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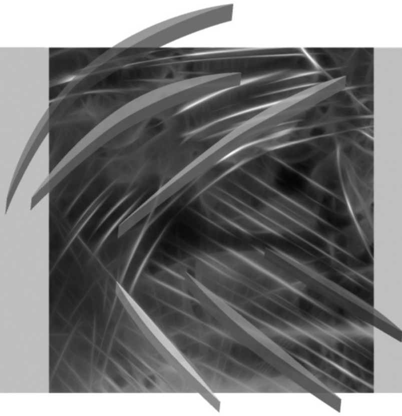

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Intelligent Technologies and Applications

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MULTIATTRIBUTE FUNCTIONAL DEPENDENCIES IN DECISION SUPPORT SYSTEMS

Abstract: This paper presents the definition of the structure of knowledge representation in decision support systems. This structure is also a decision structure. Multiattribute functional dependencies between attributes are taken into consideration in this structure. Such dependencies often appear in a decision-making process. In the second part of the paper a definition of dependent and independent attributes (elements) was elaborated. It can be used in knowledge conflict resolving, which often appears in decision support systems.

Keywords: structure of knowledge, functional dependencies, decision support systems, knowledge conflicts.

1. Introduction

Decision support systems play an important role in functioning of different types of organizations and of the whole market, because decision-making is nowadays a basic element of conversant management [Drucker 1994]. These systems allow getting actual information quickly, processing this information and present allowable decisions (that is decisions which satisfy conditions set by a decision-maker) or optimal decisions (that is decisions which are the best in the light of criterions set by a decision-maker). The final decision, however, is made by decision-makers responsible for the effects of their decisions [Sobieska-Karpińska, Hernes 2009b]. Decision support systems substantially shorten the time spent on making decisions since they can find suitable value information [Kubiak 2009; Sobieska-Karpińska, Hernes 2009b], select and process information for decision-makers, and they make also possible drawing conclusions on the basis of stored information, reacting on the basis of these conclusions and suggest different solutions to decision-makers, thus they support management of knowledge too [Zhang 2009]. If we want to use this knowledge, then it must be represented by concrete structure which is a decision structure at the same

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time. Such structures were defined, e.g., in articles [Sobieska-Karpińska, Hernes 2006, 2010], however, they do not make allowance for functional dependencies between the elements of the structure of knowledge, in this case decisions (elements of decision – features of objects the use of which is represented by this decision). In the article [Sobieska-Karpińska, Hernes 2011] a structure was defined which allows for a functional dependencies, however, it is limited to simple, monoattribute dependencies. In the management practice, however, appear multiattribute (multielement) functional dependencies between attributes of the knowledge structure (elements of decision) too, for example a decision concerns the volume of production and product price, which depend on the number of orders and manufacture costs.

In different works, e.g. [De Long, Seeman 2000; Dyk, Lenar 2006; Sobieska-Karpińska, Hernes 2009b], the problem of knowledge conflicts in decision support systems is considered. These conflicts appear when nodes of systems, e.g. experts, agents [Korczak, Lipiński 2008], prompt user different solutions (decisions). Such a situation can appear for example, when each of the system nodes works on the basis of different method of decision support. These conflicts should be resolved so that a user can get one decision from the system. For this purpose consensus methods can be used (for example [Condorced 1974; Hernes, Nguyen 2004, 2007; Sobieska--Karpińska, Hernes 2011]), however, a decision structure does not take into consideration multiattribute (multielement) functional dependencies between the attributes of the knowledge structure (elements of decision). In order to elaborate such methods, it is necessary to define a structure which consists of such dependencies.

Thus, in this article a knowledge structure allowing for multiattribute functional dependencies between its elements was defined and a definition of dependent and independent elements was presented. This definition can be used to elaborate algorithms of determining consensus.

2. Structure of knowledge representation

The structure of knowledge representation in a decision support system is a set of decision elements which describe real world, e.g. suppliers, customers, products, etc. These elements (attributes) are ordered in sequence to proceeding during decision realisation. On the basis of the structure elaborated in the article [Sobieska-Karpińska, Hernes 2010], a formal definition of the structure of knowledge representation is presented. This definition expands a structure (decision) about multiattribute functional dependencies between elements of this structure.

Definition 1.

The structure of knowledge representation (decision) P of finite set of decision elements $E=\{e_1,e_2,\dots,e_N\}$ is called as sequence:

$$P=\left\langle \{EW^{+}\},\{EW^{\pm}\},\{EW^{-}\},Z,SP,DT,F\right\rangle,$$

where:

1) $EW^{+}=\left\langle e_o,pe_o\right\rangle,\left\langle e_q,pe_q\right\rangle,\dots,\left\langle e_p,pe_p\right\rangle;$

couple $\left\langle e_x,pe_x\right\rangle$, where: $e_x\in E$ and $pe_x\in[0,1]$, denotes a decision element and its participation in the set EW^{+};
decision element $e_x\in EW^{+}$ will be denoted by e_x^{+};
set EW^{+} is called positive set, in other words it is a set of decision elements, about which the system node knows that these elements are in the environment.

2) $EW^{\pm}=\left\langle e_r,pe_r\right\rangle,\left\langle e_s,pe_s\right\rangle,\dots,\left\langle e_t,pe_t\right\rangle;$

couple $\left\langle e_x,pe_x\right\rangle$, where: $e_x\in E$ and $pe_x\in[0,1]$, denotes a decision element and its participation in the set $EW^{\pm}$;
decision elements $e_x\in EW^{\pm}$ will be denoted by $e_x^{\pm}$;
set $EW^{\pm}$ is called neutral set, in other words it is a set of decision elements that the system node does not know that these elements are in the environment.

3) $EW^{-}=\left\langle e_u,pe_u\right\rangle,\left\langle e_v,pe_v\right\rangle,\dots,\left\langle e_w,pe_w\right\rangle;$

couple $\left\langle e_x,pe_x\right\rangle$, where: $e_x\in E$ and $pe_x\in[0,1]$, denotes a decision element and its participation in the set EW^{-};
elementary objects $e_x\in EW^{-}$ will be denoted by e_x^{-};
set EW^{-} is called a negative set, in other words it is a set of decision elements about which the system node knows that these elements are not in the environment.

4) $Z\in[0,1]$ – rate of return in percent.

5) $SP\in[0,1]$ – degree of secure of rate Z.

6) DT – date of knowledge.

7) F – set of functional dependencies between elements of decision:

$$F=\{X_1\to Y_1,X_2\to Y_2,\dots,X_n\to Y_n\},\text{ where: } X_k,Y_k\subseteq E.$$

This structure meets the following conditions:

1. $EW^{+}\cap EW^{\pm}\cap EW^{-}=\varnothing$.

Elements of positive, neutral and negative sets must be separable, because any participant of the conflict must clearly determine to which set the elements of a given decision belong. It is assumptive, because knowledge about the environment must be concrete.

2. $EW^{+} \neq \varnothing \Rightarrow \sum_{i=0}^{p} pe_i^{+} \geq 1.$

Sum of participation of all the decision elements in positive set must be oversize or equal to 1.

3. $EW^{\pm} \neq \varnothing \Rightarrow \sum_{i=0}^{t} pe_i^{\pm} \geq 1.$

Sum of participation of all the decision elements in neutral set must be oversize or equal to 1.

4. $EW^{-} \neq \varnothing \Rightarrow \sum_{i=0}^{w} pe_i^{-} \geq 1.$

Sum of participation of all the decision elements in negative set must be oversize or equal to 1.

Presented knowledge representation (decision) definition allows formulating system nodes conclusions in a uniform structure. It can happen that a system node does not "know" whether a given element of decision can be used or not (for example system node has not got any information about given value paper). So, the set $EW^{\pm}$ is necessary. Presented structure is complex and multivalue, there are different data types and multiattribute functional dependencies in this structure. The example of the structure is as follows:

Let set $E = \{a_1, a_2, a_3, a_4, a_5\}$.

Examples of the structure of knowledge:

$$D1 = \langle \{\langle a_1, 0.2\rangle, \langle a_3, 0.5\rangle, \langle a_5, 0.3\rangle\}, \{\langle a_2, 1\rangle\}, \{\langle a_4, 1\rangle\}, 0.3,\ 0.7,\ 22-09-2005, a_a a_2 \rightarrow a_3 a_4 \rangle$$

$$D2 = \langle \{\langle a_2, 0.2\rangle, \langle a_3, 0.8\rangle\}, \{\varnothing\}, \{\langle a_1, 1\rangle, \langle a_4, 1\rangle, \langle a_5, 1\rangle\}, 0.6,\ 0.3,\ 14-05-2005, a_5 a_1 \rightarrow a_3 \rangle$$

In the first example sets $EW^{+}, EW^{\pm}, EW^{-} \neq \varnothing$. In the second example set $EW^{\pm} = \varnothing$.

Defined structure can be used for example in expert or multiagents decision support systems. In these systems there often appear knowledge conflicts dependent on different versions of solutions generated by an expert or agent. The user, however, expects one version, in other words one decision. So it is necessary to determine the one solution on the basis of several solutions, which will be satisfying for the user. In other words it is necessary to find a good representation set of presented solutions. A choice methods or consensus methods can be used for this purpose for example [Sobieska-Karpińska, Hernes 2010]. In the article [Sobieska-Karpińska, Hernes 2011] it was noted that to determine a representation of set of solutions, it is enough to determine the representation of these decision elements only which are independent elements. In the next step it is necessary to add dependent elements the value of which is calculated on the basis of functional dependencies. It results from the fact that the value of each of dependent elements can be calculated on the basis of value of independent elements. In the mentioned article dependent and independent elements were defined, however, this definition can be used only in monoattribute dependencies case. In the situation of multiattribute functional dependencies, it is necessary to analyse functional dependencies in another way. In consequence, dependent and independent elements have to be defined in another way. Such definition will be elaborated in the following part of the article.

3. Functional dependencies

In the article [Sobieska-Karpińska, Hernes 2011] there was presented a definition of dependent and independent elements of knowledge structure in case of monoattribute functional dependencies between elements. This definition is as follows:

Definition 2.

Set of decision elements $E = \{e_1, e_2, \ldots, e_N\}$ and set of functional dependencies $F=\{e_{x1} \rightarrow e_{x2}, e_{x3} \rightarrow e_{x4}, \ldots, e_{xm} \rightarrow e_{xn}\}$ are given.

Set $EZ = \{e_{x2}, e_{x4}, e_{xn}\}$ is called a set of dependent elements.

Set $ENZ = E \setminus EZ$ is called a set of independent elements.

It is necessary to notice that in the situation of multiattribute functional dependencies it is not enough to take into consideration open specified dependencies, but it is necessary to analyze dependencies which belong to minimum closure set of functional dependencies, because they can generate other functional dependencies.

In literature on the subject there is procedural method of generating functional dependencies which result from open specified functional dependencies without contradiction. These dependencies belong to minimum closure set of functional dependencies of knowledge structure (decision). This method is defined by Armstrong axiom.

We adopt the following definition of minimum closure set of functional dependencies:

Definition 3.

The set of functional dependencies is given:

$$F = \{X_1 \rightarrow Y_1, X_2 \rightarrow Y_2, \ldots, X_n \rightarrow Y_n\},$$

where n is natural number bigger than zero, $X_i, Y_i \subseteq E$ for each $i = 1, 2, \ldots, n$.

Minimum closure F^+ set of functional dependencies F is called a minimal set F^+ of functional dependencies determined by set of elements E appointed by next recurrent axiom [Kimura et al. 2009]:

1. If $X,Y \subseteq E$ and $Y \subseteq X$, then $X \rightarrow Y \in F^{+}$.
2. If $X \rightarrow Y \in F$, then $X \rightarrow Y \in F^{+}$.
3. If $X \rightarrow Y \in F^{+}$ and $Z \subseteq A$, then $X \cup Z \rightarrow Y \cup Z \in F^{+}$.
4. If $X \rightarrow Y \in F^{+}$ and $Z \subseteq Y$, then $X \rightarrow Z \in F^{+}$.
5. If $X \rightarrow Y \in F^{+}$ and $Y \rightarrow Z \in F^{+}$, then $X \rightarrow Z \in F^{+}$.

The first axiom states that each subset of the set X functionally depends on the set X. Such dependencies are called trivial dependencies.

The second axiom states that all functional dependencies, which are open specified at the set F, belong to minimum closure F^{+}.

The third axiom states that functional dependence of sets X and Y is true, when these sets will be expanded with a set of elements Z.

The fourth axiom states that any subset of elements of set Y also depends on the set X.

The fifth axiom states that the dependence of a set of elements is transitive.

During the analysis of these axioms, it can be noticed that not all the elements of a set of open specified functional dependencies are dependent elements. A situation can occur in which elements of a set of domain are included in a set of values of functional dependencies. These elements are not dependent elements because they depend on themselves (trivial dependence). This situation is illustrated by the following example.

Let set $E = \{a_1, a_2, a_3, a_4, a_5\}$ and a knowledge structure consist of the following functional dependencies: $F = \{a_5 a_1 \rightarrow a_3 a_1 a_5, a_3 \rightarrow a_2\}$.

Elements a_2, a_3 can be called dependent elements because they depend on the other elements. However, there are also elements a_1, a_5 in a set of values of first functional dependence. These elements are independent elements, because they do not depend on the other attributes. By the use of the fourth Armstrong axiom, it is possible to formulate definition dependent attributes in multiattribute functional dependencies:

Definition 4.

A set of knowledge structure (decision) elements $E = \{e_1, e_2, \ldots, e_N\}$ and a set of functional dependencies $F = \{X_1 \rightarrow Y_1, X_2 \rightarrow Y_2, \ldots, X_n \rightarrow Y_n\}$ are given.

The set of dependent elements we called set $EZ = \{e_{x1}, e_{x2}, \ldots, e_{xn}\}$, where for each functional dependence $X_k \rightarrow e_{xk}$ (where $e_{xk} \subseteq Y_k$), which is generated as a result of recurrent use of the fourth Armstrong axiom, the following condition is met:

$$e_{xk} \not\subset X_k .$$

Set $ENZ = E \setminus EZ$ is called a set of independent elements.

Using this definition in practice can be illustrated by the following example. Let set $E = \{a_1, a_2, a_3, a_4, a_5\}$ and a knowledge structure consist of the following functional dependencies: $F = \{a_5 a_1 \rightarrow a_3 a_1 a_5, a_3 \rightarrow a_2\}$. The result of recurrent use

of the fourth Armstrong axiom in case of the first functional dependence are the following derivative dependencies:
$a_5a_1 \rightarrow a_3a_1a_5$ $a_5a_1 \rightarrow a_3a_1$, $a_5a_1 \rightarrow a_3a_5$, $a_5a_1 \rightarrow a_5a_1$, $a_5a_1 \rightarrow a_3$, $a_5a_1 \rightarrow a_1$, $a_5a_1 \rightarrow a_5$ $a_5a_1 \rightarrow \varnothing$.

The element which meets condition $e_{xk} \not\subset X_k$ is element a_3.

Using the fourth axiom in case of the second functional dependence generates the following dependencies:
$a_3 \rightarrow a_2$, $a_3 \rightarrow \varnothing$.

The element which meets condition $e_{xk} \not\subset X_k$ is element a_2.

Thus, the set of dependent elements $EZ = \{a_2, a_3\}$, and the set of independent elements $ENZ = \{a_1, a_4, a_5\}$.

It can be stated that Definition 4 presented here can be used in situations, when it is necessary to determine one version of solution (decision) and present this version to user, in other words, in situations, when it is necessary to resolve a knowledge conflict in decision support system. It is necessary to take into consideration that such conflict has to be resolved because decision-maker has to get the best decision from the system and make a good decision, which is very important for more effective organization functioning.

4. Conclusions

The structure of knowledge representation elaborated in this article allows to present decision in formal form including multiattribute functional dependencies between attributes (elements of decision). It allows comparing the knowledge of particular system nodes (e.g. agents) and if they have different knowledge, then one decision is made and presented to a user. This decision can be coordinated by the use of consensus methods, for example, where each solution is taken into consideration, a decision is not one of results suggested by the system nodes but it is very near these results. However, algorithms of determined consensus in the situation of multiattribute functional dependencies between attributes of knowledge structure (decision elements) were not elaborated yet. The structure defined in this article allows elaborating such algorithms and expands possibility of resolving knowledge conflict in decision support systems. Thus a decision-maker gets from the system fast and actual decision, which makes the decision process more effective. Thus an organization is more elastic and competitive.

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WIELOATRYBUTOWE ZALEŻNOŚCI FUNKCYJNE W SYSTEMACH WSPOMAGANIA DECYZJI

Streszczenie: W artykule przedstawiono definicję struktury reprezentacji wiedzy w systemach wspomagania decyzji, będącej jednocześnie strukturą reprezentacji decyzji. Uwzględniono w niej wieloatrybutowe zależności pomiędzy atrybutami struktury, które często występują w praktyce podejmowania decyzji. Opracowana została również definicja atrybutów (elementów) zależnych i niezależnych, która może być wykorzystana w celu rozwiązywania konfliktów wiedzy występujących często w systemach wspomagania decyzji.

Słowa kluczowe: struktura wiedzy, zależności funkcyjne, systemy wspomagania decyzji, konflikty wiedzy.