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# Recognition of Geometric Images by Linguistic Method

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**ABSTRACT**

**Image recognition is currently one of the fastest-growing areas in applied mathematics. Of the many methods for solving problems in this area, the grammatical (linguistic) method of pattern recognition is the least studied. The essence of the grammar method is to construct appropriate grammar for object classes. In this case, the object recognition problem is related to the language generated by the given grammar. Using the linguistic method, an algorithm and software for recognizing geometric images have been developed. While the development the following tasks were solved. Methods have been developed for describing geometric images (triangles, squares, polygons) and corresponding grammars have been constructed for them so that the chains generated by this grammar represent objects of this class. The problems of constructing given classes of geometric images, as well as constructing a grammar for each class, are solved. At the training stage, classes are considered, each of which is described by a finite set of chains. To classify a new image, that is, to determine which class it belongs to, a parsing of the corresponding chain of this image was performed using grammars. Thus, the belonging of the chain to the language born by this grammar was clarified.**

**Keywords:** grammar-based method, geometric images, Image recognition, linguistic method, chain

## INTRODUCTION

The linguistic (grammar-based) approach is one of the existing alternative methods used in the field of pattern recognition [1, 2]. The grammar-based method is conditioned upon the correspondence between the structure of patterns and the language syntax.

The definitions of the grammar and the language generated by it are provided in [3]. Let $\omega_1$, $\omega_2$,..., $\omega_m$ be the classes of objects. The essence of the grammar-based method is to construct m grammars $G_1$, $G_2$,..., $G_m$, in such a way, that the chains generated by the grammar $G_i$, i = 1, ...,m were objects of the class $\omega_i$, i = 1, ..., m, respectively. Then, for an arbitrary object described by the chain x, the recognition problem is reduced to ascertaining whether $x \in L(G_i)$, i= 1, ..., m, where $L(G_i)$ is the language generated by $G_i$. In case $x \in L(G_j)$, it is considered that the pattern described by the chain x belongs to the class $\omega_j$.

This article describes a linguistic method for recognizing geometric images. The following issues have been identified and resolved

- description of geometric patterns,
- defining the classes $\omega_1, \omega_2, \ldots, \omega_m$ for geometric patterns,
- construction of a grammar $G_i$ for each class $\omega_i$, i = 1, …, m,
- classification of geometric patterns.

Description of the geometric pattern is given in a constructive form. For the description of the pattern, a finite set of atomic elements is chosen, by means of which a corresponding chain is formed. The method of atomic elements is described in [4].

In the teaching stage, the classes are given and each class is described by a finite set of chains. To check that a given pattern belongs to the class $\omega_i$, a syntax analysis of the corresponding chain by grammar $G_i$, i = 1, …, m is carried out, thereby ascertaining the fact that the chain belongs to the language $L(G_i)$ generated by $G_i$.

We have developed the software implementing the classification of some geometric patterns.

## THE PROPOSED MODEL AND SOLUTION OF THE PROBLEM

The grammatical construction of patterns includes choosing a set of atomic elements. At present, there does not exist a general solution for the selection of such a set. This selection essentially depends on the patterns' form and the application of the decoding method. The usual guide for that selection is as follows:

1.Atomic elements are chosen to serve as patterns' basic elements, so as to provide a short description of original data by means of given structural relations.

2. Since the structural information in atomic elements is not important and they are considered simple and short patterns, their extraction and recognition have to be easily implementable by the existing non-syntax methods.

For the description of patterns, it is required that atomic elements contain information important for the given problem. For example, if the size, form, or position are essential in the recognition problem, then the atomic elements should contain information about the size, form, and position so that the classes of objects used for descriptive analysis differ from each other. This requirement very often makes it necessary to use semantic data in the description of atomic elements. In our case the segments of a geometric pattern are represented in the original, part-direction, boundary format; and the chain corresponding to the pattern is obtained by joining the chains corresponding to those segments. The boundary points of the segment are numbered in any order. The atomic elements are described by an index, which defines the value of the angle formed with the x-axis. Each atomic element has one direction determined by the angle formed with the x-axis.

A choice and correspondence of the type of grammar are carried out for the description of each class by grammar. We extend the notion of context-free grammar by defining what we call program grammar. A quintet $(V_N, V_T, J, P, S)$, where $V_N$ and $V_T$ are finite sets of auxiliary and main symbols, P is the set of deduction rules, S is the original symbol ($S \in V_N$) and J is the set of labels of deduction rules, is called a program grammar $G_P$. Each deduction rule is formed by a label, kernel, and two lists of passages connected with the kernel.

A rule from P has the following form: (r) $\alpha \rightarrow \beta$, U, W, where (r) is the label of deduction rule, $\alpha \rightarrow \beta$ is the kernel of the deduction rule, U,W$\subset$J, and U is the list of passages in case of success and W is the list of passages in case of failure.

The characteristic feature of the program grammar is that after the application of the deduction rule on some intermediate chain, restrictions are put on the choice of the next deduction rule. If the rule is applicable to a chain obtained in the deduction process, then after its application the next rule is chosen from the first list, which is the list of passages in case of success. In case when the rule is not applicable, the next rule is chosen from the second list, that being the list of passages in case of failure.

The recognition system for this grammar selects objects which belong to the class corresponding to it. For any object described by the chain x, the recognition problem is reduced to finding the correct value of i in $x \in L(G_I)$, i = 1, …, m. For the chain x, the syntax analysis (construction of the corresponding deduction tree) is carried out, a choice of which is also important.

For the recognition of geometric patterns we define the set R of geometric patterns, the set of vertices $\Gamma(r)$ of pattern r and the set of polygons $R_{pol}$, $R_{pol} \subset R$.

For $\forall r \in R_{pol}$, $|\Gamma(r)| \geq 3$, we define the classes $R_3$, $R_4$, …, $R_k$, (k is a finite number), where $R_i$ is a set of polygons with a number i of vertices, that is $R_i = \{ r \in R_{pol}, |\Gamma(r)| = i \}$. Thus, $R_3$ is a set of triangles, $R_4$ is a set of squares etc. $R_{eqsid.j}$, is the set of images with equal sides (eqsid), so $R_{eqsid.j} \subset R_j$ is the subset of all equilateral polygons $R_{pol}$, $R_{pol} \subset R$.

For a given pattern r from the classes $R_3$, $R_4$,…, $R_k$ the one is chosen to which r belongs. It is possible that there is no such class, that is, the given pattern is not a polygon. If $r \in R_j$, then it is ascertained whether $r \in R_{eqsid.j}$ or not. If $r \in R_{eqsid.j}$, it must be checked if it is regular or not. In case if r is not equilateral, the program ends with the corresponding message except for the case j = 4. For j = 4, the program finds out if it is a parallelogram, right-angled or some other kind of quadrilateral.

Suppose $R_c \in \{R_3, R_4, …, R_k\}$, where $c = |\Gamma(x)|$, $\Gamma(x)$ is a set of vertices of the chain x, $G_c(V_{cN}, V_{cT}, P_c, S)$ is the grammar corresponding to $R_c$. For the grammars $G_c$, $G_{eqsid.c}$ and $G_{par}$. corresponding to the pattern classes the following proposition is proved.

***Proposition***. Any chain generated by grammar $G_c$ has the following form

a) $0\ t_0^{n0} 11\ t_1^{n1} 22\ t_2^{n2} \ldots (c-1)(c-1) t_{c-1}^{nc-1}\ 0$,

b) the chains in a) are generated by grammars $G_c$, where $c \geq 3$, $n_i \geq 1$, (i=0,1,…, c-1), $t_i$ (i=0,1,…, c-1) is the atomic element of the pattern, $n_i$ is the number of repetitions of the atomic element $t_i$ and 1, 2, …, (c-1) are the vertices of the pattern.

Let x be a chain and G is a grammar (context-free or a program one). The problem of the grammatical analysis of x is solved via the deduction of x in grammar G. In other words, the problem of grammatical analysis can be formulated in the following way: for the given chain x



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and grammar G, construct a triangle of the deduction tree and attempt to complete its internal part by a deduction of x, which is true in G.

If the attempt is successful, then $x \in L(G)$, otherwise $x \notin L(G)$. The triangle can be completed starting from the top, that is from the root of the tree (descending analysis) or from the bottom to the top (ascending analysis).

Both are called left-to-right analyses. Regardless of the approach, the separate steps represent an attempt of finding a corresponding deduction rule for the considered interval of the chain. The performance of trial steps reveals the inefficiency of grammatical analysis. The grammatical analysis is a targeted process, whose target is the deduction of x from S. In the proposed system the grammatical analysis is performed by means of tests, which contributes to the efficiency improvement.

In such a case, the deduction rule is chosen only if it satisfies some tests. For example, only those rules are being chosen which correspond to the given segment of the sentence.

At each step one of the deduction rules which passed the tests is carried out, after which the next step is performed. If it is necessary to perform a complete grammatical analysis of the sentence, then all the deduction rules, which passed the test must be tried. If it is known that the language is not unambiguous or if it is sufficient to find only one grammatical analysis then the process ends as soon as at least one grammatical analysis is found.

The modular components of the developed software provide the chain input, parting of the chain into segments, obtaining the set of vertices, verification of the chain, obtaining the set of deduction rules for the corresponding classes of grammars, as well as the construction of corresponding grammars for the classes of geometric patterns and the deduction of the chain by a program grammar. The geometric patterns recognition software was tried for the elements $R_c \in \{R_3, R_4, \ldots, R_k\}$. For given elements it checks if it is a polygon or not and if it is, it finds to what type of them it belongs:

- equilateral,
- concrete definition in case of a quadrilateral with not equal sides,
- regular.

The process stops in the case of all not equilateral polygons, except for the quadrilaterals. In the case of quadrilaterals, the process proceeds to find out if it is a parallelogram or a right-angled one.

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