Generation of Information Impacts Scenarios in Management Decision Support Systems

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Abstract. The features of developing scenario models using cognitive maps and methods for developing of information impacts scenarios based on the analysis of the content of global computer networks are considered. This approach provides a solution to the problem of generating and ranking scenarios for impacting objects that correspond to the selected key concept analyzing the input text arrays working on a full-time basis. Improved information models and computer domain analysis tools have been developed. This makes it possible for an expert analyst to investigate these processes and generate results in a form convenient for decision-making. A method is proposed for constructing a domain model in the form of a semantic graph formed according to the monitoring of computer networks by determining the most significant concepts and the relationships between them. A method is proposed for the formation of optimal scenarios of informational impacts on target objects of a subject area based on finding many routes of influence distribution. Software and algorithmic tools for transferring data to the OWL format are developed. An example of application of the developed scenario approach is considered on the example of analysis of the movement of "Yellow vests" in France.

Keywords: Information impacts scenarios · Cognitive map · Ontology · Ant colony optimization · Management decision support system

1 Introduction

The growth and complexity of the information space requires scientists to immediately solve the problem of increasing the effectiveness of the information impact in the information-analytical component of modern computer networks. The aim of this activity is to ensure the information needs of society with the help of the most modern computer technologies, through the processing of enormous data sets and the acquisition of qualitatively new knowledge. As a result, analysts have to work with information resources that are unprecedented in their volumes, versatility, dynamism and growth rates. This forces specialists to improve methods and technologies for loading, structuring and analyzing various data.

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Development of scenarios for the evolution of a situation is an important component of information security and computer systems and networks management. These scenarios provide an opportunity to investigate how significant is the impact of each influencing factor on the functioning and security of computer systems.

Without scenario modeling, it is impossible to achieve the following: support high-performance work and protect information in modern computer systems and networks; developing strategies and tactics at each level of management; determination of the effectiveness of management methods and their further improvement; rapid assessment of the effectiveness of control actions in a variety of directions and timely response to identified threats.

However, the construction and analysis of such models by traditional methods is ineffective in conditions of continuous change in the situation. Therefore, the task of developing new methods and scenario modeling techniques of information impacts by analyzing semantic models generated based on data obtained in the process of monitoring computer networks is prospective and practically useful.

2 Analysis of Recent Research and Publications

The current state of information impact modeling technologies lags behind the rapid development of the modern information society. This growth is characterized by the emergence of new forms of digital communication, the growth of data volumes and throughput of transmission channels, the improvement of the ways of interaction and mutual influence of the subjects of the information space.

This, in turn, significantly complicates the task of assessing the potential consequences of information operations in management decision support systems.

One of the ways to solve the problem of studying the nature of the distribution of influences in the information space is scenario modeling based on cognitive maps.

The first cognitive network was introduced in 1986 when Cosco (1986) improved the LCM approach proposed by Axelrod (1976) [1]. The most significant improvement made by Cosco is the integration of the concept of fuzzy logic. Scenario models are used in decision making, addressing perceptions of financial crisis policies, as well as the withdrawal, presentation, and analysis of mental models.

Carrying out these studies requires the use of artificial intelligence, and, first of all, systems and methods of decision support. Currently, many decision support systems have been developed and are being successfully applied in practice, the theoretical foundations of incentives and practical results of their implementation are reflected, for example, based on the use of cognitive maps in the study of political elites [1], preparation of decisions based on poorly structured data [2], ontological structures [3], development of scenarios using Text Mining [4].

In traditional decision support systems, a knowledge model (cognitive model) about a subject area is created with the assistance of knowledge engineers and is usually oriented toward specific tasks. The main tools for performing scenario modeling include the following: «КоСМоС»; «Канва»; PolyAnalyst; Deductor; Fuzzy Thought Amplifier; Cope; NIPPER; Gismo; iThink, Hyper; RESEARCH; FCMmapper etc.

Modeling of complex processes and systems remains a challenge. This is because such models need to generate networks that include numerous nodes and many different types of relationships.

3 Formulation of the Problem

A cognitive map is a signed oriented graph [5]: $G = <V, E>$, where: V – the set of vertices V_i is V, $i = 1, 2, \ldots k$, which are elements of the system under study; E – the set of arcs e_{ij} is E, $i, j = 1, 2, \ldots N$, reflecting the relationship between the vertices V_i and V_j; the effect of V_i on V_j can be positive when an increase (decrease) in one factor leads to an increase (decrease) in another; negative when an increase (decrease) in one factor leads to a decrease (increase) in the second, or to be absent (0).

The edges of the graph have weights +1 or −1, are abbreviated as "+" or "−". A + sign denotes a positive relationship; a sign denotes a negative relationship. The weight of the path is equal to the product of the weights of its edges, that is, positive if the number of negative edges in it is even and negative if this number is odd. With a positive relationship, an increase in the factor-cause leads to an increase in the factor-effect, and with a negative connection, an increase in the factor-cause leads to a decrease in the factor-effect. If both positive and negative paths lead from vertex ai to vertex bj, the question of the nature of the influence of factor ai on factor bj remains uncertain.

The influence of the vertex a_i on a_j ($i, j = 1, 2, \ldots, N$, where n is the number of vertices in the graph) is called the strongest if the influence on the final vertex a_j of the initial vertex ai on the kth simple path is the largest in absolute the value among all actions on other simple paths connecting the vertices a_i and a_j.

When choosing scenario options, it is necessary to use the performance indicator for which the choice is made. Thus, the impact analysis provides:

1. The strength of the influence of one factor on another along a given path depends on the length of this path (that is, the number of edges in it).
2. The more parallel actions (in different ways) exist between concepts, the stronger the influence between them.

The task can be reduced to optimization tasks:

$$f(S_k) = \frac{\sum_{i=1}^{n-1} a_i w_{i+1}}{n} \rightarrow \max, \tag{1}$$

with restrictions: $n > 1$; $1 \geq a_i > 0$; $1 \geq w_{ij} > 0$, where:
a_i is the weight of the i-th concept;
w_{ij} – the value of the influence of concept a_i on concept a_j;
n is the length of the k-th scenario.

4 Research Methodology

The key issue in scenario modeling is a cognitive map structure construction. For the subject area in question, the following groups of concepts can be distinguished in the map structure:

- factors characterizing the method (set of methods) of the assessment;
- destabilizing factors;
- indicators (factors reflect and explain the dynamics of the development of a problem situation).

When using cognitive maps, three options for modeling are possible:

- modeling with initial conditions without additional impact on the model;
- generation of scenarios for the evolution of a situation;
- selection of the value of target factors.

The list of concepts can be quite wide, however, taking into account changes in the state of a large number of concepts is a laborious task. Therefore, at the stage of formation of the map structure, it is necessary to ensure that the importance of each concept is assessed.

The concept of part *A* affects *B* if:

- in the non-directivity of the network, degree A of greater degree B;
- in sentences A is before B;
- term A is included in term B (for example, “student” → “student of KPI”).

The value of each concept depends on the values of the connected concepts with the corresponding weights and according to its previous value (Fig. 1).

When a map is built, it can be used to simulate and verify the operation of the system. We construct a matrix (Table 1). In order to better understand the nature of the mutual influence, we represent each card in the form of a square adjacency matrix. In this matrix, the variables acting as potential transmitters (affect other variables) on the vertical axis and the same set of variables that act as receivers (are influenced by other variables).

On the horizontal axis, we form a list of all individual variables compiled during the entire process and additional variables.

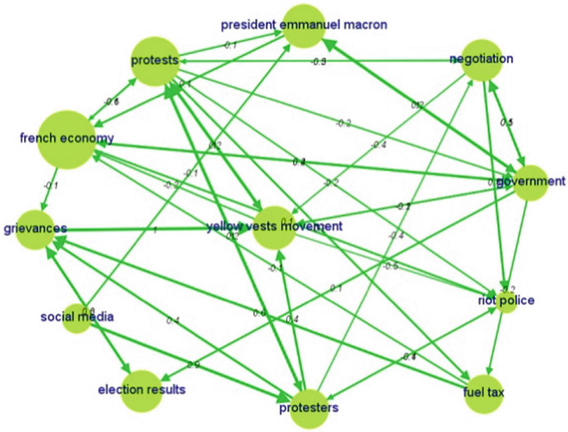

Fig. 1. The Cognitive map

Table 1. Matrix of mutual influences

Concept	Wight	president Emmanuel macron	election results	yellow vests movement	fuel tax	riot police	French economy	protests	negotiation	grievances	protesters	government	social media
president Emmanuel macron	1231	0	0	0	0	0	0,1	0	0	0	0	0,2	0
election results	1156	0	0	0	0	0	0	0	0	0,6	0	0	0
yellow vests movement	1218	0	0	0	0	-0,5	-0,2	1	0	0	0	-0,2	0,5
fuel tax	997	0	0	0	0	0	-0,1	0	0	0,6	0	0	0
riot police	208	0	0	0	0	0	0	0	0	0	-0,4	0	0
French economy	1940	0	0	0	0	0,1	0	-0,1	0	-0,1	0	0,4	0
protests	1500	-0,1	0	0,2	0,2	-0,2	-0,6	0	-0,2	0	0,2	-0,2	0,8
negotiation	1143	0	0	-0,4	0	0,3	0	-0,5	0	0	0	0,1	0
grievances	1033	0	0,2	1	0	0	0	0	0	0	0	0	0,8
protesters	1028	0	0	0,4	0	-0,1	0	1	-0,4	0,4	0	0	0,3
government	849	1	0,1	-0,1	-0,2	0	0,2	0	0,5	0	0	0	0
social media	565	-0,1	0	0	0	0	0	0	0	0	0,9	0	0

A qualitative analysis of the cognitive map (the content of its constituent blocks, target and control factors, analysis of paths and cycles, relationships between elements does not reveal the entire depth of phenomena and the process that takes place in a real system.

The next stage of the study is modeling the impulse process of the propagation of disturbances in the cognitive map, which leads to the transition of the system from one state to another. Such a process is a possible scenario for the development of the system.

Optimization methods are suitable for fuzzy cognitive maps in which concepts can take values from a range of real numbers [0, 1]. The term “fuzzy” only means that the mutual relations between factors can take not only the values 0 or 1, but also belong to the range of real numbers, which allows modeling to more accurately express the mutual influence of factors [6].

To determine the value of the scenarios, it is proposed to use the ant algorithm (application of ant colony optimization algorithm [7], analysis of such algorithms [8], meta-heuristic approach in the task of optimizing an ant colony [9]), one of the effective polynomial algorithms for finding approximate solutions to the problems of finding routes on graphs. Using a modification of the ant algorithm, which provides a reduction in the time of formation of the script. The algorithm is based on the behavior of an ant colony – marking successful routes with a large amount of pheromone.

$$\begin{cases} P_{ij,k}(t) = \frac{\left[\tau_{ij}(t)\right]^{a}\left[\eta_{ij}\right]^{\beta}}{\sum\limits_{l \in J_{ik}} \left[\tau_{il}(t)\right]^{a} \cdot \left[\eta_{il}\right]^{\beta}}, j \in J_{i,k}; \\ P_{ij,k}(t) = 0, j \notin J_{i,k}, \end{cases} \tag{2}$$

where

τ_{ij} (t) is the number of pheromones in the transition from i to j,
η_{ij} is the attractiveness of the transition to j,
T_k – passing route.

Pheromone vapor is calculated in the following way:

$$\Delta\tau_{ij,k}(t) = \begin{cases} \frac{Q}{L_k(t)}, (i,j) \in T_k(t); \\ 0, (i,j) \notin T_k(t), \end{cases} [\tag{3}$$

where

T_k – passing route,
L_k is the length of the k-th route,
J – number of unvisited nodes.

Unlike the traditional ant colony algorithm, where the edge weights are used together with the pheromone value to decide on the next vertex, the modified heuristic algorithm uses the dispersion importance of concepts – a term that is corroded to measure the advantage of some concepts over others (scripting based on analysis of terminological networks [10], creation of terminological ontologies [11], weight of concepts in integration of an ontological model with relational data [12]):

$$g_A = \frac{\sqrt{\langle \Delta A^2 \rangle - \langle \Delta A \rangle^2}}{\langle \Delta A \rangle}, \tag{4}$$

where

$<\Delta A>$ – the average value of the sequence ΔA_1, $\Delta A_2 \ldots \Delta A_K$,
$<\Delta A^2>$ – sequences ΔA_1^2, $\Delta A_2^2 \cdots \Delta A_K^2$.

The script execution program can be described in the form of an algorithm and in turn includes the execution of certain elementary operations.

The scenario structure is defined by a set of triples, which are put in accordance with the actions [10]:

$$AM_r = <\{X_i\}_{i_r=1}^{n_r}, A_r, X_{j_r}, > , \quad (5)$$

where A_r is the action; $\{X_i\}_{i_r=1}^{n_r}$ – the set of input states AM_r for actions; X_{j_r} – the initial state of AM_r, that is, the state, after the successful completion of the action; AM is the set of all actions.

A complex scenario is described as follows:

$$SM_r = <\{X_i\}_{i_r=1}^{n_r}, S_r, X_{j_r} > , \quad (6)$$

where SM_r is the script, is the set of input states of SM_r, $\{X_i\}_{i_r=1}^{n_r}$, $X_{j_r} X_{j_r}$ is the initial state of the script, that is, the state after the successful execution of the action; AM is the set of all actions.

$SM_r \in \{SM_k\} = SM$ – the set of all possible scenarios for the evolution of a situation.

We define $SV = AM \cup SM$, that is, the set of all models for the evolution of a situation and the corresponding scenarios.

As can be seen from Fig. 2, after the simulation, select 2 scenarios.

Scenario 1: No additional growth effects.
Scenario 2: Government – reduces the impact on fuel tax, instead increases the impact on negotiation and social media.

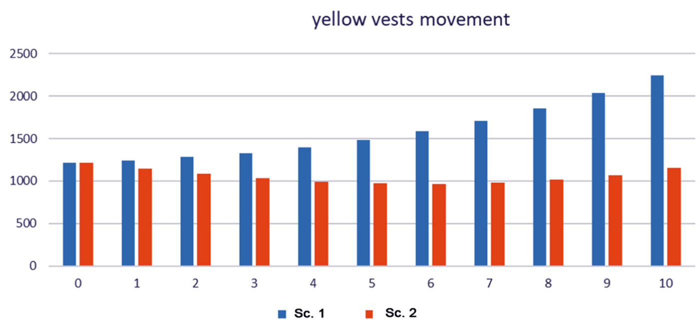

Fig. 2. Scenarios for the situation

5 Building an Ontology

Ontologies in computer science, this is the representation of knowledge about a specific subject area using a conceptual scheme (application of ontologies in influence models [13], fuzzy cognitive map based ontologies [14], ontology for applications development [15], web ontology language as standard [16], influences in ontological structures [17]). Typically, such a scheme consists of a data structure containing all relevant classes of objects, their relationships, as well as certain rules and restrictions inherent in a particular subject area (the modern direction in the field of artificial intelligence). In general terms, ontologies are defined as a knowledge base of a special kind, or as a "specification of conceptualization" of a subject area—conceptual graphs.

The general algorithm for transferring data from the semantic network to OWL is presented below (Fig. 3).

The Protégé 5 editor was chosen as the basic platform for developing ontologies in the design of knowledge-based analytical systems.

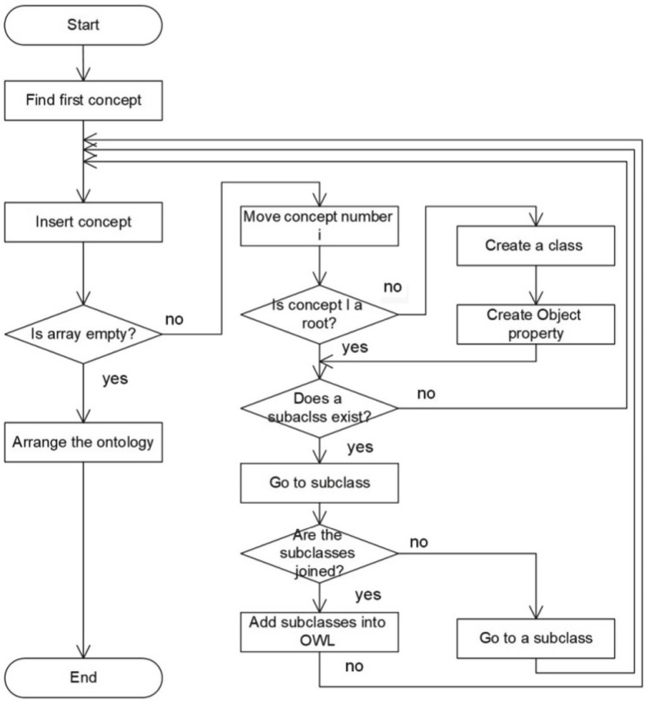

Fig. 3. An algorithm for transferring concepts to ontology

To integrate ontological and relational data models in the Protégé 5 editor, the Ontop platform is used, which is a concrete implementation of the data integration method based on the Ontology-Based Data Access approach (Protégé as ontology editor and framework for systems building [18], information retrieval with ontologies [19], ontology and semantic management [20]).

To build the ontology, we apply the following steps:

- definition of terms;
- definition of synonyms;
- definition of concepts;
- building a concept taxonomy;
- definition of relationships;
- definition of rules (Fig. 4).

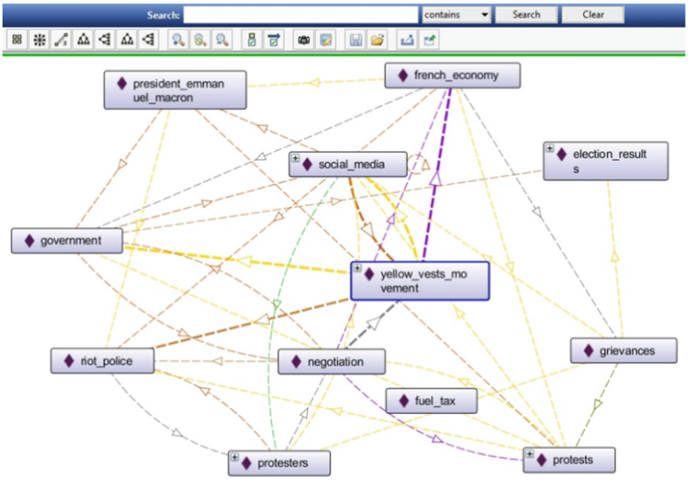

Fig. 4. Modeling of ontology with Protégé

The obtained information models and algorithms for the study of semantic networks are quite universal, due to which they can be used for control systems in various subject areas. In particular, when solving the problem of generating scenarios of analytical activity, a model was formed based on the graph shown in Fig. 5.

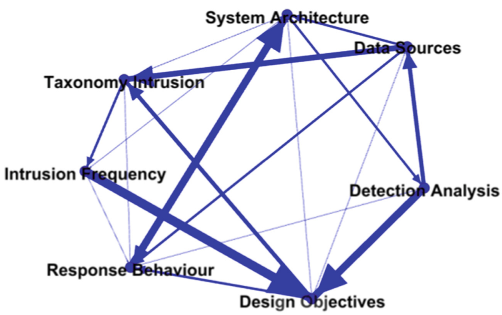

Fig. 5. Generalized graph of analytical activity factors

6 Conclusion

The article proposes an improved information technology for the automated formation of a semantic network by monitoring the information space and extracting concepts from it with the greatest frequency and taking into account their interaction. The essence of the improvement is to use an algorithm for building a network of concepts, which is based on simulating the interaction of ants – a set of dynamic mechanisms by which the program reaches a global goal as a result of the interaction of elements using only local data in combination with procedures for extracting textual information on a computer network and procedures domain research using ontologies.

The construction of cognitive maps allows you to reflect the main factors and possible reciprocal flanking between them, and is the basis for building more detailed computer scripts to develop the situation. Thus, the use of cognitive maps in the implementation of the scenario approach can significantly increase the effectiveness of analytical activities. The approach considered allows us to structure the problem, identify the most significant concepts (factors), take into account the connections between the concepts and the nature (strength) of these connections, and also choose the best combination of methods and thereby increase the validity of decisions.

The research results, in particular, information models, data analysis and visualization algorithms, are used in scenario generation tools in several security and defense decision-making support systems.

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