Modeling of Decision Making Ontology

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Abstract. Making large data decisions requires the development of effective methods for processing and analyzing information. One possible way in this direction is creation of ontologies. The purpose of the work is to construct a decision making meta-ontology and to develop on its basis basic objective ontologies, which are used in the future for the design of systems for supporting decision making in the social sphere. To assess the quality of the developed ontologies, a multi-criteria approach is proposed, in which criteria are formed on the basis of the theory of fuzzy sets and the theory of graphs. The model of meta-ontology decision making and two basic ontologies of decision making have been constructed: the court decision making and management of the pharmacies network development.

Keywords: Decision Making, Decision Support System, Ontology, Multi-Criteria Quality Assessment, Fuzzy Set, Topological Criteria, Court Decision, Pharmacy

1 Introduction

Decision making is the main point in human activity, and the decision making patterns remain the same for all subject areas. Difficulties in making decisions arise because of the uncertainty and/or insufficient knowledge about the problem situation and the resources available, the weak structure of the task, and the multi-criteria choice. The formalization of the applied problem, the choice of the decision procedure, the organization of the work of the decision maker and experts are carried out by the consultant-analyst. Introduction to the decision making process of decision support systems (DSS) reduces the level of subjectivity by solving the problems of insufficiency and uncertainty of the initial information.

This paper proposes a method for modeling ontology of decision making, one of the stages of which is the construction of a multi-criteria assessment of the ontology quality. The discussion is conducted on two examples: models of the ontology of a court decision and the ontology of managing the development of a pharmacies network. In these examples, decision areas are distinguished by the initial degree of formalization and the level of possible automation.

2 Related Works

The paper [1] proposed a methodology for developing an information system for decision making using the Information Data Bank of high-tech technologies, which is based on an object-cognitive analysis of the subject area, integrating the methods of object-oriented analysis, ontological analysis and semantic knowledge representation network with a goal of describing knowledge used in the management of complex dynamic objects in problem situations.

The main provisions of the automated development of ontology based on the analysis of texts in natural languages are set out in the work of the authors V.V. Litvin, A.B. Demchuk, M.Ya. Gopyak [2], where the criteria optimization of the constructed ontology are formed in accordance with the quality standard ISO 9126. This theme is further developed in [3], which is devoted to the adaptation of the characteristics of the ISO / IEC25012 standard for assessing the quality of knowledge systems ontologies. These characteristics include: functionality in use, reliability, clarity, convenience, portability, recoverability, confidentiality. By functionality is meant the ability of a computer system to satisfy functional user requirements and tasks.

The fuzzy-set approach to assessing the quality of ontology, described in [4, 5], offers an integral criterion for the quality of an ontology fragment, which consists of three components: fuzzy functionality, fuzzy injectivity, and fuzzy everywhere certainty. It is applied to individual fragments of the ontology according to the following formulas.

Defines the prototype of a set of concepts C in compliance $\tilde{\Gamma}_{TC}$:

$$\tilde{\Gamma}^{-1}(\mathrm{C}) = \{< \mu_{\tilde{\Gamma}^{-1}(\mathrm{C})}(t), t > | t \in T\}, \quad (1)$$

where $\mu_{\tilde{\Gamma}^{-1}(\mathrm{C})}(t) = \vee_{c \in C}(\mu_{\tilde{F}_{TC}} < t, c >)$, $\mu_{\tilde{F}_{TC}}$– membership function value.

The degree of fuzzy functionality implies that each ontology concept will have textual inputs that have a small number of common terms, and is determined by the formula:

$$\beta(\tilde{\Gamma}_{TC})_{fon} = 1 - \alpha(\tilde{\Gamma}_{TC})_{fon} \quad (2)$$

where $\alpha(\tilde{\Gamma}_{TC})_{fon} = \frac{1}{C^2_{|C|}} \sum_{c_i, c_j \in C} \left(\frac{1}{|T|} \sum_{t \in T} \left(\mu_{\tilde{\Gamma}^{-1}(c_i)}(t) \& \mu_{\tilde{\Gamma}^{-1}(c_j)}(t) \right) \right)$; $|\mathrm{C}|$ - the number of concepts in the group of homogeneous ontology concepts; $|\mathrm{T}|$ the number of terms associated with concepts; $\mathrm{C}^2_{|\mathrm{C}|}$- the number of combinations of C in two, corresponding to the number of all possible pairs of concepts.

The greater the value of fuzzy functionality, the higher the quality of the ontology fragment. Estimates of the degree of injectivity and non-injectivity are found according to the following formulas:

$$\beta(\tilde{\Gamma}_{TC})_{inj} = 1 - \alpha(\tilde{\Gamma}_{TC})_{inj} \tag{3}$$

where $\alpha(\tilde{\Gamma}_{TC})_{inj} = \frac{1}{C^2_{|T|}} \sum_{t_i,t_j \in T} \left(\frac{1}{|C|} \sum_{c \in C} \left(\mu_{\tilde{\Gamma}_{(t_i)}}(c) \& \mu_{\tilde{\Gamma}_{(t_j)}}(c) \right) \right)$.

The quality estimates (1-3) presented in [5] are applied to the analysis of ontology fragments; therefore, to take into account the structure of the entire ontology, we suggest using topological characteristics of the graphs. In the work of J. Tevet [6], the measurement of a structure is considered in the attributes of the theory of information, which is based on the internal variety of the structure. The measure of diversity in absolute terms is the amount of information, and the variety of degrees of vertices of the graph (elements of the system) determines the degree of topological entropy. Topological entropy HE is calculated through the degree of elements deg ϑ_i:

$$HE = -\sum_{i=1}^{|V|} (deg\vartheta_i / 2|E|) \times \log(deg\vartheta_i / 2|E|) \tag{4}$$

where deg ϑ_i - valence of structural element ϑ_i and $2|E| = \sum_{i=1}^{|V|} deg\vartheta_i$.

For the structure analysis of a complex system, it is advisable to take into account such graph characteristics: a hierarchy of the structure; the diameter of the graph; the bandwidth of the structure.

Vitor Basto Fernandes [7] explores the problem of multi-criteria optimization of ontology quality on such characteristics: usability; functional basis; structural metrics; semantic.

Despite a fairly representative presentation of ontology modeling and quality assessment of their construction in the scientific literature, there are still unresolved issues of modeling decision making meta-ontology, problems of automating decision making in the social sphere, multi-criteria assessment of the quality of decision making ontologies. This paper is devoted to the problems of using ontologies in designing decision support systems in areas related to human activity (i.e., in the social sphere), and to determining the multi-criteria assessment of the quality of such ontologies based on non-multiple and topological approaches. As you can see, the intersection of a set of characteristics proposed by different researchers [2, 3, 5, 7] is traced, according to two estimates - functionality and reliability (injectivity), which are also the main characteristics of the ISO / IEC 25012 standard. Therefore, next, these two criteria include in the construction of multi-criteria evaluation, complementing various options for topological (structural) criteria.

3 New approach for modeling ontology decision making

In the theory of artificial intelligence, “ontology” is understood as the formalization of a certain field of knowledge by a conceptual scheme. We will consider decision making as a process taking place according to the scheme shown in Fig. 1, where the sign "→" shows the corresponding relationship between superclasses (SC). Define the ontology of decision making as

$$O = \left\langle \left\{ O^{form} \right\}, \left\{ O^{alternative} \right\}, O^{choice} \right\rangle \tag{5}$$

where $\left\{ O^{form} \right\}$ - a set of subject ontologies of task formalization; $\left\{ O^{altern} \right\}$ - subject ontologies of producing a variety of alternatives (possible solutions); O^{choice} - ontology of decision making from a given set of alternatives.

SC Situation	→ Formalization	SC Formal Task	→ Production	SC Set of alternatives	→ Analysis	SC Solver	→ Selection	SC Solution
		← Adjustment						

Fig. 1. Decision making scheme.

Filling in subject ontologies O^{form} and O^{altern} requires working with a specific subject area, researching specific tasks. Each representative O^{form} of the set $\left\{ O^{form} \right\}$ of ontologies of formalization of the tasks of the subject areas includes the superclasses "Situation" and "Formal Task", which are in the relation of Formalization. Each representative O^{altern} of a multitude $\left\{ O^{altern} \right\}$ of ontologies for producing a set of alternatives to subject areas includes the superclasses "Formal Task" and "Set of Alternatives" that are in the relation "Production". The ontology O^{choice} of decision making from a given set of alternatives includes the superclasses “Set of alternatives”, “Solver” and “Decision made”, relations “Analysis”, “Decision choice”. To provide feedback in decision making, lets define an additional relation $\mathrm{Adjustment} : \mathrm{Solver} \rightarrow \mathrm{Formal\,Task}$. The superclass "Situation" includes many classes containing information from a specific subject area and describes the situation in which a decision must be made. The “Formal Problem” superclass consists of a set of classes that carrying information on the construction of formalizations, mathematical models in a particular subject area. At this stage, the decision making task is presented as a tuple $\langle X, opt\_rule \rangle$ where X is a set of alternatives, opt_rule is the criterion of the quality of the alternative. The superclass "A set of alternatives" contains many classes, which include methods for generating multiple alternatives X in a particular subject area. The “Solver” superclass includes a set of classes containing exact and heuristic methods for constructing decision rules $solv\_rule$ on a set of alternatives, as well as the class “Decision making subject” with the subclasses “Decision maker” and “Automatic”. The “Decision Making” superclass consists of a set of classes that contain information on the decision made in a particular subject area.

To describe ontologies and work with them, the freely distributed editor Protégé 5.5.0 was used [8]. Fig. 2 shows the decision ontology as an ontograph using the GraphViz graphical module of the Protégé editor.

Vector objective function (VOF) includes criteria of functionality and injectivity, defined on the basis of fuzzy sets, as well as topological criteria TG, which characterize the structure and information capacity of the ontograph:

$$Q(O') = (F, I, \{TG\}) \rightarrow \max \tag{6}$$

where F - the functionality of the ontology fragment, which is calculated by the formula (2); I - the injectivity of the ontology fragment, calculated by the formula (3); {TG} - topological criteria, from which in this case, those whose values are maximized are selected. For example, in the examples discussed below, bandwidth is used.

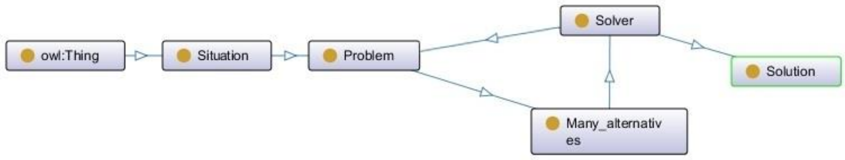

Fig. 2. Ontology of decision making in the form of ontograph.

The calculation of the ontology fragments estimates is performed on the fuzzy-weighted parts of the ontograph, whose weights are determined by an expert method. VOF (6) establishes a relation of either dominance or partial order on the set of alternative ontologies $O' = \{O'_1, O'_2, ...\}$. If for all criteria F, I, TG with $i \neq j$ inequalities $F(O'_i) \geq F(O'_j)$, $I(O'_i) \geq I(O'_j)$, $TG(O'_i) \geq TG(O'_j)$ and at least one inequality is strict, then they say that the alternative O'_i dominates the alternative O'_j, i.e. $O'_i \succ O'_j$.

Thus, the general algorithm for constructing an ontology of decision making, which is followed in this work, consists of the following steps:

1. building a decision meta-ontology;
2. the construction of a basic ontology manually based on the analysis of the texts of documents;
3. multi-criteria assessment of the quality of the basic ontology;
4. automating the expansion of the base ontology by acquiring new knowledge from various sources with the help of the Protégé editor;
5. integration of ontology with other related ontologies.

4 Experiments

Next, we consider the construction of a basic ontology of decision making on the example of two subject areas.

4.1 Example 1. The ontology of a court decision.

Court decisions are made in accordance with Art. 65 of the Criminal Code of Ukraine (CC of Ukraine) [9], the court imposes penalties within the limits established in the sanction of the article of the Special Part, which provides for responsibility for the committed crime, in accordance with the provisions of the General Part, taking into account the degree of gravity of the crime, the person guilty and the circumstances , softening and aggravating punishment. When choosing a sentence the judge must assess all elements of the crime and all the circumstances of its implementation in order to determine the extent of liability of the defendant and the appointment of him a co-sentence. The degree of punishment, depending on the composition of the crime is regulated by the rules of law, which allows formally determine the limits of maximum and minimum penalty. In addition to the objective factors in this process, there is also subjectivity, the so-called judicial oversight.

Walkman, Hala [10] developed the basic ontology for the legal domain, where the formation of a court decision is indicated by a binary relation: *listened_court→court_process*. The proposed ontology of the court decision proposed by the authors of this article allows us to extend the basic ontology for the system of law from the work [10] by introducing the formalization of this binary relation. The ontology of the court decision is a structure that reflects the connection between the classes of input data (the participants in the process, the personality of the defendant, the personality of the judge, the circumstances burdening and mitigating the crime) necessary for the decision, and the measure of punishment, which is represented by many elements: a fine, restriction and imprisonment (real and conditional), public works. When imposing a punishment determine the circumstances that mitigate the punishment specified in Art. 66 of the CC of Ukraine [9]. There are eleven such circumstances. Circumstances that burden a punishment are specified in Art. 67 [9]. These circumstances are determined by 14. The mechanism for making a court decision is determined by the relations schematically shown in Fig. 3.

SC Situation	→	SC Formal Task	→	SC Set of alternatives	→	SC Solver	→ Selection	SC Solution
Criminal case	Form alizati on	Qualification of a crime under the articles of the CC of Ukraine	Production	Definition of sanctions on selected articles	Analysis	Formation of a court decision	Selection	Announcement of a verdict
		← Adjustment						

Fig. 3. The scheme of the court decision.

The court decision ontology allowed to develop a general DSS court model in form [13]:

$$(Fine,Years,RF,PW,Cond)=F(Severity,Mitigation,Personality,Burden,Lawyer) \quad (7)$$

where F is the corresponding output algorithm, PW – public work, Cond – condition, Severity- characterizes the severity of the crime; Personality - characterizes the guilty person; Mitigation - mitigating circumstances; Burden - circumstances that burden the punishment; Lawyer - the level of neutrality of a court's decision and takes value with the term -small {loyal, neutral, strict}; Fine - the size of the fine, Years - the number of years of imprisonment, RF - restriction of freedom.

PW, Cond - determines the actual or conditional entry into action.

Let's evaluate the efficiency of introducing into the ontology class "Judgment Solution", which will have three representatives – neutral (N), strict (H) and loyal (L), within the limits allowed by the rule of law. There are factors shaping the court decision: B - burdening circumstances, M - mitigating circumstances, P+ -positive properties of the defendant's personality, P- - negative qualities of the defendant. Calculate the estimates for the three situations Var_1, Var_2, Var_3. The initial data of the first situation Var_1 are presented in Table 1, which is the matrix of adjacency of the fuzzy graph of the fragment of the ontology.

Table 1. Initial data of the first situation (Example 1).

Var_1	L	N	H
P+	0,8	1	0,1
P-	0,2	1	0,9
B	0,1	1	0,9
M	0,7	1	0,1

The second situation Var_2 corresponds to the automated decision making process (Table 2).

Table 2. The second situation (Example 1).

Var_2	N
P+	1
P-	1
B	1
M	1

Situation three Var_3 describes the initial data presented in Table 3.

Table 3. The third situation (Example 1).

Var_3	L	N	H
P+	1	1	0
P-	0	1	1
B	0	1	1
M	1	1	0

This is an idealized option in which soft solutions take into account all positive and mitigating factors, and rigid ones are all negative and aggravating factors.

For the automatic ontology construction, such topological criteria TG as topological entropy (4) of work [6] and bandwidth are of interest. The results of the calculations of the VOF (6) for the three decision making situations are presented in Table 4. Comparing the results, we get a ranking $Var_3 \approx Var_1 \succ Var_2$.

Table 4. The results of the calculations(Example 1).

Indicator	Var_1	Var_2	Var_3
Functionality	0,64	0	0,67
Injectivity	0,51	0	0,56
Bandwidth	0,25	0,25	0,25
Topological entropy	2,824	2,824	2,824

4.2 Example 2. Ontology of decision making on managing the development of a pharmacy network

The choice of the most preferred pharmacy development strategy is the task of making marketing decisions and management. Unlike a court decision based on structured legal documents, this task refers to unstructured, requiring selection of criteria for evaluating the decision, as well as the construction of methods for their initialization. In this case, the source of data for building a basic ontology is mainly the texts of scientific articles and practical publications from scientific journals and the Internet. An example of such a publication is the article by an international group of researchers [11] representing a medical ontology for the care of chronically ill patients, which helps health care providers to detect abnormal circumstances such as irregular diagnoses, unobservable concomitant illnesses, missing information, unobserved associated illnesses or preventive actions. Another example is the work of Thomas Puschmann [12]. An ontological approach is used to harmonize conceptual descriptions of subject areas compiled by various specialists (medicine, pharmacy, commerce).

Ontology for managing the pharmacies network is a mechanism for describing the subject area, including the basic concepts of this area, their properties and the connections between them. Such connections are a type of interaction between the concepts of the subject domain. The ontology of decision making on managing the development of the pharmacy network is a structure that describes the relationship between input classes (the class of target management objects: Buying Capacity - CA, Internet Pharmacy - E, Assortment - As, Traffic - T) needed for decision making, and class A set of control strategies: S_1, S_2, S_3, ..., S_i, by introducing the formalization of the binary relationship: Selection: Manager→Preferred strategy. The mechanism of decision making on managing the development of the pharmacy network is determined by the relationships shown schematically in Fig. 4.

SC Situation	→	SC Formal Task	→	SC Set of alternatives	→	SC Solver	→	SC Solution
Financial Planning for the Development of a Network of Pharmacies	Formalization	Management Objects	Production	A set of management strategies: S_1, S_2, S_3, ..., S_i	Analysis	DSS, Manager	Selection	The most preferred strategy
				← Adjustment				

Fig. 4. The scheme for decision making the pharmacy network development.

The construction of ontology has allowed us to formulate a general model of DSS management by the development of a pharmacy network, which has the form:

$$S = \mathrm{f}(\mathrm{CA}, \mathrm{As}, \mathrm{E}, \mathrm{T}), \quad (8)$$

where S is the most preferred management strategy.

In addition, the elements can be included in the ontology: the quality of the pedestrian flow, the type of district, the competitive environment, the distance to the medical institutions. More detailed DSS for the situation of opening a new pharmacy is considered in article [14].

Let's evaluate the effectiveness of different decision making situations with the help of the VOF (6). The first situation Var_1 corresponds to the decision of the manager (PDM). The second situation Var_2 corresponds to the automatic choice of the decision using DSS. The first situation Var_1 corresponds to the manager's choice of the most preferred of three different strategies: S_1 - oriented to the development of an online pharmacy; S_2 - aimed at increasing the purchasing power (loyalty program) and increasing the range, S_3 - select a place with high traffic for pharmacy placement. The second situation is represented by one strategy, which includes consideration of all criteria for increasing the efficiency of pharmacies, corresponding to the classes of ontology. The results of the calculations of the estimates for the two decision making situations are presented in Table 5. From the calculations we get that the second situation of decision making is not worse than the first, $Var_1 \approx Var_2$.

Table 5. The results of the calculations (Example 2).

Indicator	Var_1 (manager)	Var_2 (DSS)
Functionality	0,958	0,783
Injectivity	0,917	0,822
Bandwidth	0,33	0,33
Topological entropy	0,985	0,985

5 Discussions and Conclusions

The proposed algorithm for constructing a decision making ontology was used to create meta-ontology and two basic decision making ontologies in the social sphere. Conceptualization of decision making (5) defined the need for the construction of objective ontologies for the formalization of problems O^{form} and the production of alternatives O^{altern} in the presence of a common for all areas of human activity ontology of choosing solutions from a given set of alternatives O^{choice}. The introduction of the "Adjustment" relationship raises the question of the possibility and level of decision making automation for various areas. In the presence of a representative of "PDM "class "Solver", the decision is subjective, since a person is involved in the decision.

The introduction of the "Automaton" representative of the class "Solver" makes the decision to be formalized. For example, the court decision making ontology belongs to a strictly structured area. The ontology of decision making on managing the development of the pharmacy network belongs to a weakly structured area. Experiments were conducted to determine the effectiveness of the introduction of automation of decision making. The criterion of effectiveness is the VOF (6), which consists of non-commensurate indicators reflecting the degree of functionality and injectivity, as well as topological criteria characterizing the throughput and topological entropy of the ontographs. The introduction of a full formalization of the sentence resulted in an assessment of the functionality of the system, demonstrating the need for a judge (PDM).

6 Future Works and Acknowledgment

The emphasis in decision making meta-ontology (5) on the ontologies of formalization of tasks O^{form} and on the production of alternatives O^{altern} emphasizes the need for integration between content-related ontologies. Decision making in the social sphere requires the formation of new knowledge from documents available in the semantic web of different nature, which is impossible without the automatic detection of latent knowledge.

The ontological knowledge bases of the consolidated linguistic resources of the syntactic processing of Ukrainian-language texts in the work [15] opens the possibilities for further automated development of ontologies of decision making, in particular, in the social sphere. The work was carried out within the research work "Mathematical modeling of socio-economic processes and systems" at the Department of System Analysis and Computational Mathematics of Zaporizhzhya National Technical University.

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