CONSTRUCTION OF CLASS LEVEL DESCRIPTION FOR EFFICIENT RECOGNITION OF A COMPLEX OBJECT

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Abstract: *Many artificial intelligence problems are NP-complete ones. To increase the needed time of such a problem solving a method of extraction of sub-formulas characterizing the common features of objects under consideration is suggested. Repeated application of this procedure allows forming a level description of an object and of classes of objects. A model example of such a level description and the degree of steps number increasing is presented in the paper.*

Keywords: *artificial intelligence, pattern recognition, predicate calculus, complexity of an algorithm, level description of a class.*

ACM Classification Keywords: *I.2.4 Artificial Intelligence Knowledge Representation Formalisms and Methods – Predicate logic, I.5.1 Pattern Recognition Models – Deterministic, F.2.2 Non numerical Algorithms and Problems – Complexity of proof procedures.*

Introduction

Many artificial intelligence problems may be formalized by means of predicate calculus language [Kosovskaya, 2011]. Such a formalization (called a logic-objective approach to AI problems solving) allows to take into account not only properties of an object as a whole but properties of its parts and relations between them. It is proved in [Kosovskaya, 2007] that such a way formalized problems are NP-complete ones, and upper bounds of the number of their solving steps are proved for an exhaustive algorithm and for algorithms based on derivation in a predicate calculus.

A level description of recognized classes was introduced in [Kosovskaya, 2008]. It is based on the definition of auxiliary predicates in the terms of the initial ones. These predicates are determined as “frequently” occurred sub-formulas of the class description having “small complexity”. Conditions of the step number decreasing while solving a recognition problem with the use of a level description were proved. But such an extraction of the mentioned sub-formulas was leaved to a human will.

The notion of partial deduction was introduced in [Kosovskaya, 2009] to recognize an object with incomplete information. The use of partial deduction allows to state that the given information is enough to claim that the r-th part (with the extracting of this part) of the recognized object belongs to the pointed class with the certainty degree q.

The notion of partial deduction was offered in [Kosovskaya, 2012] for determination of a distance (as well as for the degree of similarity) between objects described in the frameworks of the logic-objective approach. The base of a distance determination is sub-formulas of object descriptions which differ one object from another.

Below it is offered to use the notion of partial deduction for the extraction of "frequently" occurred sub-formulas of a class description and construction a level description of this class with the use of a training set. These sub-formulas describe similar characteristics of objects from the same class.

Logic-objective approach to recognition problem setting

To recognize objects from the done set Ω every element of which is represented as a set of its elements $\omega = \{\omega_1, ..., \omega_t\}$, a logic-objective approach was described in [Kosovskaya, 2007]. Let the set of predicates $p_1, ..., p_n$ (every of which is defined on the elements of ω) characterizes properties of these elements and relations between them.

Logical description $S(\omega)$ of an object ω is a collection of all true formulas in the form $p_i(\tau)$ or $\neg p_i(\tau)$ (where τ is an ordered subset of ω) describing properties of ω elements and relations between them.

Let the set Ω is a union of classes $\Omega = \cup_{k=1}^{K} \Omega_k$. Logical description of the class Ω_k is such a formula $A_k(\mathbf{x})$ that if the formula $A_k(\omega)$ is true then $\omega \in \Omega_k$. The class description may be represented as a disjunction of elementary conjunctions of atomic formulas.

Here and below the notation $\mathbf{x}$ is used for an ordered list of the set x. To denote that all values for variables from the list $\mathbf{x}$ are distinct the notation $\exists \mathbf{x}_{\neq} A_k(\mathbf{x})$ is used.

The introduced descriptions allow solving many artificial intelligence problems [Kosovskaya, 2011]. These problems may be formulated as follows. **Identification problem:** to pick out all parts of the object ω which belong to the class Ω_k. **Classification problem:** to find all such class numbers k that $\omega \in \Omega_k$. **Analysis problem:** to find and classify all parts τ of the object ω. The solution of these problems is reduced to the proof of logic sequents $S(\omega) \Rightarrow \exists \mathbf{x}_{\neq}\ A_k(\mathbf{x})$, $S(\omega) \Rightarrow \vee_{k=1}^{K} A_k(\mathbf{x})$, $S(\omega) \Rightarrow \vee_{k=1}^{K} \exists \mathbf{x}_{\neq}\ A_k(\mathbf{x})$ respectively and determination of the values of $\mathbf{x}$ and k.

The proof of every of these sequents is based on the proof of the sequent

$$S(\omega) \Rightarrow \exists \mathbf{x}_{\neq}\ A(\mathbf{x}) \quad (1)$$

where $A(\mathbf{x})$ is an elementary conjunction.

It is proved in [Kosovskaya, 2010] that every of these problems is an NP-complete one. If the sign $\exists$ is changed by the sign ? then every of these problems is an NP-hard one.

Moreover, the number of steps of an algorithm solving the problem (1) (and the problem with the changing of the sign $\exists$ by the sign ?) is $O(t^m)$ (m is the number of arguments in $A(\mathbf{x})$) for an exhaustive algorithm, and $O(s^a)$ (s and a are the maximal and respectively the summary numbers of occurrences of the same predicate in the description $S(\omega)$ and in the formula $A(\mathbf{J})$ respectively) for logical derivation in the first order predicate calculus.

Level description of a class

Let $A_1(\mathbf{x}_1), ..., A_K(\mathbf{x}_K)$ be a set of class descriptions. Let's find all sub-formulas $P_i^1(\mathbf{y}_i^1)$ with the "small complexity" which "frequently" appear in the formulas $A_1(\mathbf{x}_1), ..., A_K(\mathbf{x}_K)$ and denote them by atomic formulas with new predicates p_i^1 having new first-level arguments y_i^1 for lists $\mathbf{y}_i^1$ of initial variables. Such a new predicate p_i^1 is called a first-level predicate. Write down a system of equivalences

$$p_i^1(y_i^1) \Leftrightarrow P_i^1(\mathbf{y}_i^1).$$

Let $A_k^1(\mathbf{x}_k^1)$ be a formula received from $A_k(\mathbf{x}_k)$ by means of a substitution of $p_i^1(y_i^1)$ instead of $P_i^1(\mathbf{y}_i^1)$. Here $\mathbf{x}_k^1$ is a list of all variables in $A_k^1(\mathbf{x}_k^1)$ including both some (may be all) initial variables of $A_k(\mathbf{x}_k)$ and first-level variables appeared in the formula $A_k^1(\mathbf{x}_k^1)$.

A set $S^1(\omega)$ of all atomic formulas of the type $p_i^1(\omega_{ij}^1)$ for which the formula $P_i^1(\tau_{ij}^1)$ (for some $\tau_{ij}^1 \subset \omega$) is valid is called a first-level object description. Such a way extracted lists of ω elements $\omega_{ij}^1 = \tau_{ij}^1$ are called first-level objects.

Repeat the above described procedure with all formulas $A_k^1(\mathbf{x}_k^1)$. After L repetitions L-level descriptions in the following form will be received [Kosovskaya, 2008].

$$A_k^L(\mathbf{x}_k^L)$$

$$p_1^1(y_1^1) \Leftrightarrow P_1^1(\mathbf{y}_1^1)$$

$$\cdots$$

$$p_{n1}^1(y_{n1}^1) \Leftrightarrow P_{n1}^1(\mathbf{y}_{n1}^1)$$

$$\cdots$$

$$p_i^l(y_i^l) \Leftrightarrow P_i^l(\mathbf{y}_i^l)$$

$$\cdots$$

$$p_{nL}^L(y_{nL}^L) \Leftrightarrow P_{nL}^L(\mathbf{y}_{nL}^L).$$

Such an L-level description may be used for efficiency of an algorithm solving a problem formalized in the form of logical sequent (1).

Let's describe an algorithm solving the problem in the form (1) with the use of a level description of a class.

- First, for every i check $S(\omega) \Rightarrow \exists \mathbf{y}_i^1{}_{\neq} P_i^1(\mathbf{y}_i^1)$ and find all values of true first-level predicate arguments. Add these first-level true atomic formulas to the object description and form $S^1(\omega)$. If an l-level ($l = 1, \ldots, L-1$) object description $S^l(\omega)$ is formed then for every i check $S^l(\omega) \Rightarrow \exists \mathbf{y}_i^l{}_{\neq} P_i^{l+1}(\mathbf{y}_i^{l+1})$ and find all values for true $(l+1)$-level predicate arguments.
- Second, add these $(l+1)$-level true atomic formulas to the object description $S^l(\omega)$ and receive $S^{l+1}(\omega)$.
- Then substitute $p_i^l(y_i^l)$ instead of $P_i^l(\mathbf{y}_i^l)$ into $A_k^l(\mathbf{y}_k^l)$.
- Repeat the previous steps for $l = 1, \ldots, L$.
- At last check $S^L(\omega) \Rightarrow \exists \mathbf{y}_k^L{}_{\neq} A_k^L(\mathbf{y}_k^L)$.

To decrease the number of steps of an exhaustive algorithm (for every t greater than some t_0) with the use of 2-level description it is sufficient that

$$n_1 t^r + t^{s1+n1} < t^m, \qquad (2)$$

where r is a maximal number of arguments in the formulas $p_i^1(y_i^1) \Leftrightarrow P_i^1(\mathbf{y}_i^1)$, n_1 is the number of first-level predicates, s^1 is the number of atomic formulas in $S^1(\omega)$, m is the number of variables in the initial class description [Kosovskaya, 2008].

Analogous condition for decreasing the number of steps of a logical algorithm solving the problem (1) is

$$\Sigma_{k=1\ldots K}\, s^{a_k} - \Sigma_{j=1\ldots n_1} s^{\rho_j} \geq \Sigma_{\kappa=1\ldots K} (s^1)^{a_{k1}}, \qquad (3)$$

where a_k and a_k^1 are the numbers of atomic formulas in $A_k(\mathbf{x}_k)$ and $A_k^1(\mathbf{x}_k^1)$ respectively, s and s^1 are the maximal numbers of atomic formulas with the same predicate in $S(\omega)$ and $S^1(\omega)$ respectively, ρ_j is the number of atomic formula in $P_j^1(\mathbf{y}_j^1)$ [Kosovskaya, 2008].

Partial deduction

The notion of partial deduction was introduced by the author in [Kosovskaya, 2009] to recognize objects with incomplete information. During the process of partial deduction instead of the proof of (1) we search such a maximal sub-formula $A'(\mathbf{x}')$ of the formula $A(\mathbf{x})$ that $S(\omega) \Rightarrow \exists \mathbf{x}'_{\neq} A'(\mathbf{x}')$ and there is no information that $A(\mathbf{x})$ is not satisfiable on ω.

Let a and a' be the numbers of atomic formulas in $A(\mathbf{x})$ and $A'(\mathbf{x}')$ respectively, m and m' be the numbers of objective variables in $A(\mathbf{x})$ and $A'(\mathbf{x}')$ respectively. Then partial deduction means that the object ω contains an r-th part ($r = m'/m$) of an object satisfying the description $A(\mathbf{x})$ with the certainty $q = a'/a$.

More precisely, the formula $S(\omega) \Rightarrow \exists \mathbf{x}_{\neq} A(\mathbf{x})$ is partially (q, r) - deduccible if there exists a maximal sub-formula $A'(\mathbf{x}')$ of the formula $A(\mathbf{x})$ such that $S(\omega) \Rightarrow \exists \mathbf{x}'_{\neq} A'(\mathbf{x}')$ is deducible and τ is the string of values for the list of variables $\mathbf{x}'$, but the formula $S(\omega) \Rightarrow \exists \mathbf{x}_{\neq} [DA'(\mathbf{x})]^{\mathbf{x}'}_{\tau}$ is not deductible. Here $[DA'(\mathbf{x})]^{\mathbf{x}'}_{\tau}$ is obtained from $A(\mathbf{x})$ by deleting from it all conjunctive members of $A'(\mathbf{x}')$, substituting values of τ instead of the respective variables of $\mathbf{x}'$ and taking the negation of the received formula.

Class description based on the training set

Given a training set $\Omega^0 = \cup_{k=1}^{K} \Omega_k^0$ let's make such a class description that every object from Ω^0 would be successfully classified. Every object $\omega = \{\omega_1, \ldots, \omega_t\}$ from Ω^0 is represented by its description $S(\omega)$. If one replaces in $S(\omega)$ every constant ω_j by a variable x_j ($j = 1, \ldots, t$) and substitute the sign & between the received atomic formulas then such an elementary conjunction $A(\mathbf{x})$ would be valid for every object with the same description.

A disjunction upon all objects from Ω_k^0 of all such a way received elementary conjunctions may be regarded as a description of the class Ω_k^0. Moreover, if for a display screen image the indexes of neighboring pixels are changed, for example, by x and $x + 1$ then every image differing from the one in the training set only by its localization on the display screen will be correctly classified.

The object that does not satisfy any of the received class description may be classified according to the metric described in [Kosovskaya, 2012].

Formation of a level description for one class

Let the class description $A_k(\mathbf{x})$ is a disjunction of elementary conjunctions $A_{k,1}(\mathbf{x}_{k,1}), \ldots, A_{k,J}(\mathbf{x}_{k,J})$. For every i and j ($I < j$) check whether $A_{k,i}(\mathbf{x}_{k,i}) \Rightarrow \exists \mathbf{x}_{k,j\,\neq}\ A_{k,j}(\mathbf{x}_{k,j})$. Using the notion of partial deduction we may receive such a maximal sub-formula $Q^1_{i,j}(\mathbf{x}_{i,j})$ of the formula $A_{k,j}(\mathbf{x}_{k,j})$ that $A_{k,i}(\mathbf{x}_{k,i}) \Rightarrow \exists \mathbf{x}_{i,j\,\neq}\ Q^1_{i,j}(\mathbf{x}_{i,j})$. But $Q^1_{i,j}(\mathbf{x}_{i,j})$ is also a maximal sub-formula of $A_{k,i}(\mathbf{x}_{k,i})$ (up to the names of variables) such that $A_{k,i}(\mathbf{x}_{k,i}) \Rightarrow \exists \mathbf{x}_{i,j\,\neq}\ Q^1_{i,j}(\mathbf{x}_{i,j})$ because the both formulas $A_{k,i}(\mathbf{x}_{k,i})$ and $A_{k,i}(\mathbf{x}_{k,i})$ are elementary conjunctions.

So such a way received formula $Q^1_{i,j}(\mathbf{x}_{i,j})$ is a common sub-formula of $A_{k,i}(\mathbf{x}_{k,i})$ and $A_{k,i}(\mathbf{x}_{k,i})$ (up to the names of variables).

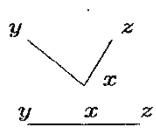
A common sub-formula $Q^l_{i1\ldots il,j1\ldots jl}(\mathbf{x}_{i1\ldots il,j1\ldots jl})$ of the formulas $Q^{l-1}_{i1\ldots il}(\mathbf{x}_{i1\ldots il})$ and $Q^{l-1}_{j1\ldots jl}(\mathbf{x}_{j1\ldots jl})$ (up to the names of variables) may be received in the similar way.

Note that the length of $Q^l_{i1\ldots il,j1\ldots jl}(\mathbf{x}_{i1\ldots il,j1\ldots jl})$ decreases while increasing the value of l. That is why the process would stop. One can fix such a number r ($r > 1$) that if the length of $Q^l_{i1\ldots il,j1\ldots jl}(\mathbf{x}_{i1\ldots il,j1\ldots jl})$ is less than r then it is not involved into the further search of sub-formulas.

Choose sub-formulas $Q^l_{i1\ldots il,j1\ldots jl}(\mathbf{x}_{i1\ldots il,j1\ldots jl})$ satisfying a condition (2) or (3) in dependence of what algorithm would be used for the proof of (1). All these sub-formulas are denoted by $P_i^1(\mathbf{y}_i^1)$ ($i = 1, \ldots n1$) and form the set of first-level predicates.

The $(l + 1)$-level predicates are formed from $Q^l_{i1\ldots il,j1\ldots jl}(\mathbf{x}_{i1\ldots il,j1\ldots jl})$ which sub-formulas are included into the set of l-level predicates taking into account a condition (2) or (3).

Example of sub-formulas extracting



Given two predicates $V(x,y,z) \Leftrightarrow$ "$\angle yxz < \pi$" and $L(x,y,z) \Leftrightarrow$ "*x belongs the segment (y,z)*" describe the class of "boxes" according to the training set represented on the Figure 1 and extract common sub-formulas in order to built a level description.

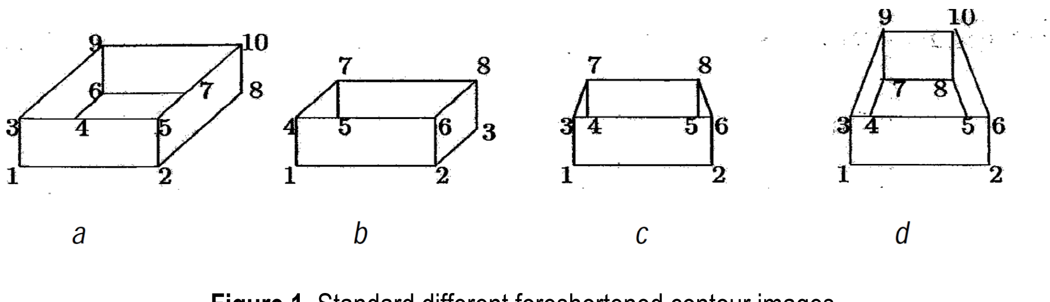


Figure 1. Standard different foreshortened contour images

These standard images allow forming a description (up to mirror image) of almost all boxes. Such a description is a disjunction of 4 elementary conjunctions containing respectively 10, 8, 10, 8 variables and 30, 22, 26, 32 atomic formulas. For example, the elementary conjunction corresponding to the image *b* is $V(x_1,x_4,x_2)$ & $V(x_2,x_1,x_6)$ & $V(x_2,x_6,x_3)$ & $V(x_2,x_1,x_3)$ & $V(x_3,x_2,x_8)$ & $V(x_4,x_5,x_1)$ & $V(x_4,x_6,x_1)$ & $V(x_4,x_7,x_5)$ & $V(x_5,x_4,x_7)$ & $V(x_5,x_7,x_6)$ & $V(x_6,x_2,x_5)$

& $V(x_6,x_2,x_4)$ & $V(x_6,x_5,x_8)$ & $V(x_6,x_4,x_8)$ & $V(x_6,x_8,x_2)$ & $V(x_7,x_5,x_4)$ & $V(x_7,x_8,x_5)$ & $V(x_7,x_8,x_4$ & $V(x_8,x_3,x_6)$ & $V(x_8,x_6,x_7)$ & $V(x_8,x_3,x_7)$ & $T(x_5,x_4,x_6)$.

Given a “box” inside a complex contour image containing t nodes it would be recognized in $O(t^{10})$ steps by an exhaustive algorithm and in $O(s^{29})$ steps by a logical algorithm (here s is the maximal number of occurrences of the same predicate in the description $S(\omega)$).

Pair wise partial deduction of these elementary conjunctions allows extracting common sub-formulas corresponding to the images represented on Figure 2.

These sub-formulas contain respectively 8, 8, 7, 7, 7, 8 variables and 18, 15, 11, 11, 15, 16 atomic formulas.

The following extraction by means of pairwise partial deduction between common sub-formulas corresponding images *ab, ac, ad, bc, bd, cd* gives a sub-formula corresponding to the image represented on Figure 3.

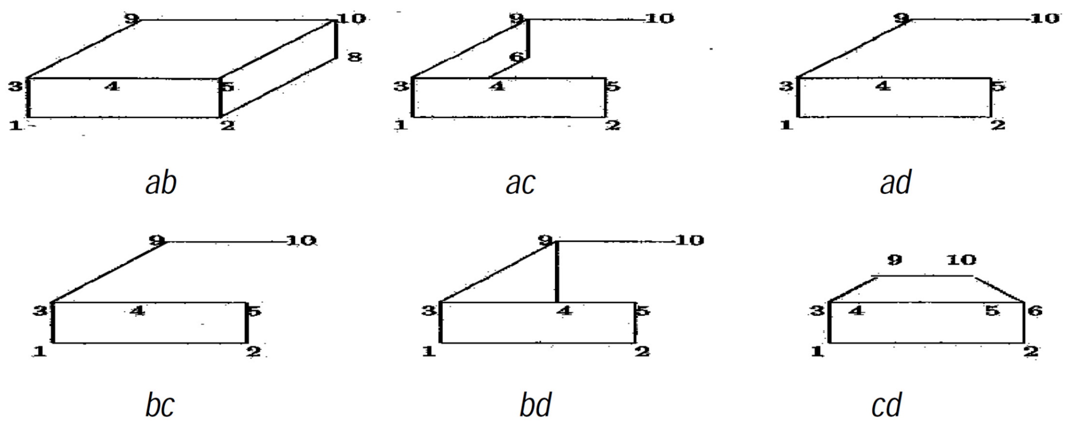


Figure 2. Images corresponding to extraction of common sub-formulas

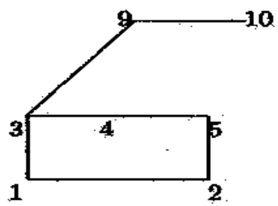


Figure 3. Image corresponding to the second extraction of common sub-formulas

Elementary conjunction $P^1(x_1,x_2,x_3,x_4,x_5,x_9,x_{10}) = V(x_1,x_3,x_2)$ & $V(x_2,x_1,x_5)$ & $V(x_3,x_4,x_1)$ & $V(x_3,x_5,x_1)$ & $V(x_3,x_9,x_4)$ & $V(x_3,x_9,x_5)$ & $V(x_3,x_9,x_1)$ & $V(x_5,x_2,x_4)$ & $V(x_5,x_2,x_3)$ & $V(x_9,x_{10},x_3)$ & $T(x_4,x_3,x_5)$ corresponding to this image defines a first-level predicate $p^1(x^1)$. The first-level variable x^1 is a variable for a list of 7 initial variables.

Elementary conjunctions $P_1^2(\mathbf{y}_1^1)$, $P_2^2(\mathbf{y}_1^1)$, $P_3^2(\mathbf{y}_1^1)$, $P_4^2(\mathbf{y}_1^1)$ corresponding to the images *ab, ac, bd, cd* and written with the use of the predicate $p^1(x^1)$ define second-level predicates $p_1^2(x_1^2)$, $p_2^2(x_2^2)$, $p_3^2(x_3^2)$, $p_4^2(x_4^2)$.

For example, a sub-formula corresponding to the image *ab* is $P_1^2(\mathbf{y}_1^1) = p^1(x^1)\ \&\ V(x_2,x_5,x_8)\ \&\ V(x_2,x_1,x_8)\ \&\ V(x_5,x_4,x_{10})\ \&\ V(x_5,x_3,x_{10})\ \&\ V(x_8,x_2,x_{10})\ \&\ V(x_{10},x_8,x_5)\ \&\ V(x_{10},x_5,x_9)\ \&\ V(x_{10},x_8,x_9)$, where $\mathbf{y}_1^1$ is a list of variables $x^1,x_1,x_2,x_4,x_5,x_8,x_9,x_{10}$ and x^1 is a variable for a list of initial variables $x_1,x_2,x_3,x_4,x_5,x_9,x_{10}$.

Given a "box" inside a complex contour image containing *t* nodes the proof the sequence from $S(\omega)$ of elementary conjunction $P^1(x_1,x_2,x_3,x_4,x_5,x_9,x_{10})$ defining the first-level predicate $p^1(x^1)$ and the denotation of variables $x_1,x_2,x_3,x_4,x_5,x_9,x_{10}$ would be done in $O(t^7)$ steps by an exhaustive algorithm and in $O(s^{11})$ steps by a logical algorithm.

Elementary conjunctions $P_1^2(\mathbf{y}_1^1)$, $P_2^2(\mathbf{y}_1^1)$, $P_3^2(\mathbf{y}_1^1)$, $P_4^2(\mathbf{y}_1^1)$ contain respectively only 1, 1, 0, 1 "new" variables and 7, 4, 4, 5 "new" atomic formulas. The proof of the sequence from $S^1(\omega)$ of these elementary conjunctions defining the second-level predicates $p_1^2(x_1^2)$, $p_2^2(x_2^2)$, $p_3^2(x_3^2)$, $p_4^2(x_4^2)$ and the denotation of the "new" variables would be done in $O(t)$ steps by an exhaustive algorithm and in $O(s^7)$ steps by a logical algorithm.

Elementary conjunctions obtained from the class description by means of second-level predicates instead of the corresponding sub-formulas contain respectively 2, 0, 2, 2 "new" variables and 7, 4, 11, 16 "new" atomic formulas. The proof of the sequence from $S^2(\omega)$ of these elementary conjunctions and the denotation of the "new" variables would be done in $O(t^2)$ steps by an exhaustive algorithm and in $O(s^{16})$ steps by a logical algorithm.

As $O(t^7) + O(t) + O(t^2) = O(t^7) < O(t^{10})$ and $O(s^{11}) + O(s^7) + O(s^{16}) = O(s^{16}) < O(s^{29})$ then both an exhaustive algorithm and a logical algorithm using the built level description of the class of "boxes" make the less number of steps then the same ones using the initial description.

Conclusion

In the frameworks of logic-objective approach, objects and classes of an AI problem are described in the terms of properties of the object parts and relations between them. Such an approach allows taking into account characteristics that are common for many objects from the same class. It is very important because while checking the belonging of an object to a class, some generalized characteristics of an object have the main significance. The most of the objects of a class must have these generalized characteristics.

A level description of recognized classes was offered to decrease the computational complexity of a recognition problem solving. It is not proved now that the proposed manner of sub-formulas extraction provides such a decreasing. But it is illustrated above by an example (and may be illustrated by several other examples) that the computational complexity of an analysis problem decreases and a generalized characteristic of a class is formed.

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Bibliography

[Kosovskaya, 2007] T.M. Kosovskaya. Proofs of the number of steps bounds for solving of some pattern recognition problems with logical description. In: Vestnik of St.Petersburg University. Ser. 1. 2007. No. 4. P. 82 – 90. (In Russian)

[Kosovskaya, 2008] T.M. Kosovskaya. Level descriptions of classes for decreasing step number of pattern recognition problem solving described by predicate calculus formulas. In: Vestnik of St.Petersburg University. Ser. 10. 2008. No. 1. P. 64 – 72. (In Russian)

[Kosovskaya, 2009] T.M. Kosovskaya. Partial deduction of a predicate formula as an instrument for recognition of an object with incomplete description. In: Vestnik of St.Petersburg University. Ser. 10. 2009. No. 1. P. 77 – 87. (In Russian)

[Kosovskaya, 2010] T.M. Kosovskaya. Some artificial intelligence problems permitting formalization by means of predicate calculus language and upper bounds of their solution steps // Proceedings of SPIIRAS. 2010, No 14.

[Kosovskaya, 2011] Kosovskaya T. Discrete Artificial Intelligence Problems and Number of Steps of their Solution // In: International Journal "Information Theories and Applications", Vol. 18, Number 1, 2011. P. 93 – 99.

[Kosovskaya, 2012] Kosovskaya T. Distance between objects described bt predicate formulas // In: International Book Series. Informational Science and Computing. Book 25. Mathematics of Distances and Applications (Michel Deza, Michel Petitjean, Krasimir Markov(eds)), ITHEA-Publisher, Sofia, Bulgaria, 2012. P. 153 – 159.

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Major Fields of Scientific Research: Logical approach to artificial intelligence problems, theory of complexity of algorithms.