of an event. The classic definition (see e.g. [HAJN96] p. 4) says that an event is a dynamic picture of the world, causing changes in facts. Following Hobbs and Pan, we will however understand events very broadly – as “anything that may be placed in time” ([HOPA04] p. 70), so not only event by itself, but also a state, a process, a logical statement etc.
As said above, Hobbs and Pan propose four predicates. Because we adopt a discrete model of time, we do not use predicate*during*, concerning intervals, and the predicate*timeSpan*will have a narrower definition compared to the original one (see*ibid.*, p. 71).
Predicate*atTime*link san event with a time point, therefore it is crucial for the ontology of discrete time. It says that an event happens, occurs at time point *t*.

$$atTime(e,t) \rightarrow Instant(t) \quad (8)$$

Predicate*Holds*is generally a duplicate of predicate*atTime*. In the original approach by Hobbs and Pan it says that an event occurs at time point *t* or over a time interval *T.* As we assume time discreteness, we omit the second meaning of the predicate and in this way we duplicate the two predicates. We may write:

$$holds(e,t) \equiv atTime(e,t). \quad (9)$$

Finally, the predicate *timeSpan*links events with time points (or sequences of time points) – it is a narrowed version of the original predicate by Hobbs and Pan, which linked events also with intervals and sequences of intervals. This predicate is used for states or processes that adhere to each other, it shows the whole time span during which a process or a state holds. Formally:

$$timeSpan(T,e) \rightarrow TemporalEntity(T) \vee tseq(T) \quad (10)$$

where*tseq(T)*is a sequence of time points.
Moreover

$$timeSpan(t,e) \wedge Instant(t) \rightarrow atTime(e,t)$$
$$timeSpan(t,e) \wedge Instant(t) \wedge t_1 \neq t \rightarrow \neg atTime(e, t_1) \quad (11)$$

The predicate*atTime*links an event with a concrete time point, but this is not a direct linking of an event with the date of its occurrence. At the same time, dates are necessary in the description of economic reality. Therefore there is a question how to link time branching into the future with calendar time.
As McDermott pointed out [MCDE82], two dated cannot be placed on two different time branches, but one date (the same one) may be placed on many branches, as time branches are independent. Therefore in McDermott’s opinion one should discuss a date line independent from the main time structure. In this way, the date line preserves a linear order.

If we adopt the solution proposed by McDermott, we will have to extend the time structure presented in section 2 to the following one[1]:

$$T = \langle T, D, <_{tt}, <_{dd}, <_{td}, <_{dt} \rangle \quad (12)$$

where T – a set of time points, D – a set of dates, $<_{tt}$ – backward partial linear order over T, $<_{dd}$ – a linear order over D, $<_{td}$ and $<_{dt}$ are precedence relations linking the former two orders. In this situation we need to add a few new axioms to the ones presented in section 2. Hajnicz calls them the axioms of quasi-transitivity:

$$t_1 <_{tt} t_2 \wedge t_2 <_{td} d \rightarrow t_1 <_{td} d$$
$$d_1 <_{dd} d_2 \wedge d_2 <_{dt} t \rightarrow d_1 <_{dt} t$$
$$d <_{dt} t_1 \wedge t_1 <_{tt} t_2 \rightarrow d <_{dt} t_2$$
$$d_1 <_{dt} t \wedge t <_{td} d_2 \rightarrow d_1 <_{dd} d_2$$
$$t <_{td} d_1 \wedge d_1 <_{dd} d_2 \rightarrow t <_{td} d_2$$
$$t_1 <_{td} d \wedge d <_{dt} t_2 \rightarrow t_1 \neq t_2 \wedge \neg (t_2 <_{tt} t_1) \quad (13)$$

Adopting the extended structure of time and additional axioms, we have a time theory that is described by the notions of transitivity, anti-symmetry, backward linearity and quasi-transitivity. Together with the ontology of left linear time, we are able to place economic events in time.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In the paper we presented the basic ontology of time branching into the future (left linear one), for economic reality description.

We presented motivation for the choice of this time structure. Next, we modified the ontology by Hobbs and Pan, extending it to the nonlinear time. The next step consisted of presenting, how to link such time with the line of dates. For this purpose, we combined the modified ontology with the proposal by McDermott and Hajnicz, thus proposing a complete model of time, allowing to temporally describe economic phenomena.

The main conclusion is that the classical structure of linear time is too simple and non-adequate to complex economic reality. However – and this is the next conclusion – the ontology of time by itself is also insufficient (even the ontology of nonlinear time). It is necessary to link with it the dates, because economic activities are registered using the standard calendar. This was the reason for combining the proposal of Hobbs and Pan with the proposal by Hajnicz, introducing additional axioms.

There are several potential future research directions.

The first one is developing an ontology of a selected part of economic reality and then combining it with the ontology presented in this paper. A good example of the part of economic reality are barriers to entry to a marketspace. They are interesting, because they are a good exemplification of economic environment: they are heterogeneous, they change in time, they can be both qualitative and quantitative, dense or discrete.

The second research direction is the implementation of nonlinear time ontology in the temporal intelligent system. The need of using such systems for economic domain was suggested in [MACH07]. In the temporal system it is assumed that the knowledge base is encoded using temporal logic. Therefore time is explicit. It is also explicit in the reasoning mechanism. It seems that implementing the ontology of nonlinear time would be useful at least in the reasoning layer of the system.

References

[BEGA04] Bennett B., Galton A. P., *A unifying semantics for time and events*. “Artificial Intelligence”, Vol. 153, 2004, pp. 13-48.

[EDKO05] Eder J., Koncilia Ch., *Interoperability in Temporal Ontologies*. Proc. Of the Open Interop Workshop on Enterprise Modeling and Ontologies for Interoperability (EMOI-INTEROP’05), June 13-14, 2005, Porto, Portugal; ceur-WS.org, accessed 04.11.2010 [GREN03] Grenon P., *The Formal Ontology of Spatio-Temporal Reality and its Formalization*. AAAI Technical Report SS-03-03. www.aaai.org, accessed 04.11.2010

[1]The solution presented in this section comes from [HAJN96], p. 24-25.

[HAJN96] Hajnicz E., *Time Structures. Formal Description and Algorithmic Representation.* LNAI 1047, Springer, 1996.

[HOPA04] Hobbs J. R., Pan F., *An Ontology of Time for the Semantic Web.* "ACM Transactions on Asian Language Information Processing", Vol. 3, No. 1, March 2004, pp. 66-85.

[KLIM99] Klimek R., *Wprowadzenie do logiki temporalnej*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 1999.

[MACH07] Mach M. A., *Temporalna analiza otoczenia przedsiębiorstwa. Techniki i narzędzia inteligentne.* Wydawnictwo Akademii Ekonomicznej, Wrocław 2007.

[MCDE82] McDermott D., *A TemporalLogic for ReasoningaboutProcesses and Plans*. "Cognitive Science" Vol. 6, 1982, pp. 101-155.

[PEHA06] Perry M., Hakimpour F., Sheth A., *Analyzing Theme, Space, and Time: An Ontology-based Approach.* Proc. 14th annual ACM international Symposium on Advances in geographic information systems (GIS-06). ACM, New York, NY, USA, 2006, pp. 147-154.

[PRHA98] Przybyłowski K., Hartley S. W., Kerin R. A., Rudelius W., *Marketing. Pierwsza polska edycja*. Dom Wydawniczy ABC Sp. z o. o., 1998.

[SAAR08]Salguero A., Araque F., Delgado C., *Spatio-temporal ontology based model for Data Warehousing*. 7th WSEAS International Conference on Telecommunications and Informatics (TELE-INFO'08), Istanbul, Turkey, May 27-30, 2008, pp. 125-130

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

[VILA94] Vila L., *A Survey on Temporal Reasoning in Artificial Intelligence*. "AI Communications", 7(1), 1994, pp. 4-28.

[WIHE11] Wiendahl, , H.P., Heger, , C.L., *Justifying Changeability. A Methodical Approach to Achieving Cost Effectiveness*. "Journal for Manufacturing Science and Production". Volume 6, Issue 1-2, Pages 33–40, ISSN (Online) 2191-0375, ISSN (Print) 0793-6648, DOI: 10.1515/IJMSP.2004.6.1-2.33, May 2011

[CHST12] Cecil Eng Huang Chua, Veda C. Storey, Roger H.L. Chiang, Deriving knowledge representation guidelines by analyzing knowledge engineer behavior, Decision Support Systems, Volume 54, Issue 1, December 2012, Pages 304-315. (http://www.sciencedirect.com/science/article/pii/S0167923612001492)