# REASONING BY STRUCTURAL ANALOGY TAKING INTO ACCOUNT THE CONTEXT FOR INTELLIGENT DECISION SUPPORT SYSTEMS

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*Abstract: Development of methods and tools for modeling human reasoning (common sense reasoning) by analogy in intelligent decision support systems is considered. Special attention is drawn to modeling reasoning by structural analogy taking the context into account. The possibility of estimating the obtained analogies taking into account the context is studied. This work was supported by RFBR.*

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## Introduction

Reasoning by analogy plays a central role in many cognitive processes affecting: problem solving, creativity, basic cognitive perceptions and especially learning. However, analogy is primarily of interest as a workaday process, supporting inference in novel situations by comparison with past experience. Rather than reasoning from "first principles", analogical reasoning uses a noted similarity between some problem domain and a well-known one to infer useful facts about that problem domain. The analogy can be used in various applications of artificial intelligence (AI) [1]. The great interest in this problem is caused by the necessity of modeling human reasoning (common sense reasoning) in AI systems and, in particular, in intelligent decision support systems (IDSS) [2].

At the present time, there are a great number of various models, schemes, and methods that describe mechanisms of reasoning by analogy [3-10]. The best known models of reasoning by analogy from the 1960's were *ARGUS* and *ANALOGY* [3]. The analogy used for solving various problems, e.g., for solving problems of automated theorem proving [4], for generation of hypotheses about an unknown subject domain, for generalizing the experience in the form of an abstract scheme, etc. [5-10]. Starting from Winston's work there is widely used the notion of structural analogy [7].

Unfortunately, there are not such modern systems and tools of reasoning by analogy, which are oriented to use in IDSS and, in particular, in real-time IDSS (RT IDSS).

In this paper, we consider approaches and methods of reasoning by structural analogy, which are oriented towards use in RT IDSS. These systems are usually characterized by strict constraints on the duration of the solution search [1, 2].

The use of the respective methods in IDSS broadens the possibilities of IDSS and increases the efficiency of making decisions in various problem (abnormal) situations.

Special attention in this paper will be paid to the most efficient inference method on the basis of structural analogy that takes into account the context.

## Reasoning by analogy

The English word *analogy* is derived from the Greek word *analogia* meaning equality of ratios or proportion. In everyday usage, analogy means similarity or resemblance or an argument or reasoning based on them. Analogy treats cases as "like" if they possess quantitative or qualitative attributes or relations in common which are regarded as relevant or material or important for the purpose in question and these outweigh the differences between them. Such attributes or relations in common will be referred to as "material resemblances".

*Reasoning by analogy* is the transfer of knowledge obtained from an object to a less studied one, which is similar to the latter with respect to some essential properties or attributes. Thus, reasoning by analogy can be defined as a method that allows to understand a situation when compared with another one.

Analysis of the literature has shown that one can distinguish various types of analogies [1, 13, 14]. Depending on the nature of information transferred from an object of an analogy to the other one, the analogy of properties and that of relations can be distinguished.

The analogy of properties considers two single objects or a pair of sets (classes) of homogeneous objects, and the transferred attributes are properties of these objects.

The analogy of relations considers pairs of objects, where the objects can be absolutely different and the transferred attributes are properties of these relations.

According to plausibility degrees one can distinguish three types of analogies: strict scientific analogies, nonstrict scientific analogies, and nonscientific analogies.

A strict scientific analogy is applied to scientific studies and mathematical proofs.

Unlike the strict analogy, a nonstrict scientific analogy results only in plausible (probable) reasoning. If the probability of a false statement is taken equal to 0 and that of the true statement is taken equal to 1, then the probability of inference by a nonstrict analogy lies in the interval from 0 to 1.

The probability of conclusions by a nonscientific analogy is not high and often is close to 0. A nonscientific analogy is often used deliberately to perplex the opponent. Sometimes, a nonscientific analogy is used unintentionally, by someone not knowing the rules of analogies or having no factual knowledge concerning the objects and their properties that underlie the inference. For example, nonscientific analogies underlie superstitions.

In what follows, we consider in detail the method of reasoning by structural analogy, which allows one to take into account the context. We use semantic networks (SNs) as a model of knowledge representation [1, 11].

## Knowledge representation in the form of a semantic network

The choice of an SN for knowledge representation possesses an important advantage, which distinguishes it from other models, such as natural representation of structural information and fairly simple updating in a relatively homogenous environment. The latter property is very important for RT IDSSs oriented towards open and dynamical problem domains.

A *semantic network* is a graph <$V$, $E$> with labeled vertices and arcs, where $V$ and $E$ are sets of vertices and arcs, respectively. The vertices can represent objects (concepts, events, actions, etc.) of the problem domain, and the arcs represent the relation between them.

We consider the structure of the SN in more detail using an example from power engineering - operation control of the nuclear power unit (see fig. 1-3) [1, 11, 12].

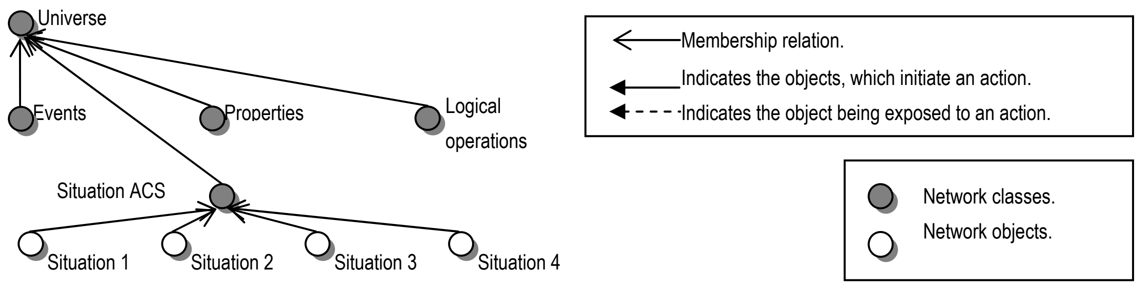


Fig. 1 Meta-level of semantic network

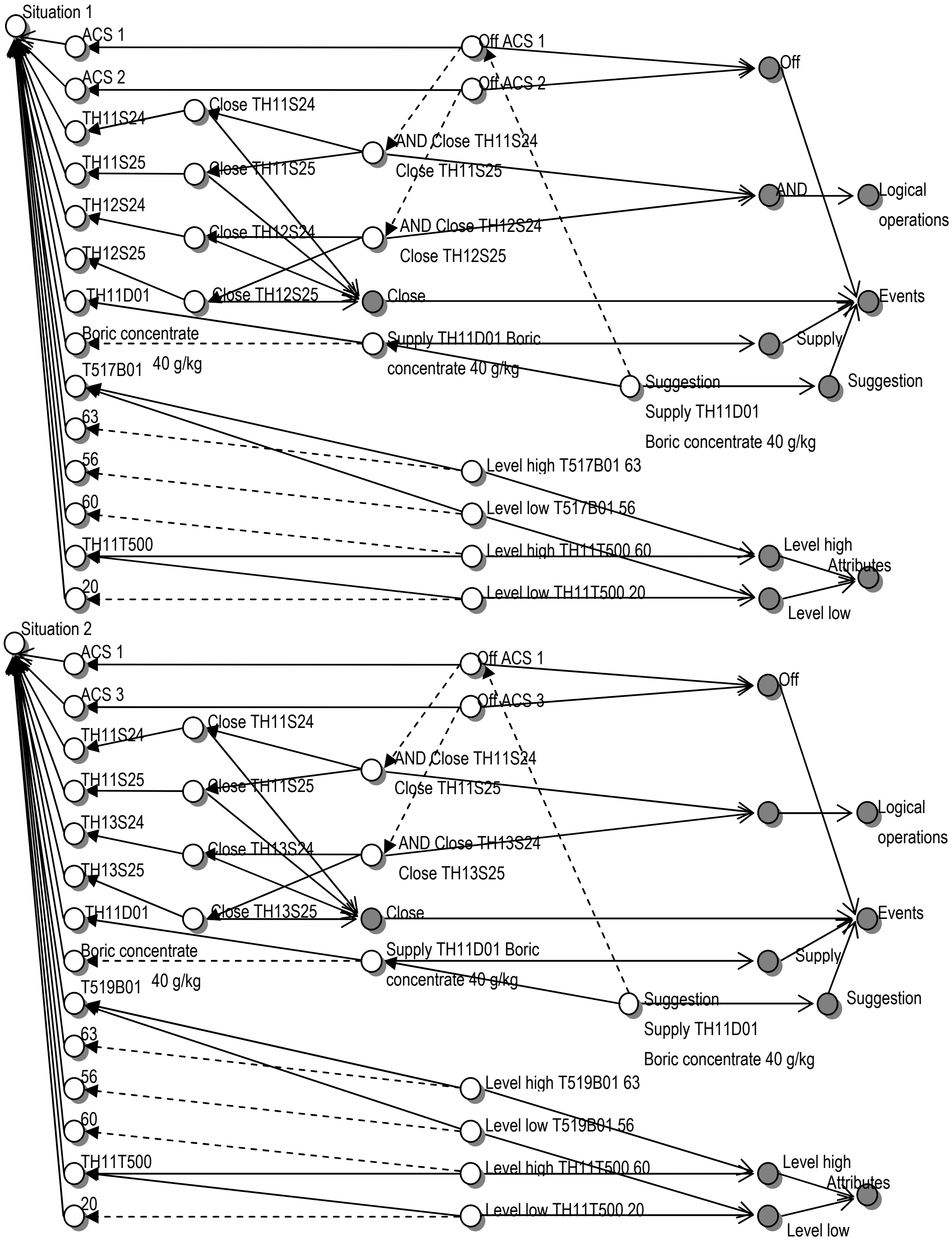


Fig. 2 Part of semantic network, which illustrates Situation 1 and 2
formed in the process of reactor zone automatic cooling system (ACS) operating

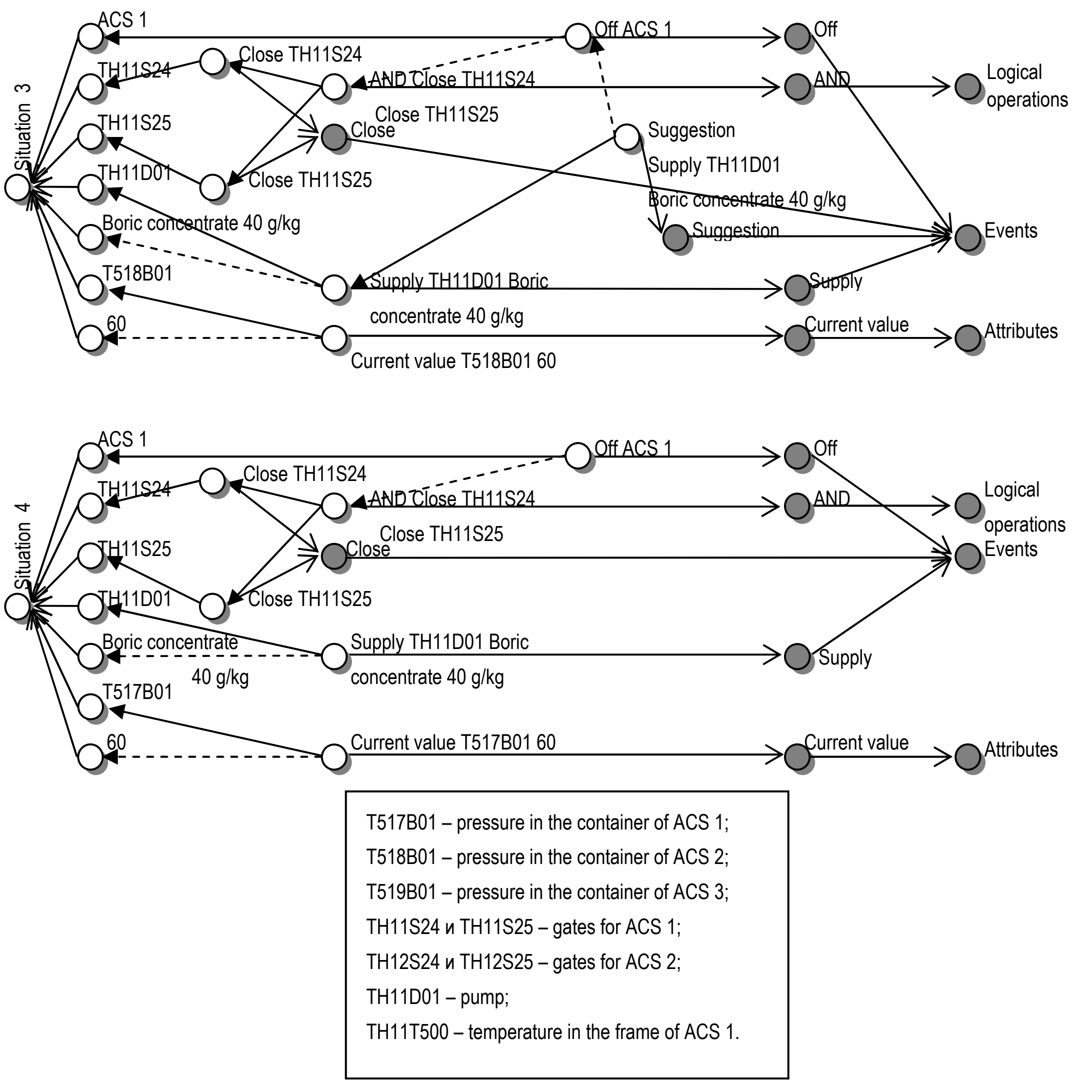


Fig. 3 Part of network, which illustrates Situation 3 and 4
formed in the process of reactor zone automatic cooling system (ACS) operating

## Reasoning by structural analogy taking into account the context

In [8] it was proposed to consider an analogy as a quadruple *A* = <*O*, *C*, *R*, *P*>, where *O* and *R* are the source object and the receiver object and *C* is the intersection object, i.e., the object that structurally is intersected with the object source and object receiver, and has a larger cardinality of the set of properties in the comparison with these objects. In other words, the analogy between the source object and receiver object is considered in the context of the intersection *C*, and *P* is the property for definition of the original context. The structure of this analogy is represented in fig. 4.

Using the described structure of the analogy, the authors of [8] propose the algorithm for the problem solution that is based on an analogy of the properties. An SN with information about the problem domain, a receiver *R*, and the property for defining the original context *P* provide input data for this algorithm.

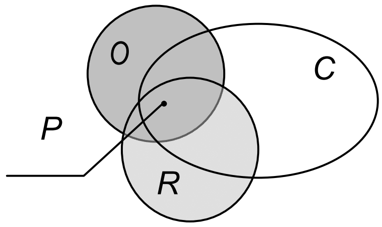


Fig. 4 Structure of analogy using the context

*The algorithm for the problem solution on the basis of an analogy taking into account the context* consists of the following stages:

*Stage 1.* Determine all objects of the SN, except for receiver *R*, that have property *P*. If there are no objects of this kind, then the search for a solution fails (without finding an analogy), otherwise, go to stage 2.

*Stage 2.* For the objects found in stage 1, determine all possible intersections of *C* with *R* taking into account *P*. If there are no intersections of *C* with *R*, the first search for a solution fails, otherwise, go to stage 3.

*Stage 3.* From the objects extracted in stage 1, determine all possible sources *O* for analogies with the receiver and the intersection taking into account *P*. In the case of success (possible analogies for *R* are defined), go to stage 4, otherwise, the search for a solution fails.

*Stage 4.* From the analogies extracted in stage 3, choose the most appropriate ones (taking into account the requirements of the decision making person (DMP)). In the case of success, go to stage 5; otherwise, the search for a solution fails.

*Stage 5.* The analogies obtained in stage 4 (which could be previously compared with each other taking into account the context) are given to the DMP, which means successful termination of the algorithm.

Having obtained analogies, the DMP may then make the final choice of the best ones. On the basis of these facts, the facts (properties) that hold for the source *O* are transferred to the receiver *R*.

Consider a modified algorithm for a problem solution that uses the structural analogy based on the modified structure of an analogy and the algorithm for the search of minimal intersections [1, 11, 14]. The modification consists in the fact that *P* is considered not as a unique property, but as a set of properties that determine the original context of the analogy.

As compared with the base variant, one of the main advantages of this modified algorithm is the possibility of implementing the search for a solution on the basis of an analogy without refining the original context, since in the result of the search for the minimal intersection, one can easily distinguish all possible contexts for the analogy. Another important advantage of the modified algorithm is the possibility of a more detailed refinement of the original context for the determination of analogies. This is especially important in the work with a complex object, when one should operate with large amount of information, since the more detailed the original context, the faster the search for a solution on the basis of analogies will be implemented and the more qualitative the solution will be obtained. Moreover, in the modified algorithm there is a possibility to construct an analogy taking into account the context between well-known objects, the source and the receiver.

Thus, in the execution of the modified algorithm the procedure of searching for minimal intersections is used. In turn, the minimal intersections determine the context for the analogy. At the second stage, depending on the fact whether an object source and a property or a set of properties are given, or there is no properties for definition of the original context from objects that are contained in the set of generators of minimal intersections, analogies are formed. In the case of successful termination of the search for a solution on the basis of analogies, new facts for the receiver object will be obtained.

## Estimation of analogies taking into account the context

Upon finding the set of possible analogies $V_A$ for receiver $R$ the problem of choosing the most preferable (best) variants arises. We introduce the preference relation on the set of analogies taking into account the context.

An analogy $A = <O, C, R, P>$ is *preferable* to the analogy $A' = <O', C', R, P>$ ($A \succ A'$) if and only if $n_{OCR} > n_{O'C'R}$, where $n_{OCR}$ and $n_{O'C'R}$ are the number of properties in the sets $P_{OCR} = P_O \cap P_C \cap P_R$ and $P_{O'C'R} = P_{O'} \cap P_{C'} \cap P_R$, where $P_O$ is the properties of $O$, $P_C$ is the properties of $C$, $P_R$ is the properties of $R$, $P_{O'}$ is the properties of $O'$, $P_{R'}$ is the properties of $R'$.

An analogy $A = <O, C, R, P>$ is *incomparable* with an analogy $A' = <O', C', R, P>$ if and only if $n_{OCR} = n_{O'C'R}$.

The set of incomparable analogies for the receiver object $R$ in the context of properties $P$ is denoted by $V_A^*$.

Consider the estimation of analogies by the following example. Let the application of the algorithm of the search for a solution on the basis of analogies result in five analogies:

$$A_1 = <O_1, C_1, R, P>, P_{O1C1R} = \{p^1{}_1, \ldots, p^1 n_1\}, n_1=3;$$
$$A_2 = <O_2, C_1, R, P>, P_{O2C1R} = \{p^2{}_1, \ldots, p^2 n_2\}, n_2=4;$$
$$A_3 = <O_3, C_1, R, P>, P_{O3C1R} = \{p^3{}_1, \ldots, p^3 n_2\}, n_3=7;$$
$$A_4 = <O_2, C_2, R, P>, P_{O2C2R} = \{p^4{}_1, \ldots, p^4 n_4\}, n_4=6;$$
$$A_5 = <O_4, C_2, R, P>, P_{O4C2R} = \{p^5{}_1, \ldots, p^5 n_5\}, n_5=7.$$

Then, we denote the following preferences:

$$A_2 \succ A_1;$$
$$A_3 \succ A_1, A_3 \succ A_2, A_3 \succ A_4;$$
$$A_4 \succ A_1, A_4 \succ A_2;$$
$$A_5 \succ A_1, A_5 \succ A_2, A_5 \succ A_4.$$

As a result, we have two incomparable analogies $A_3$ and $A_5$, which are more preferable than $A_1$, $A_2$, and $A_4$ and form the Pareto set $V_A^* = \{A_3, A_5\}$.

By means of the described procedure one can reduce the general number of analogies given by DMP (expert) for the analysis and the final choice. It is possible to compare the analogies obtained for different objects $R$ and $R'$ in the context of different properties $P$ and $P'$. In this case, the relation of the preference is defined in the following way.

An analogy $A = <O, C, R, P>$ is *preferable* to the analogy $A' = <O', C', R, P>$ ($A \succ A'$) if and only if $k_{OCR} > k_{O'C'R'}$, where $k_{OCR} = n_{OCR} / (n_{RC} + n_{OC} - n_{OCR})$, $k_{O'C'R'} = n_{O'C'R'} / (n_{R'C'} + n_{O'C'} - n_{O'C'R'})$. The value $k_{OCR}$ reflects the likeness (similarity) of receiver $R$ and source $O$ in the given context $C$ and can be expressed in percent, and $n_{OCR}$ and $n_{O'C'R'}$ are the numbers of properties in the sets $P_{OCR}$ and $P_{O'C'R'}$, while $n_{RC}$, $n_{R'C'}$, $n_{OC}$, $n_{O'C'}$ is the number of properties in sets $P_{RC}$, $P_{R'C'}$, $P_{OC}$, $P_{O'C'}$.

An analogy $A = <O, C, R, P>$ is *incomparable* with analogy $A' = <O', C', R, P>$ if and only if $k_{OCR} = k_{O'C'R'}$.

Consider the estimation of two analogies taking into account the context by the above-described example from power engineering (see fig. 1-3):

$A_1$ = <Situation 3, Situation 1, Situation 4, $P$>, $P$ = {Close TH 11S24},

$P_{\text{Situation 3, Situation 1, Situation 4}}$ = {Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25},

$P_{\text{Situation 3, Situation 1}}$ = {Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25, Suggestion Supply TH11D01 Boric concentrate 40 g/kg},

$P_{\text{Situation 4, Situation 1}}$ ={Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25},

$n_{\text{Situation 3, Situation 1, Situation 4}} = 5$, $n_{\text{Situation 3, Situation 1}} = 6$, $n_{\text{Situation 4, Situation 1}} = 5$,

$k_{\text{Situation 3, Situation 1, Situation 4}} = n_{\text{Situation 3, Situation 1, Situation 4}} / (n_{\text{Situation 4, Situation 1}} + n_{\text{Situation 3, Situation 1}} - n_{\text{Situation 3, Situation 1, Situation 4}}) =$ 5/(5+6–5) = 0,8333 (83,33%);

$A_2$ = <Situation 3, Situation 2, Situation 4, $P$>, $P$ = {Close TH 11S24},

$P_{\text{Situation 3, Situation 2, Situation 4}}$ = {Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25},

$P_{\text{Situation 3, Situation 2}}$ = {Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25, Suggestion Supply TH11D01 Boric concentrate 40 g/kg},

$P_{\text{Situation 4, Situation 2}}$ ={Off ACS 1, Supply TH11D01 Boric concentrate 40 g/kg, AND Close TH11S24 Close TH11S25, Close TH 11S24, Close THS11S25},

$n_{\text{Situation 3, Situation 2, Situation 4}} = 5$, $n_{\text{Situation 3, Situation 2}} = 6$, $n_{\text{Situation 4, Situation 2}} = 5$,

$k_{\text{Situation 3, Situation 2, Situation 4}} = n_{\text{Situation 3, Situation 2, Situation 4}} / (n_{\text{Situation 4, Situation 2}} + n_{\text{Situation 3, Situation 2}} - n_{\text{Situation 3, Situation 2, Situation 4}}) =$ 5/(5+6–5) = 0,8333 (83,33%).

Thus, it is clear that the two obtained analogies are incomparable, since their values of likeness have the same value 83,33%. They can be both represented by the DMP for the choice of the most preferable variant ($V_A^* = \{A_1, A_2\}$).

## Conclusion

In this paper, a solution of problem of real-time diagnostics and forecasting in modern IDSS on the basis of a structural analogy was proposed.

Various types of analogies were analyzed. The method of reasoning by structural analogy was considered from the aspect of its application in RT IDSS.

The example of an algorithm for the solution search on the basis of an analogy of properties that takes into account the context was proposed. The more efficient algorithm, in the sense of the solution quality, is proposed [11, 13]. It uses a modified structure of an analogy that is capable of taking into account not one property (as in the base algorithm), but a set of properties. These properties determine the original context of the analogy and transfer from the source to the receiver only those facts that are relevant in the context of the constructed analogy. The possibility of estimating the obtained analogies taking into account the context is studied [1].

The proposed mechanism of reasoning by structural analogy was implemented in Borland C++ Builder for Windows [14].

The presented methods and tools were applied in prototype of a RT IDSS on the basis of nonclassical logics for monitoring and control of complex objects like power units.

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