



# The Concept of Quasi-objects in a Temporal Intelligent System

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**Abstract.** The paper presents the notion and concept of quasi-objects that form a representation layer of a temporal intelligent system. The tasks of such a system are briefly discussed to justify the use of quasi-objects, the origin of the concept is presented, and the main features of quasi-objects are outlined. Two examples of quasi objects are presented and discussed. Finally, advantages of this concept are briefly shown.

**Keywords:** quasi-object, temporal intelligent system, heterogeneous domains.

## 1 Introduction

Modern enterprises that operate in a complex economic environment have to react to changes of this environment quickly and properly [10]. Any enterprise has to react to all types of changes: the past, the present and the anticipated ones. Analysis of past changes may be the starting point for prognosis, present changes influence current operations, while anticipated changes allow formulating strategic plans for the future. It is obvious that the time factor is absolutely crucial in the strategic analysis.

We assume that the analysis of the environment that respects and reflects its changes is performed by an intelligent system. As the analysis is put in the temporal context, the system has to be temporal in its nature to provide a complete analysis. By “complete” analysis we mean: putting elements of the environment on the time axis, providing information on past, present and future changes, which is followed by the historical analysis, the analysis of current trends, and analysis of future changes. Also the causal relationships between economic phenomena in time have to be taken into account, as they allow a proper evaluation of phenomena and processes in the environment of an enterprise [11]. Such an analysis will allow better, more accurate and quicker decisions on the current and future strategy.

## 2 A Temporal Intelligent System

By a temporal intelligent system we understand an artificial intelligence system that explicitly and directly performs temporal reasoning. Such a system not only contains a fact base, a rule base and an inference mechanism, but also takes and expresses time in a direct way. For an intelligent system to be considered temporal, explicit time references should be found at least in the representation and reasoning layers.

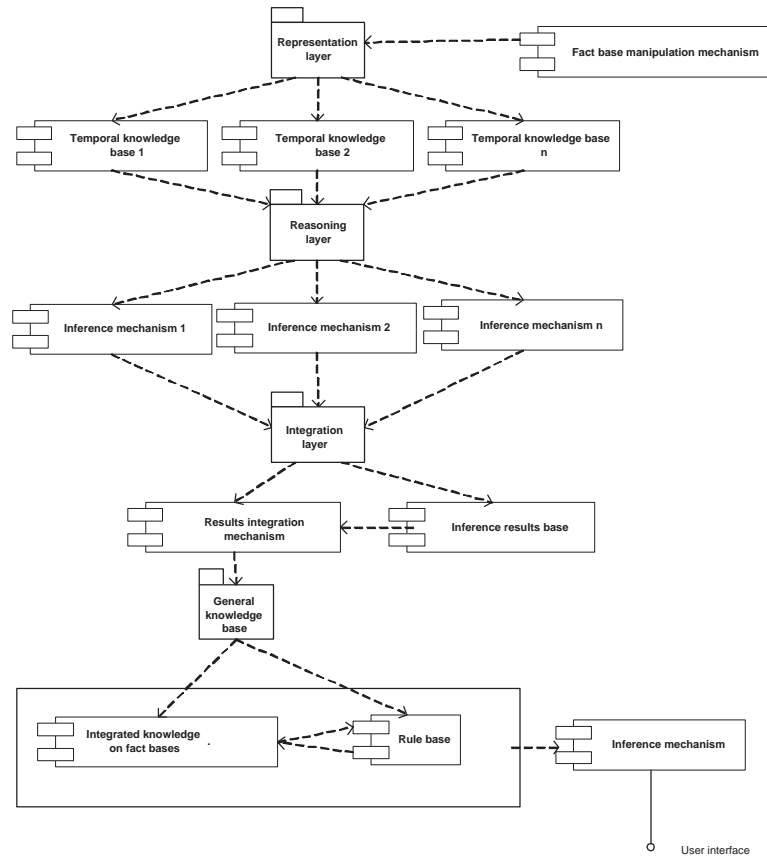
Temporal intelligent system may be considered a decision support system in a sense that its purpose is to support decisions that need an advanced temporal analysis of the environment. To perform this task, the system should be able to:

1. represent time – discrete and/or dense one, depending on the needs and on the nature of phenomena being analysed,
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. analyse future changes.

A temporal intelligent system is composed of several layers. The representation layer contains knowledge about the environment and is composed of several temporal knowledge bases. Such a division of the representation layer is based on several observations. The first one concerns heterogeneity of economic environment, that is of phenomena observed there, and of the pace of changes of these phenomena. This in turn leads to different time granularities, which justify using different representations for the elements of the environment. Moreover, the representation containing different temporal formalisms allows depicting knowledge about the environment in a more precise and complete manner. Using single temporal formalism may lead to omission of some features, if it is impossible to represent them with the formalism chosen. In consequence, the knowledge about the environment would be “flattened”, that is would not concern some important facts or features. All these observations justify using several knowledge bases in the first layer of the system. This layer is responsible for a proper representation and description of elements in the heterogeneous environment of the enterprise. Choosing appropriate temporal formalisms fulfils this task. As these formalisms usually contain inference rules, that are also taken into account in the representation process (see e.g. [12] p. 172; [7]; [2] p. 129nn; [14]; [15]; [19]), they do not only allow to describe and represent heterogeneous elements of the environment and their temporal features, but they also provide a way of reasoning about each knowledge bases’ behaviour. These temporal knowledge bases are called quasi-objects. This notion, its genesis and main features will be discussed in the next section.

The second – reasoning – layer is responsible for reasoning about the domain. It contains individual inference mechanism, one for each individual knowledge base.

Next there is an integration layer. Regardless of the reasoning process concerning individual parts of the environment, it is necessary to integrate the



**Fig. 1.** General architecture of a temporal intelligent system with quasi-objects (temporal knowledge bases) in the first layer

temporal knowledge from the first layer, in order to obtain a general knowledge base. Having such knowledge base the system is able to reason about changes in the environment treated as a whole. The need for integration comes directly from the idea of quasi-objects: each of them is formalised in a different way, there occur differences in time granularity and semantic ones. Also the type of knowledge in each quasi-object is different, because characteristics of elements of the environment are different.

The last layer of the system is the one performing integrated reasoning and the analysis of future changes.

The general architecture of the system, with the first layer containing quasi-objects (temporal knowledge bases), is presented in Fig. 1.

Although each of the layers in the system is worthy of a detailed description, in the paper we will focus on the basic concept linked with this architecture,

namely the concept of quasi-objects, that constitute the layer responsible for temporal knowledge representation. The next section is devoted to this concept.

### 3 The Concept of Quasi-objects

A quasi-object is an individual knowledge base concerning a selected element of the environment (domain), formally represented by the means of a temporal logic, containing temporal knowledge and inference rules specific for the selected logic. Therefore the representation layer consists of a spectre of  $n$  knowledge bases (quasi-objects), where  $n$  is the number of domain elements represented.

The term “quasi-object” refers to the object-oriented paradigm, and emphasizes the fact, that despite some similarities with this paradigm, the concept of quasi-objects does not adopt mechanically all the assumptions of the paradigm. Using the term “quasi-object” is justified because – as Beynon-Davies points out – “there is no common agreement on what object paradigm really is” [3] p. 103. It seems that there is much freedom in using the term “object”.

Although the concept of quasi-objects adopts some notions from the object-oriented paradigm, the two concepts are not identical. The comparison of both paradigms is presented in Table 1.

### 4 Examples

Formally, a quasi-object is defined as:

$$QO_n = \{K_n, A_n, R_n, O_n\} \quad (1)$$

where:

- $K_n$  – knowledge in a quasi-object  $n$ ,
- $A_n$  – axioms of a logic used to formalize knowledge,
- $R_n$  – rules characteristic of a given logic,
- $O_n$  – assumed ontology of time.

Let us consider two examples of quasi-objects. The first one contains knowledge on legal barriers to entry to a market space, the second one – knowledge on capital barriers to entry. According to the above definition, the first quasi-object is built of the following elements:

a) Knowledge

Knowledge in this quasi-object concerns the need of obtaining a licence, according to the Polish law on economic activity [16]. It is encoded in the LTR language [20] in the following way<sup>1</sup>:

```
Attributes(licence, {who_issues, who_gets})
Attributes(is_issued, {what})
Attributes(valid, {what},_,)
Granularity(day)
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<sup>1</sup> Basic concepts of the LTR theory are presented in Appendix A.

**Table 1.** Objects vs. quasi-objects.

CLASSIC OBJECT NOTIONS	QUASI-OBJECT NOTIONS
Object – a package of data and procedures	Quasi-object – temporal representation and temporal inference rules of a specific logic
Object – composed of state (value) and behaviour (operations)	Quasi-object – state (in a given moment) and evolution rules
Object – data structures and algorithm	Quasi-object – knowledge and inference rules
Object – attributes and methods	Quasi-object – features resulting from a given temporal logic, and knowledge base evolution rules
Object – represents a real-world phenomenon	Quasi-object – represents a real-world phenomenon
Object – a symbol representing one or more real-world „beings”	Quasi-object – represents a selected segment of the domain (environment)
Objects – grouped into classes	Quasi-objects may be grouped into classes but not necessarily
Class hierarchy and inheritance	No class hierarchy nor inheritance
Possible changes with reference to objects: – value of attribute – domain of attribute – a set of attributes – composition of objects – class membership of an object – types of relations between objects and/or classes – a set of methods describing object’s behaviour	Possible changes with reference to quasi-objects: – appearance/disappearance of objects (resulting from changes in the domain) – a set of rules describing object’s behaviour – a set of inference rules connected to a quasi-object – causality relationships between quasi-objects (domain elements) – features (attributes) of quasi-objects (domain elements)

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If TT1: licence(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]
    
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b) Axioms of the knowledge representation logic

The LTR theory is based on Vila and Schwalb’s IP-CD theory [19], therefore axioms connected with this quasi-object are as follows:

- IP<sub>1</sub>:  $\neg(i < i)$ ,
- IP<sub>2</sub>:  $i < i' \Rightarrow \neg(i' < i)$ ,
- IP<sub>3</sub>:  $i < i' \wedge i' < i'' \Rightarrow i, i''$ ,

- $IP_4: i < i' \vee i' < i \vee i = i'$ ,  
 $IP_{5.1}: \exists i' (i' < i)$ ,  
 $IP_{5.2}: \exists i' (i < i')$ ,  
 $IP_6: \text{begin}(i, p) \wedge \text{end}(i', p) \Rightarrow i < i'$ ,  
 $IP_{7.1}: \exists i \text{ begin}(i, p)$ ,  
 $IP_{7.2}: \exists i \text{ end}(i, p)$ ,  
 $IP_{8.1}: \text{begin}(i, p) \wedge \text{begin}(i', p) \Rightarrow i = i'$ ,  
 $IP_{8.2}: \text{end}(i, p) \wedge \text{end}(i', p) \Rightarrow i = i'$ ,  
 $IP_9: i < i' \Rightarrow \exists p (\text{begin}(i, p) \wedge \text{end}(i', p))$ ,  
 $IP_{10}: \text{begin}(i, p) \wedge \text{end}(i', p) \wedge \text{begin}(i, p') \wedge \text{end}(i', p') \Rightarrow p = p'$ .

Axioms  $IP_1$ - $IP_4$  provide a strict linear order of time points, axioms  $IP_{5.1}$  and  $IP_{5.2}$  mean that a set of time points is unbounded, axiom  $IP_6$  provides an ordering of interval's endpoints, axioms  $IP_7$ - $IP_8$  assure an unique startpoint and endpoint of any interval, axioms  $IP_9$  and  $IP_{10}$  state that for a given ordered pair of timepoints an interval exists.

Moreover, the standard syntax and semantics of the 1st order predicate calculus (see e.g. [8], p. 43-54) is in force. It is augmented with temporal predicates *Holds*, *Occurs*, *Holds\_at*, *Holds\_on* (details are to be found in [20]).

c) LTR inference rules

The LTR theory is based on the 1st order predicate calculus, and because it assumes points and intervals of time as basic temporal entities, therefore the inference rules characteristic of this theory encompass predicate calculus rules and mixed point-interval TCSP.

d) Time ontology

According to the LTR theory assumptions, the basic temporal entities are points and intervals. The set of temporal relations is given as  $\{<, \text{begin}, \text{end}, \text{next}, \text{previous}, \text{immediateBefore}, \text{immediateAfter}\}$ . Time is ordered by a strict linear order.

The second quasi-object is built of the following elements:

a) Knowledge on capital barriers to entry

It is encoded using Allen's temporal logic [1]:

- $\text{occurs}(\text{unstable}(\text{DER}), p) \Rightarrow \text{holds}(\text{high}(\text{barrier}), p)$   
 $\& \text{holds}(\text{high}(\text{barrier}), p') \& \text{before}(p, p') \vee \text{meets}(p, p')$   
 $\vee \text{overlaps}(p, p')$   
 $\text{occurs}(\text{high}(\text{barrier}), p_1) \Rightarrow \text{occurs}(\text{increase\_of}(\text{OP}), p_2)$   
 $\vee \text{occurs}(\text{increase\_of}(\text{DER}), p_2) \& \text{before}(p_2, p_1)$   
 $\text{ecause}(\text{increase\_of}(\text{rate}), p_3, \text{increase\_of}(\text{capital}, p_4)$   
 $\& \text{before}(p_3, p_4) \vee \text{meets}(p_3, p_4) \vee \text{overlaps}(p_3, p_4)$   
 (DER – dollar exchange rate, OP – oil prices)

b) Axioms of logic – Allen's theory

As knowledge in this quasi-object is formalized using Allen's theory, the part of this object are axioms concerning interval relations [18] p. 7:

$A_1: \forall p, p' \in P, R \in AR \exists p': (R(p, p'))$  – given any interval there exists another interval related to it by a relation from Allen's set of relations, where AR denotes this set.

$A_2: \forall p, p' \in P, R \in AR \forall R' \in AR-R : R(p, p') \Rightarrow \neg R'(p, p')$  – relations are mutually exclusive

$A_3$ : relations have a transitive behavior, according to Allen's transitive table [1], p. 836.

c) Inference rules

Allen's interval logic is based on the 1st order predicate calculus, therefore its inference rules are the same as in this calculus, augmented with qualitative TCSP, because only intervals are considered as basic temporal entities.

d) Ontology of time

Allen assumes a time ontology consisting of basic temporal entities – intervals and 13 basic temporal relations between time intervals (see [1]; [2]).

## 5 Quasi-objects in a Temporal System – Advantages

Using the concept of quasi-objects in a temporal intelligent system may reveal the same advantages as those pointed out with reference to object-oriented paradigm (see e.g. [13], p. 218). Speaking in terms of a temporal system, these advantages would be as follows:

1. the concept of quasi-objects will make the construction and maintenance process of a knowledge base spectre easier. In case of changes (resulting e.g. from changes of domain elements) only one knowledge base will have to be changed (compare to objects' changes – [13], p. 254);
2. each quasi-object may be represented with means of different temporal logic, thanks to this the reality will be depicted in a more precise way;
3. knowledge divided into fragments, put into quasi-objects, will be more clear and ordered;
4. with quasi-objects, a temporal intelligent system will be more domain-oriented. In case when each knowledge base is constructed separately, it is more easy to understand and to represent fragments of the environment;
5. The construction process of a representation layer, based on quasi-object concept, is easier than constructing a traditional knowledge base, not divided into fragments;
6. Division of a knowledge base into quasi-objects makes the formalization of changes of domain elements easier, and enables modelling of domain's dynamic aspects.

Knowledge representation may be assessed according to different criteria. In regard of the criteria presented in [21], p. 31, the knowledge representation based on temporal formalisms, and organised in the form of quasi-objects, is:

1. clear – temporal formalisms, arising from classical logic, allow an easy identification of the domain represented,

2. precise – especially in the temporal aspect, thanks to the explicit notion of time,
3. natural – it presents the reality being modelled in an easy way, moreover, due to the features of temporal logics it is close to human commonsense reasoning and perception,
4. efficient – allows an easy access to the knowledge needed. It is so because the representation layer is divided into separate quasi-objects (access to knowledge on a selected fragment of the environment) and because of explicit temporal references (access to knowledge from any point/interval of time),
5. adequate to the domain (changing in time) and to the tasks of the system (temporal analysis),
6. modular – fragments of knowledge are independent (because quasi-objects are independent), but at the same time there are causal relationships between them. Nevertheless changes in one knowledge base (quasi-object) do not entail changes in other knowledge bases.

Summing up, the advantages of the proposed representation come from the advantages of the concept of quasi-objects and from the advantages of temporal logics. The latter are discussed e.g. in [9]; [4]; [6].

## 6 Conclusions and Future Research Directions

To the best of our knowledge, up till now in the literature concerning intelligent temporal systems only one knowledge base, and in consequence only one logical formalism has been assumed. If there was a need for integrating representations of elements in the domain, it was performed “beyond” the system (see e.g. [5]; [17]). Such a solution could lead to a loss of information and knowledge, as it has been pointed out in the paper. The concept of quasi-objects is an answer for the need to represent heterogeneous domains as precisely as possible.

It seems that this concept may lead to a better and more precise representation of knowledge about complex, changing domain of enterprise’s environment. It is so despite some difficulties that may arise due to the necessity of formalizing knowledge using several temporal formalisms, and to the necessity of subsequent integration in higher layers of the system. With a more precise temporal knowledge representation, decisions generated by the system would be also more precise and accurate.

The concept of quasi-objects constitutes a first step in a way leading to construction of a heterogeneous temporal intelligent system. Such a representation may cause significant problems that will have to be solved while working on next system’s layers. Once you have more than one formalism to represent different quasi-objects, there must be developed a technique to merge their semantics and/or inference procedures. In other words, having more than one logic language with its own formal semantics, putting them together may lead to an undecidable logic. If you want to reason on the (temporal) knowledge you have on all the quasi-objects in your system, you have to map all the languages (both

their syntax and their formal semantics) in a common language. If you have no restriction on temporal languages, the common language will very probably be FOL in all its expressiveness. And then you will have an undecidable language. Therefore, having these serious possible problems in mind, the future work will concern mainly developing an integration procedure (second layer) and inference mechanisms – to reason both about individual quasi-objects and merged knowledge gained from them.

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#### Appendix A – Basic Concepts of the LTR Theory

The LTR theory is based on the 1st order predicate calculus. The set of temporal relations is given as  $\{<, \textit{begin}, \textit{end}, \textit{next}, \textit{previous}, \textit{immediateBefore}, \textit{immediateAfter}\}$ . Time is ordered by a strict linear order, points and intervals are basic temporal elements. Basic axioms of the LTR theory are to be found in [20], of course standard axioms of the 1<sup>st</sup> order predicate calculus also are in force. Predicates of the LTR are 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.

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, where time is introduced as one or more additional arguments, for example:

$$\text{Valid}(\text{act}, t1, t2)$$

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

$$\text{Valid}(\text{act}, \text{tt1})$$

which allows for the following interpretations:  $\text{begin}(\text{tt1}) = 01/01/1990$  – the starting point for token tt1; or  $\text{period}(\text{tt1}) = [01/01/1990; 31/12/1990]$  – 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.