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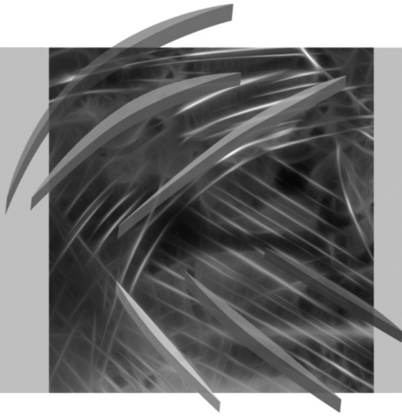

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ANALYSING ECONOMIC ENVIRONMENT WITH TEMPORAL INTELLIGENT SYSTEMS: THE R-R-I-M ARCHITECTURE AND THE CONCEPT OF QUASI-OBJECTS

Summary: The paper presents a new architecture for building temporal intelligent systems, called R-R-I-M. The architecture is based on the concept of quasi-objects, used in the representation layer. The concept is presented and discussed in detail. Other layers of the system are also discussed. We show the advantages of the new architecture and discuss the possibilities of incorporating the already existing solutions in the architecture.

Keywords: economic environment, heterogeneity, economic analysis, intelligent system, temporal representation, quasi-objects.

1. Introduction

The modern environment of any enterprise is complex, dynamic, and suffers from turbulences. At the same time, its role in formulating enterprise's strategy is more crucial than ever before. In our opinion, classic decision support systems are nowadays not sufficient to help in strategy formulation, due to two main reasons:

1. They do not support explicit temporal representation of a domain. This in turn leads to the omission of a very important aspect: time and change in the environment.
2. They do not support heterogeneous representation – a knowledge base is usually uniform and formulated (expressed) in qualitative or quantitative terms, not both at the same time.

In our opinion, temporal intelligent systems with a heterogeneous knowledge base are needed to capture properly the complex aspects of economic environment and to analyse them. The pace of change in the economic environment evokes a need to take into consideration the temporal aspect of the environment in an explicit way. Therefore, we see a need to build temporal intelligent systems which would be helpful in such tasks as: providing an appropriate description of different aspects of the environment, taking into account their temporal characteristics, unifying those descriptions, which would allow further, more general inference (meta-reasoning), historical analysis of changes of the environment, diagnosing current state, and forecasting.

The main goals of the paper are to propose architecture of a temporal intelligent system, which would assure realisation of the tasks mentioned above, and to discuss the core concept that underlies the architecture, namely the concept of quasi-objects.

2. Problems to be solved

A temporal intelligent system is an artificial intelligence 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 for inference about changes of phenomena in time, for historical analysis of phenomena, for prediction and – generally speaking – for a dynamic analysis of reality depicted.

Here we face the problem of heterogeneity of knowledge sources for an intelligent system. It is impossible to describe all the aspects of economic environment in a single knowledge base, because those aspects differ significantly. There are for example qualitative and quantitative features, which need different description formalisms; there are features that change faster than others – and this in turn needs different time granularities, etc. Therefore, it is obvious that – no matter which part of economic environment one would try to describe – several, heterogeneous knowledge sources are indispensable.

What problems do we face while trying to build a temporal intelligent system based on heterogeneous knowledge sources? First, the problem of representation. As already pointed out, several description formalisms will be needed, according to specific characteristics of each aspect being described. The choice of the formalism is an absolutely crucial and important step. Second, the problem of integration/unification of descriptions. We agree with Brusoni et al. [1994] that for proper inference about temporal information we have to unify them properly and adequately. Thus, this is the second problem to be solved: the choice of appropriate unification (integration) method that at the same time would allow working with the knowledge base about all barriers to entry and with each of descriptions of barriers' groups. And finally third, the problem of reasoning about temporal knowledge – about each knowledge source and about all sources treated as a whole.

In our opinion, the key to success is to find a good architecture of the system. In the following sections we will propose and discuss an architecture called R-R-I-M, which stands for Representation-Reasoning-Integration-Meta-reasoning.

3. The R-R-I-M architecture. A general view

As visible in Figure 1, a system built according to the R-R-I-M architecture (Representation-Reasoning-Integration-Meta-reasoning) consists generally of four layers. The first one – the representation layer – is responsible for an appropriate

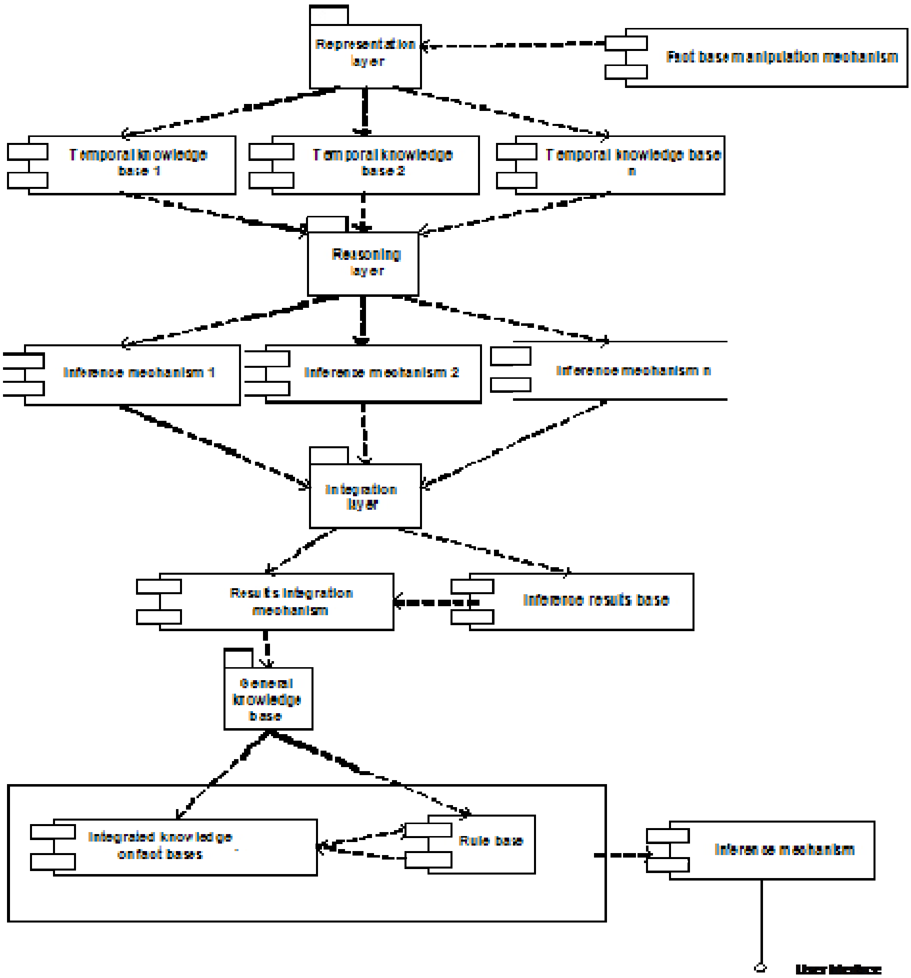

Figure 1. The R-R-I-M architecture

Source: author's own study.

"description" of changing phenomena in the economic environment. It has been already pointed out that several temporal formalisms will be needed for representation, due to heterogeneity of the environment. We propose that the representation layer consist of several individual knowledge bases, called quasi-objects. The concept and the idea of quasi-objects will be discussed in detail in Section 3.

The first layer contains also a fact base manipulation mechanism. Its tasks are to enable (together with the user's interface) not only the maintenance of individual knowledge bases, but also the historical analysis of environment's element.

The situation calculus might be considered here because it has been used to maintain temporal databases and formulate temporal queries.

The reasoning process performed against individual knowledge sources, as well as against the general (integrated) knowledge base, provides a user with information on the "current state" of elements of the environment, it also enables historical queries.

In a system built according to the R-R-I-M architecture, reasoning is performed immediately after completing the representation of each component of the environment. Therefore, a user has a direct access to non-integrated reasoning results, concerning each of the components in the knowledge bases spectre (each quasi-object).

The system contains an integration/unification layer responsible for providing a uniform representation of individual reasoning results. This allows building a general knowledge base, containing facts inferred upon individual KBs and general reasoning rules, and performing general reasoning concerning this base. Thanks to this, a user gets information on both aspects of the analysed environment: detailed and general. The question of formulating inference rules for the general knowledge base is not trivial. They may be gained, e.g., from domain experts. The reasoning process is to concern changes of the economic environment in time; therefore, the rules should have a temporal form, that is, possess an explicit temporal component.

In the next section the layers of the R-R-I-M architecture will be presented in more detail. The first layer, based on the notion of quasi-objects, will be discussed precisely, while other layers will be treated in a more general manner. This is due to the fact that in our opinion the idea of quasi-objects is a core element of the architecture.

4. Layers of the R-R-I-M architecture

4.1. Knowledge representation

The representation layer in a temporal intelligent system is based on the concept of quasi-objects. A quasi-object is an individual knowledge base concerning a selected element of the environment (domain), formally represented by 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 emphasises 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" [Beynon-Davies 2003, p. 103]. It seems that there is much freedom in using the term "object".

The concept of quasi-object 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 environment in a more precise and completing manner. Using only one temporal formalism may lead to omission of some features, impossible to represent with the formalism chosen. In consequence, knowledge about environment would be "flattened", that is, would not concern some important facts or features.

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

Table 1. Objects *versus* 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)

Source: author's own study based on Beynon-Davies [2003]; Elmasri, Navathe [2000]; Bahrami [1999]; Coad, Yourdon [1994]; Kania [2004].

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 for example Nowicki (ed.) [1998, p. 218]). Speaking in terms of a temporal system, these advantages would be as follows:

- the concept of quasi-objects will make the construction and maintenance process of a knowledge base spectre easier; in the case of changes (resulting, e.g., from changes of domain elements), only one knowledge base will have to be changed (compare to object changes – [Silberschatz, Korth, Sudarshan 1997, p. 254]);
- 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;
- knowledge divided into fragments, put into quasi-objects, will be more clear and ordered;
- with quasi-objects, a temporal intelligent system will be more domain-oriented; in the case when each knowledge base is constructed separately, it is more easy to understand and to represent fragments of environment;
- the construction process of a representation layer, based on quasi-object concept, is more easy than constructing a traditional knowledge base, not divided into fragments;
- division of a knowledge base into quasi-objects makes formalisation of changes of domain elements easier and enables modelling of domain's dynamic aspects.

Choosing proper temporal logics to be used for representation in quasi-objects is not an easy task. The choice depends mainly on the domain features, time structure resulting from those features, and the features of temporal formalisms themselves. Here we will only give some examples of formalisms that may be used to represent knowledge about enterprise's environment. The choice of these formalisms was explained in detail in Mach [2005].

Somewhat between the representation and the reasoning layers, there is also a mechanism responsible for manipulation of quasi-objects. It belongs to the first layer in the sense that representation of changes of all domain elements is also needed. In other words, it is necessary to represent changes of all knowledge bases (quasi-objects) treated as a whole. It is a so-called "knowledge about knowledge", that is, knowledge about how domain knowledge evolved in time [Lorentzos, Yialouris, Sideridis 1999, p. 313]. The manipulation mechanism belongs also to the second (reasoning) layer because, to assure coherence of the evolving knowledge, it is necessary to implement temporal constraint satisfaction rules. And the TCSP problem is one of the approaches to temporal reasoning.

Knowledge representation may be assessed according to different criteria. Applying the criteria formulated in Zieliński (ed.) [2000, p. 31], to the representation layer discussed above, we may point out the following advantages of using temporal quasi-objects:

1) the representation is clear – temporal formalisms, originating from classical logic, assure an easy identification of the domain represented;

2) the representation is accurate – especially in the temporal context, thanks to the explicit treatment of time;

3) the representation is natural – it depicts reality in an easy way; moreover, thanks to the features of temporal logics, it is close to human commonsense perception;

4) the representation is efficient – it allows for an easy access to the needed knowledge. It is so because the representation layer is divided into quasi-objects (access to knowledge concerning a specific part of the domain), and because there are explicit time references (access to knowledge from any point/interval of time);

5) the representation is adequate to the time-evolving domain and to the tasks of the system (temporal analysis);

6) the representation is modular – its fragments are independent from each other (quasi-objects), but at the same time they are connected by causal relationships. Nevertheless, interference in one knowledge base does not cause the necessity for interfering in other bases.

Summing up, it may be said that the advantages of the representation proposed above come from two sources: the advantages of quasi-objects and from the advantages of temporal formalisms.

4.2. Reasoning

The type of reasoning process in an intelligent system depends on the type of problem(s) to be solved. This process influences the quality and accuracy of conclusions, and in consequence it influences the quality of the whole system.

In a temporal intelligent system, the temporal reasoning is placed in second, fourth, and partly in the first layer (see Figure 1). Thanks to the concept of quasi-objects, there is much freedom in choosing the type of reasoning and its strategy because of the similarities between object and quasi-objects concepts. As already said, each quasi-object contains inference rules specific to the temporal formalism used in this object. As in most cases these rules concern time ordering of facts and events, they may be treated as constraint satisfaction rules.

Each quasi-object in a temporal intelligent system is connected to a dedicated inference engine. The reasoning performed by these individual engines is strongly domain-oriented.

4.3. Integration

The need for integration comes directly form the concept of quasi-objects: each of them is formalised differently, there are differences in time granularities and semantic differences (to point out only the most important ones). Also knowledge in each of the quasi-objects is different, because there are differences between the elements of the domain represented. Independently from reasoning about individual knowledge bases, the system should integrate temporal knowledge from the first layer in a general knowledge base. With such a general base, the system will be able to reason about changes of the environment treated as a whole.

Integration in a temporal intelligent system may be seen form many different points of view. From the economic point of view, it is the integration of features, because the elements of the environment that are represented, e.g., the barriers to entry, are heterogeneous. And from the knowledge representation point of view, one may speak about:

1) logical integration – because basic representation formalisms are temporal logics,

2) temporal integration – because the pace of change of the elements in the environment is different, which causes different time granularities in the representation layer.

In our opinion, actually the majority of solutions, concerning integration of knowledge from heterogeneous sources, could be – after some modifications, if needed – used for dynamic analysis of barriers to entry (of the economic environment in general). We are even convinced that there is no need to develop a new particular method of integration.

4.4. Meta-reasoning and analysis of future changes

The last layer of the system is responsible for execution of three tasks. First, for reasoning about the environment treated as a whole (meta-reasoning). The reasoning is performed with relation to knowledge gathered in the general, integrated knowledge base (see Figure 1). It serves for historical and current-state analysis, for conclusions concerning relationships among the elements of the environment, etc. Second, reasoning in the last layer is aimed also at the analysis of future changes. And third, the last layer contains also a user interface, responsible for communication and for query maintenance.

The historical and current-state analysis should provide information on past and present states of the environment. A properly chosen query language may be used for this task. Moreover, the rule base in the last layer should contain – the same as the second layer – inference rules, both static and temporal ones since the integrated knowledge is dual with respect to the temporal aspect: static and temporal. It is due to the fact that the knowledge about elements of the environment, used to build the general knowledge base, is also dual.

The historical and current state analysis is also a starting point for a future changes analysis, which should make possible:

– the evaluation of possible directions of changes,
– the evaluation of present changes' impact on future state of the environment,
– the evaluation of changes' strength,
– the prediction of target events in a sequence of past and present events.

These evaluations serve to generate pieces of advice concerning the future strategic behaviour of an enterprise. The last part of the fourth layer in the system is a user interface, but it will not be discussed here.

5. Conclusions and future research

In the paper we presented the R-R-I-M architecture of a temporal intelligent system. In our opinion, a new architecture of temporal intelligent systems is necessary, as the tasks for such systems are not achieved by classic decision support systems (see Section 1), and the new architecture needs new underlying concepts. In the paper we presented and discussed the concept of quasi-objects, which we consider to be the core idea of the architecture.

The main advantage of building and using a temporal intelligent system based on heterogeneous data sources lies in the concept of "the economy of speed" [Tvede, Ohnemus 2001]. The sooner the changes in the environment are captured, the sooner the strategic decisions are made, the bigger "first mover advantage".

Obviously, there is a lot of future research to be done. The main directions of the research are as follows. First, we have to choose the temporal rules construction method for the general knowledge base. Second, we are planning to describe one barrier to entry in a temporal logic, to check whether our idea of the first representational layer is correct. Obviously, other layers should also be designed and implemented. We are currently working on temporal inference rules, using Sowa's conceptual graphs theory [Sowa 2000], extended with fuzzy temporal qualifications.

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ANALIZA ŚRODOWISKA EKONOMICZNEGO PRZY POMOCY INTELIGENTNYCH SYSTEMÓW TEMPORALNYCH – ARCHITEKTURA R-R-I-M I KONCEPCJA QUASI-OBIEKTÓW

Streszczenie: Artukuł prezentuje nową architekturę do tworzenia inteligentnych systemów temporalnych zwaną RRIM. Architektura ta jest oparta na koncepcji wykorzystania quasi-obiektów, używanych w warstwie reprezentacji. Koncepcja jest przedstawiona i omówiona szczegółowo. Omówione są również inne warstwy systemu. Autor prezentuje zalety nowej architektury i omawia możliwości włączenia do architektury istniejących już rozwiązań.

Słowa kluczowe: środowisko ekonomiczne, heterogeniczność, analiza ekonomiczna, systemy inteligentne, reprezentacja temporalna, quasi-obiekty.