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The approach of granular computing and rough sets for identifying situations

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Abstract. In the article are described problems related to creation and maintenance of situational awareness systems. The definitions of concepts of situation and its identification are presented. An approach based on situational knowledge representation with ontological models is selected for attaining situational awareness in complex intelligent enterprise systems, where objects can be in several situations in the same time and some situations are defined imprecisely. Granular computing approach is used for reduction of situational knowledge management complexity. In order to work with situation defined imprecisely, rough set approximations are proposed for situation definition. The usage of mechanisms inherent to ontological modeling for situation representation and reasoning about them are also discussed.

Key words: situation, situational awareness system, ontology, situational assessment, granular computing, rough sets theory.

INTRODUCTION

The technology of intellectual decision support systems is one of the most developed areas of artificial intelligence [1]. Due to the rapid development of artificial intelligence, computer networks, distributed architectures, multi-agent systems and robotics it has become possible to develop intellectual systems that are able to achieve the desired results through cooperation of different autonomous units with a purpose of understanding their current situation. The development and maintenance of situational awareness is a necessary condition for such systems.

Today, the concept of situation awareness is very popular. It means the ability to obtain information about the state of environment and using this data in combination with knowledge about domain to make decisions on necessary actions. The prognosis about the future state of environment is also made [2]. Thus, the task of situational awareness system is to provide fully autonomous decision making by intellectual system in a dynamic environment.

At any stage of human and computer activity we might encounter difficulties when we cannot solve a problem using known methods with available knowledge and facts. In view of this, we are faced with problematic situation which should be identified. As well as, we need to develop such methods and tools for problematic situations identification which would allow not only identify the situation and its definition in decision support systems, but also to detect faults in systems and avoid recurrence of problematic situations. The task of evaluating the problem situation is one of the central task of decision support systems with situation awareness. Proper estimate of the current situation is necessary to make correct decisions. The solution of this problem by expert is usually conducted in the presence of incomplete, poorly structured information of subject area, constant change of state of this subject area, large amounts of irrelevant data for decision-making purposes, and hard constraint over time of decision-making [3].

RECENT RESEARCH ANALYSIS

Situation awareness is based on representation and analysis of situations. It is impossible to achieve situational awareness without the preliminary analysis of the situation. Moreover, in most cases, if the situation is properly assessed, we can automatically determine the sequence of actions that need to be done [4].

The concept of situation can be considered in different contexts settings focused on reasoning, logic, human-machine interaction or information system perspective. For example, in paper [5] author defines the situation as a logical concept being the finite sequence of actions. Cambridge Advanced Learner’s Dictionary [6] gives the definition of situation as a set of things that occur and conditions that exist in a particular time and place. However, generally accepted is the formalization of the situation proposed by John Barwise and John Perry. They created the Situation theory and determined that intellectual agent understands the world as a set of situations. Thus, the behavior of an agent is determined and depends on a set of situations [7].

Identification of situation is a process of matching between the current state of system and some specific knowledge pattern defining the situation. Generally, identification is a particular case of classification problem, because classification is made using different methods such as comparison, recognition, decision trees and also includes identification.

Due to the rapid development of information technology and decision support systems, the number of automated systems which are used not only in specific industrial areas, but also in everyday life is increased. Therefore, the identification of a problematic situation is a key factor for improving the accuracy, performance and quality of complex system. In particular, the identification of the situation is very important for systems with situational awareness, since the correct assessment of the situation based on available knowledge makes it possible to improve the existing system and to avoid similar mistakes in the future.

The definition of situational awareness is a quite a difficult task and different authors interpreted it from different perspectives.

Sometimes situational awareness is defined as a situational assessment and certain sources frame it as a same unit. However, it must be understood that these concepts have some differences. While situation assessment is focused on system interaction, the notion of situational awareness (SAW) is centered on the interaction of system with the users (in this case, “awareness” refers to the awareness of the final user of the current system state for forecasting and prediction its next states) [8]. That is, the concept of situational awareness involves not just the perception of information (state of the environment, system etc.), but as well a high-level understanding of the current state of the system in accordance with its objectives in order to be able to select the desired (suitable) action. Thus, situation awareness is a state of knowledge, and situation assessment – processes used to achieve this knowledge.

In this way, situation awareness – the ability to identify the process and understand the most important elements of information of what is going on.

It's becoming clear that the systems with situational awareness are important not only in artificial intelligence, but also in other fields and areas. This is because the development of systems capable of identification of problematic situation and proposing or predicting future actions is a promising trend in any development field.

For example, situational awareness can be used in economy in what is known as intelligent enterprise. It used with a purpose of improving the efficiency and flexibility of business processes. Knowledge-based business process modelling, using ontological tasks model, allows to create common enterprise-wide system of concepts and relations in form of ontology [9].

Paper [10] proposes an approach to situation identification using causality relationships between events at an enterprise based on methods and tools of data mining. The author notes that the problematic situation can be investigated according to such scheme: problem (consequence) – symptoms (indicator) – parameters – factors – causes – underlying causes. The differences between this mechanism of decision management and the approach presented in our paper are as follows:

- in paper [10] human-machine systems are considered. In other words, system helps the analytic to identify potential situations. In our paper we consider fully autonomous systems based on knowledge. So, the system will detect the situation using available knowledge and will reason with it. This knowledge is presented in the form of ontological models;
- our work examines the case of uncertainty. In other words, information may be incomplete or not clearly marked, etc.;
- paper [10] formulates the problem of situation identification on purely conceptual level, our work analyses the advantages of using ontological modeling and granular computing as a basis of method for situation identification.

Paper [11] considers identification of problematic situations and their states in complex engineering systems using a modified algorithm FOREL. The paper uses a modified algorithm because the algorithm as presented in the classic version is not acceptable for identification problematic situations and their states in complex technical systems because it involves determining the radius of the cluster, which may be unknown in advance.

Paper [12] develops a simulation of emergencies in railways with methods of cluster analysis. It proposes a software tool DEDUCTOR, based on the classic k-means algorithm and modified k-means algorithm.

Paper [13] proposes an approach for construction of semantic metrics based on thesaurus of the domain of linguistics. The authors are using the methods of intellectual data analysis, such as decisions trees to define the weight of some subset of concepts. Then based on the ontology of the subject area they develop the concept weights for the whole ontology. The ontologies with semantic metrics can be used in reasoning about situations by helping to identify similar concepts and apply situational knowledge to them.

OBJECTIVES

The aim of the paper is to develop the ontology-based model of situational knowledge representation using a granular computing approach and rough sets theory in order reduce complexity of situational knowledge management.

THE MAIN RESULTS OF THE RESEARCH

Situational awareness systems for a long time were focused on human-machine applications [14]. However, current industry trends of introduction artificial intelligence and robots determine the necessity to change research focus from human-machine systems to fully autonomous intellectual systems. Such systems must be flexible, self-governed and be able to make decisions in real world situations. That is, virtually all research conducted up to date have been focused on the development of situation awareness in systems with human operator and support of him making decisions. Those studies were based on models and took into account the peculiarities of human cognitive processes. However, the research and development of purely computer-based situational awareness needs other models.

Today, in order to correctly represent domain and resolve problems in systems with situation awareness not only different methods should be used, but also they should be combined within a single system and selected according to context [15]. For this reason, more and more popular becomes the domain representation in the form of ontology. It makes possible to complement different methods to solve various tasks within a single situation awareness system.

One of the well-known situational awareness (SAW) model is Data Fusion Model (JDL model) [16]. It describes the process in SAW system as having consecutive stages (levels). A characteristic feature of the Data Fusion Model is an abstraction from operations of data collection, situation assessment and decision-making previously presumed as made only by human operator. As a result, it enables the analysis of SAW for human-machine systems and purely autonomous systems in the same time [2].

Situation awareness was envisioned as the main part of Level 2 and Level 3 processing in the JDL model.

To solve the problem of identification of problematic situations a method should be created that allows formalize expert knowledge about the properties of problematic situations, acquiring and reusing the knowledge about decision making in similar situations. The process of knowledge management in SAW systems is shown on figure.

Sensors collect data about environment. Those data are attributed to objects in fact base (first level of JDL model). Next, the data in fact base are processed by logical reasoner which uses available knowledge for drawing conclusions. In result, fact base can be updated with new facts or attribute values. Than situation modeling software processes data in order to identify problematic situations.It also uses knowledge about situation identification rules and situation properties. Those activities are performed on second level of JDL model. On third level, based on identified situations and contextual knowledge about domain, necessary actions are planned, impacts and prognoses created [16].

Knowledge base is constantly updated with new facts that show the state of the domain. It contains ontology-based representation of domain that allow to similarly treating all objects from knowledge base and determine a single structure of knowledge for them.

In addition, knowledge database contains logical inference mechanisms and rules used to identify situations. It includes also the ontological models of situations to store these rules.

Often, when trying to encode knowledge about a certain situation we face difficulties of its identification. This due to by presence of various types of situation representation.

For instance, situation can be defined as:

- the set of static conditions;
- similar states – groups of states as one state;
- neighboring states;
- the dynamics of transitions between states;
- trajectories between states, associative and causal relations;
- derived situations (using ontologies for domain representation and inference capabilities such as description logic, other forms of logic, models based reasoning);
- taking into consideration uncertainty and reasoning about uncertainty.
- neighbor state situations defined as a set of situations which are close to specific target situation.

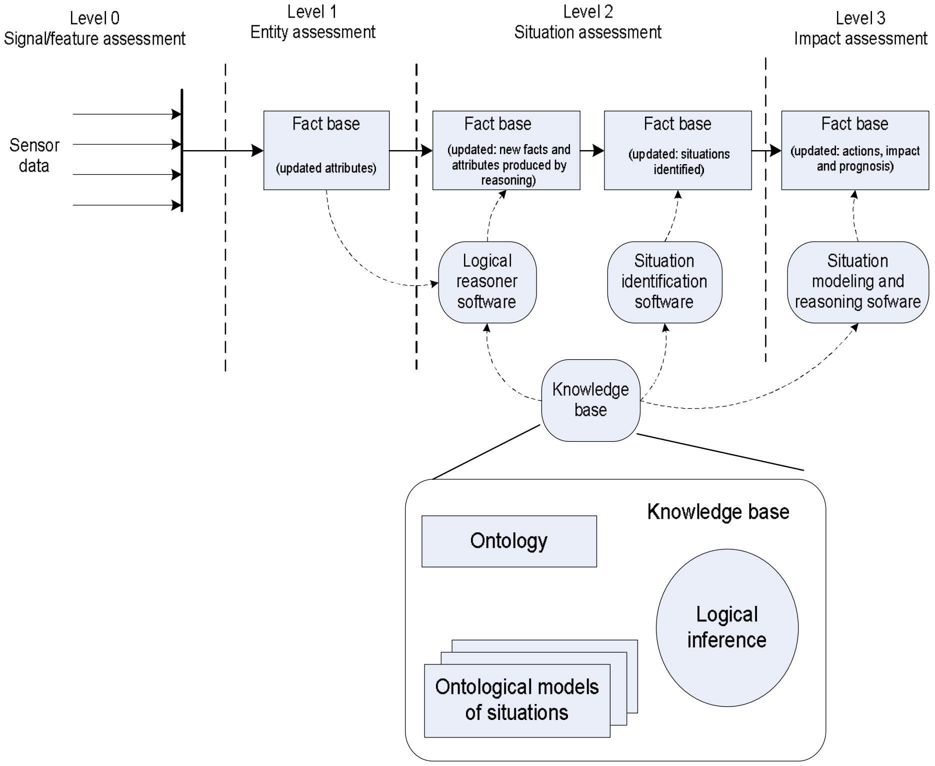

Fig. The process of situation identification

There are many methods of obtaining knowledge about problematic situations in complex technical systems. In particular, the most popular are cluster analysis, association rules and so on [17]. However, despite the variety of approaches for identification of problematic situations often there are difficulties when using available methods.

In particular, in process of identification of problematic situations in complex technical and economic systems with situational awareness we encounter such difficulties:

- complexity of managing knowledge about situations.

The complexity of managing knowledge about situations and their monitoring springs from the complexity of the subject area, availability a large number of objects and different relationships between them. It complicates the task of identification and encoding knowledge about situation, as well as, maintaining the integrity of such knowledge and avoiding contradictions and errors.

- significant number of potentially-enabled situations for each object.

Number of situations specified for monitored object can be significant. Accordingly, the analysis of situations by simple enumeration of these situations definitions leads to inefficient use of resources.

- fuzziness and inaccuracy of data and knowledge used in situation definition.

At any specific time, a given object can be in many different situations. Some of those situations are imprecisely identified with possible exceptions. On the other hand, different situations for the same object can specify conflicting actions.

- situation interpretation depending on context.

Situation and the relevant situational model are often represented as several objects with relations between them. The definition of situation uses attributes of these objects and relations. Detecting and formally presenting such context-sensitive situations is a difficult task. In addition, situation's identification should take into account the state of all objects in its definition and the state of their relations. It further complicates the solution of the problem.

Using knowledge of the subject area presented in the form of ontology and ontology-based models to identify situations has important advantages in comparison with using decision tables, trees or rule sets. Moreover, the use of ontologies to identify situations provide additional possibilities for situation definition and processing using structural features of ontology and logical inference mechanisms.

Situational model specification is represented and stored in xml format. Below is an example of situational model specification for contextual definition of situations during a tourist tour [3].

```
<Model>
        <ModelMetadata>
                <GeneralInfo>
                        <ModelId> id </ModelId>
                        <ModelType> SituationalModel
</ModelType>
                        <OntologyURI>
www.acme.org/TourismOntology</OntologyURI>
                </GeneralInfo>
                <ActivationInfo>
                        <Condition>
                                <ConditionId>
cd1</ConditionId>
                                <ConditionBd>
CurrentDate()in InBase(Voyage.DatePeriod) <ConditionBd>
                        </Condition>
                        <Condition>
                                <ConditionId>
cd2</ConditionId>
                                <ConditionBd> Every(5
min) <ConditionBd>
                        </Condition>
                        <Activate> (cd1) and
(cd2)</Activate>
                </ActivationInfo>
        </ModelMetadata>
        <Signature>
                <Condition>
                        <ConditionId>
sigcd1</ConditionId>
                        <ConditionBd>
InBase(Some(Site).Location) nearDistance
InBase(Person.CurLocation) <ConditionBd>
                        <Result> InBase(Site)</Result>
                </Condition>
                <Condition>
                        <ConditionId>
sigcd2</ConditionId>
                        <ConditionBd> CurrentTime()
nearTime
InBase(Some(Voyage.Schedule.ScheduleEntry.Time))<Condit
ionBd>
                        <Result>
InBase(Voyage.Schedule.ScheduleEntry)</Result>
                </Condition>
                <Condition>
                        <ConditionId>
sigcd3</ConditionId>
                        <ConditionBd> Result(sigcd1,
InBase(Location)) nearDistance Result(sicd2,
InBase(Location))
                        <Result> </Result>
                </Condition>
                <Execute> (sigcd1) and (sigcd2) and
(sigcd3)</Execute>
        <Signature>
        <ActionSpecification>

        <ActionType>LoadContentfromURL</ActionType>
                <URL>Result(sigcd1,URL)</URL>
        </ActionSpecification>
</Model>
```

In the description of model there are two sections: the section of metadata and model body. For the sake of simplicity in the example above in metadata section only two subsections are shown: the subsections of general data and activation mode. In general subsection model identifier, its type, references to ontology, model repository and fact base are shown.

In activation subsection two activation conditions are shown: model is activated during tour and in every five minutes.

Model body includes sections of signature and action. In signature subsection there are three conditions which all must hold in situation. The first one specifies that tourist should be near one of the objects from fact base representing tourist attraction. This condition used the predicate *NearDistance* which has a true value if the positon of tourist and tourist attraction are within some predefined walking distance. Second condition checks whether visiting of object was planned in a given tour and current time. With this purpose the predicate *NearTime* which takes value "True" if current time is within some predefined interval from planned time. Finally, third condition combines previous ones. In action section is specified the action of accessing web page with information about visited object.

Formally, situational knowledge within the ontology is encoded as descendants of a separate class *Situation*. The description of the situation (attribute *DefinedFor*) contains a reference to the class for which this situation is determined. It simplifies finding situations in the process of solving practical problems, when there is a need to find a situation for a particular object of certain class.

Let $\overline{S} = \{S_1, S_2, ..., S_n\}$ – to be a set of situations. We define function, which maps the set of classes in the ontology to the set of situations:

$$F_{TS} : T \to \overline{S} \ . \tag{1}$$

This function allows to divide the set of situations into subsets corresponding to ontology classes:

$$\overline{S} = \bigcup_{i=1}^{nt} S_{Ti} \ . \tag{2}$$

Sets S_{Ti} can overlap, because the object of a certain class can be in several situations simultaneously.

A promising approach to simplification of situational knowledge management is using the paradigm of granular computing [18], creating default situation definitions for large groups of objects.

Granular computing is an umbrella term to cover any theories, methodologies, techniques, and tools that make use of granules in problem solving. Basic ingredients of granular computing are granules such as subsets, classes, and clusters of a universe [19, 20].

The definition of situation S_j contains an attribute *SDefinition* – At_{def}, which stores Boolean expression CS_j (signature), which takes a value “true” for objects of given class that reside in certain situation. That is, object $t_{ij} \in T_i$ reside in S_{Ti} if $Cs_{STi}(t_{ij}) = True$.

In the simplest case, when the situation is defined by the state of an object of a given class T_i, the signature CS_j contains only attributes of this class:

$$CS_j = BooleanExpression(a_1, a_2, ..., a_n) \ , \tag{3}$$

where: $\forall i : a_i \in At_i \in T_i$, $BooleanExpression(a_1, a_2, ..., a_n)$ – is Boolean expression with arguments $(a_1, a_2, ..., a_n)$.

In the basis of logical inference mechanisms in ontological modeling is the description logic. It uses a set theory to form axioms and to construct new classes of ontology based on existing classes.

Ontology modelling presents a good base to definition of *situationally-oriented concepts*. These concepts and the corresponding classes of ontology are determined by situation definitions. Therefore, they are subclasses of ontology classes for which such situation applies. Examples of situationally-oriented concepts are the concepts of “meeting attendee” or “traffic rules violator”. The definition of ontology concepts through the situations allows not only to justify their creation, but also to find all necessary attributes and relations used by these concepts.

A set of all objects (population) of situational class T_s, specified for class T_i by situation S_{Ti} is a subset of objects of class T_i for which axiom CS_{STi} in situation S_{Ti} is a class constructor.

$$\forall t_s : Cs_{STs}(t_s) = True, T_s \subseteq T_i \tag{4}$$

In addition to the attributes and relations inherited from the higher levels of hierarchy, such situationally-oriented ontology classes have their own attributes and relationship identified in the situation model. Using situational concepts allows us to enrich the ontological model of subject area and use logical inference to obtain and use new knowledge about the situation.

On the other hand, using the mechanisms of logical inference based on description logic allows us to build complex situational concepts with basic operations of set theory and therefore consider and find objects which, for example, simultaneously reside in several different situations.

In practice, the situation is often determined by the relations of objects of several different types. Let, for situation S_i situational model contain a set of ontology classes $\left\{T_1, T_2, ..., T_k\right\}$ which are combined by relation $\left\{R\left(T_i, T_j\right)\right\}$, де $i = 1 \div k-1, j = i+1 \div k$.

Each class T_i has a set of attributes At_{Ti}, and every relation $R\left(T_i, T_j\right)$ is also characterized by a set of attributes $At_{Ri,j}$. Then signature, which determines the situation S_i contains attributes of classes and relations of situational models:

$$CS_{Si} = BooleanExpression(a_1, a_2, ..., a_n) \ , \tag{5}$$

where $\forall i : a_i \in At_{Ti} \bigcup At_{Rij}$.

In some cases, it is impossible to exactly pinpoint the characteristics of the situation, or for certain objects that belong to the situation, there are exceptions.

Let the situation S^i be defined for a particular class of ontology T^k using Boolean signature Cs^i. However, some objects that fit under this definition is not related to the situation (being exceptions) or experts are doubtful of their belonging to this situation.

In this case, the upper approximation of situation population is defined as a subset of the objects class T^k for which Cs^i holds.

$$\overline{Po}(S^i) = \{t^k \mid t^k \in T^k, Cs^i(t^k) = True\} \tag{6}$$

To determine the lower approximations, it is necessary to find a subset of objects that do not in full correspond to situation. Such border subset $Po_B(S^i)$ is defined by experts by enumeration of objects that are included in it. Then lower approximation of population situations S^i is defined by the formula:

$$\underline{Po}(S^i) = \overline{Po}(S^i) - Po^B(S^i) \tag{7}$$

In the particular case, objects that do not meet the situation can be defined using the attributes of class by condition $Cs^B(S^i)$. For example, when the situation is defined on a level of a certain general class of objects, but not all of its subclasses, then border subset can be defined as:

$$Po^B(S^i) = \{t_k \mid t_k \in T_k, Cs_i^B(t_k) = True\} \qquad (8)$$

and the lower approximation is given by (7).

Thus, the use of granular computing and rough sets theory allows to simplify situational knowledge management and formulate new knowledge in the form of situationally-oriented concepts.

CONCLUSIONS

Modeling and building intellectual systems able to make decisions autonomously and identify real world situations is a popular research and development area. This relates to growing interest to creation of intellectual multi-agent systems in all areas of human endeavor. Such systems require the implementation of situational awareness capable of using several different methods of identifying situations in the same time based on domain knowledge. This is the reason why we used ontological modeling as a basis for storing and organizing knowledge about situations. The mechanisms of reasoning provided by ontological modeling create an additional advantage and flexibility for situational awareness achievement.

In process of development of situation aware systems using ontological modeling it is important to reduce complexity of situational knowledge management. In order to resolve this task, the approach based on granular computing and rough sets theory is used.

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