SUS A NEW GENERATION THINKING ROBOTS
The Visual Intelligence Tests

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Abstract: In this paper understanding abilities of the shape understanding system (SUS) are tested based on the methods used in the intelligence tests. These tests are formulated as tasks given to the system and performance is compared with the human performance of these tasks. The tests were based on the progressive matrices test which requires the good visual problem solving abilities of the human subject. SUS solves these tests by transforming the visual form into the string form. The proposed string form makes it possible to perform complex visual reasoning. The experiment proved that the proposed method, which is part of the SUS visual understanding abilities, can solve the test that is very difficult for human subject.

1 INTRODUCTION

Understanding is based on abilities called intelligence such as a verbal communication, spatial orientation, memorizing, and reasoning. Intelligence tests are series of tasks designed to measure the capacity to make abstractions, to learn and to deal with novel situations. Intelligence tests that include tasks that deal with visual forms (shapes) are called the visual tests. They are divided into several groups: the visual discrimination tests, the visual memory tests, the visual-spatial relationship tests, the visual form constancy tests, the visual sequential memory tests, the visual figure ground tests or the visual closure tests (Colaruso 2003), (Gardener 1996).

The system that has abilities to understand the visual information needs to be able to solve tasks that are presented in the form of visual intelligence tests. Intelligence tests include tasks that deal with visual forms (shapes). In the present research, that is part of the shape understanding method, the shape is considered as a meaningful unit called the phantom. Existing methods of shape analysis are mostly concerned with shape recognition (Bhanu 1984), (Lu 1993), (He 1991), (Kartikeayan 1989), (Pal 1993). Visual systems applying shape as their knowledge are called the model-based object recognition systems and have been used extensively by vision researchers (Pope 1994).

2 UNDERSTANDING OF THE VISUAL OBJECT

Shape understanding method (Les 2002), (Les 2003) is a multidisciplinary research area that is focused on understanding of the visual objects. This method is based on the concept of possible classes of shape. For example, the convex polygon class consists of the elements that are called convex polygons and is denoted as L^n, where n refers to the number of sides. The symbol L^n denotes the symbolic name of the class. The detailed description of the classes such as the thin class, the convex polygon class, the curve polygon class, the cyclic class and the complex class are given in references (Les 2002), (Les 2003), (Les 2005), and (Les 2005). In this paper the short description of the notation of the symbolic names is given. The description is limited to the class from which exemplars are part of the visual intelligence test. In Fig.1 are presented exemplars from the convex polygon class: the triangle class L^3, the quadrilateral class L^4, the convex curve polygon class M, the convex curve class K, the concave polygon classes $Q_{L^5}(L^3)$ and $Q^2_{L^5}(2L^3)$ (Fig. e,f), the concave curve class $Q^1_{M^1}(M^1)$, the thin class

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$\Theta^3_{L^3_E}([l,m,m])$, the acyclic class $A^3_{L^4}(3L^3)$, the drawing class $G\{A^3_{L^4}(3L^3)\}$, and the complex thin class $C(K^1,\Theta(s,s,b,s,s)$, $C(K^1,\Theta(c(h),s(l),b,s(l),c(h)))$.

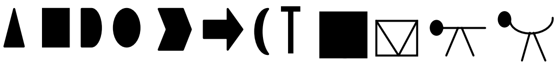


Figure 1: Exemplars from the convex polygon class

3 THE STRING FORM - THE TYPE OF THE CLASS

Archetypes of the shape class are described in the form of the symbolic names. For the purpose of the visual reasoning the symbolic name is transformed into the string form. The string consists of combination of the selected letters, numbers and the symbol "|". The string has a following form: B1|…|Bi|...|Bn|, where Bi denotes the symbolic names of the class.

There is a conversion from the notation of the symbolic name into the string notation. For example, the convex class L^3 is expressed as L3 in the string form.

The string notation is used to introduce the type of the class. The string without symbol "|" denotes the type P of the class. It represents exemplars of the convex classes. For example, exemplars of convex classes given in Fig.2 (L3A, L4R, M1L3A, M1L4R, M2L4R) are all of type P.

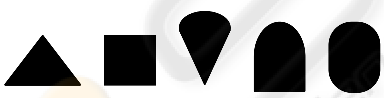


Figure 2: Exemplars of the class of type P

Type S represents cyclic and concave classes. The type S is given in the form Sn|A|1X|…|iX|…|nX|. The type Sq (the concave type) is given in the form Qn|G|1R|…|iR|…|nR|, whereas the type Sa (the cyclic type) is given as An|C|1W|…|iW|…|nW|. Examples of the exemplars type Sn|A|1X|…|iX|…|nX| are given in Fig.13, 14, and 15. The type S1|A|1_S1|1_A|1_X| and the type S1|A|1_S1|1_A|2_S1|2_A|2_X| represent the exemplars o of the convex or cyclic classes on the first and the second level of iteration. The concave class $Q^4_{L^4}(4L^3)$ is expressed as Q4|L4|L3|L3|L3| in the string form.

4 VISUAL TESTS IN SUS

In SUS visual test is given as a series of eight objects v_i, $i=1,..8$. These objects are denoted using matrix notation $v_{i,j}$, $i,j=1,..3$ to represent the pattern in the test. The five objects that are given as an answer are denoted as o_k, $k=1,..5$ (see Fig 3).

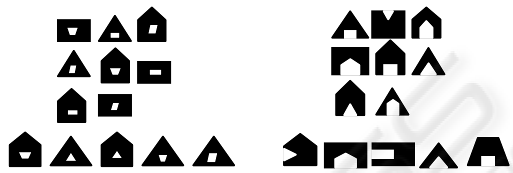


Figure 3: Examples of tests and answers

The task is formulated as 'find the object o_k, $k=1,..5$ that fills the missing entry in the matrix $v_{i,j}$, $i,j=1,..3$:

$[\exists o_k : o_k \otimes v_{i,j},\ \ for\ i,j=1,..3\ \ k=1,...,5] \Rightarrow o_k \triangleright \sigma$. The symbol '$\otimes$' denotes the matching between the possible solution $v_{i,j}$ and the answer object o_k.

The visual test is given as a pattern that consists of eight figures (shapes) for testing and five figures as a possible answer. In SUS the matrix pattern is transformed into the series of the eight test figures v_i, $i=1,..8$ and for each figure the symbolic name η_i, $i=1,..8$ is obtained during the visual reasoning. The symbolic name η_i is transformed into the string form $\wp^S_i$. As it was described in the previous chapter, the string form consists of the combination of the selected letters, numbers and the symbol "|". The string has a following form: B1|…|Bi|...|Bn|, where Bi denotes the symbolic names of the class. The test string form is given as follows:

1. A11|A21|….|An11|
2. A12|A22|….|An22|
3. A13|A23|….|An33|
4. A14|A24|….|An44|
5. A15|A25|….|An55|
6. A16|A26|….|An66|
7. A17|A27|….|An77|
8. A18|A28|….|An88|

The answer string form is given as follows:

1. B11|B21|….|Bn11|
2. B12|B22|….|Bn22|
3. B13|B23|….|Bn33|
4. B14|B24|….|Bn44|

5. B15|B25|….|Bn55|.

4.1 Representation and Generalization

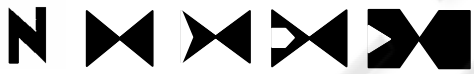
The symbolic name η_i , $i = 1,..8$ that is obtained during visual reasoning refers to one of the symbolic representations. SUS gives the symbolic representation in the SUS notation that includes all possible symbolic representations (on all levels of descriptions).

This notation is transformed into the basic form by the ClassDescriptionExpert. The basic form includes symbols that refer to the symbolic names (general level of description). In this example, the string is transformed into the form Q<L4>[R]|<L3>[A]<L3>[A]| that refers to the symbolic notation $Q^2_{L^4_R}(2L^3_A)$. There are classes such as the complex class that have two synonymous symbolic names. For example, the symbolic names for the archetypes shown in Fig.4 b,c,d,e are as follows: Fig b $Q^2_{L^4_R}(2L^3_O) \equiv D(L^3_A, L^3_A)$, Fig.c

$Q^3_{L^4_R}(3L^3_O) \equiv D(L^3_A, Q^1_{L^3_A}(L^3_O))$, Fig.d

$Q^3_{L^4_R}(2L^3_O L^5_M) \equiv D(L^3_A, Q^1_{L^3_A}(L^5_M))$, Fig.e

$Q^3_{L^4_R}(3L^3_A) \equiv D(L^5_M, Q^1_{L^5_M}(L^3_A))$,.



a b c d e

Figure 4: Exemplars from the concave class a. and from the complex classes b,c,d,e

In the case of the complex class the SUS selects at first the complex representation that is transformed into string form and if the solution is not found, the concave class representation is used. The Q representation (does not give the solution) and the representation D (gives the solution) is as follows:

1.Q3|L4R|L3A|L3O|L3O|	1.D2|Q1|L3A|L3A|L3A|
2.Q3|L6U|L3O|L3O|L4R|	2.D2|Q1|L4R|L4R|L4R|
3.Q3|L4R|L3A|L3A|L5M|	3.D2|Q1|L5M|L5M|L5M|
4.Q3|L6U|L3O|L3O|L5M|	4.D2|Q1|L4R|L5M|L4R|
5.Q3|L4R|L3A|L3A|L3A|	5.D2|Q1|L5M|L3A|L5M|
6.Q3|L4R|L3O|L3O|L4R|	6.D2|Q1|L3A|L4R|L3A|
7.Q3|L4R|L3A|L3A|L4R|	7.D2|Q1|L5M|L4R|L5M|
8.Q3|L4R|L3O|L3O|L5M|	8.D2|Q1|L3A|L5M|L3A|

Solution consists of three possible configurations:

1.D2|Q1|L4R|L3A|*|,
2.D2|Q1|*|L3A|L4R| and
3.D2|Q1|L4R|L3A|L4R|.

4.2 Generalization

Translation of the symbolic name into a string form requires including all details of the symbolic name. The level of details is marked by introducing the symbol "_". The symbolic name is translated into the form L0_L1_...Ln, where the level Ln denotes the level of the detailed description of the archetype of the class. The test that is converted into the string form needs to preserve the level of details. The n-th level of details can be written in the string form as follows:

$jA^0_1 \ldots \_ \; jA^H_1 \; | \ldots | \; jA^0_i \ldots \_ \; jA^H_i \; | \ldots | \; jA^0_1 \ldots \_ \; jA^H_n \; |$ Examples of the test for one and two levels of details are given in Fig. 5.

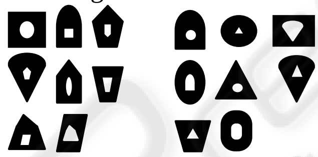


Figure 5: The first level of generalization and the second level of generalization

A_1|L4_R|L5_T|	A_1_*|M_1_L4R|K_1_C|
A_1|L3_O|L4_R|	A_1_*|K_1_C |L_3_A|
A_1|L5_Y|L3_O|	A_1_*|L_4_R |M_1_L3A|
A_1|L3_A|L3_A|	A_1_*|K_1_E |M_1_L4R|
A_1|L5_M|L5_M|	A_1_*|L_3_A |K_1_C|
A_1|L4_R|L4_Y|	A_1_*|M_1_L3A|L_3_A|
A_1|L5_O|L4_T|	A_1_*|L_4_T |L_3_A|
A_1|L4_T|L3_A	A_1_*|M_2_L4R|M_2_L4R|

Solution test 1. A_1|**L3_***|**L5_***|, and
test 2. A1|**K_*_***|**K_*_***|

During generalization the symbol is dropped from the left to the right. For example, for the test in Fig 5a the first level of generalization (the first raw) is A|L4|L5|. For the test in Fig. 5b the first level of generalization (the first raw) is A_1|M_1|K_1| and the second level of generalization is A|M|K|. The generalization is performed by the TestGeneralizationExpert.

5 SHAPE UNDERSTANDING SYSTEM

The shape understanding system consists of the main reasoning module and the peripheral modules for performing the special tasks such as solving the visual intelligence test. The test is solved by part of the peripheral module called the test solver that consists of the SymbolicNamesTestConverterExpert,
the StringFormConverterExpert,
the TestIdentificationExpert,
the CompatibilityFormExpert,

the TestGeneralizationExpert and the specialized test solver experts. The schema of the test solver that is part of the peripheral module of SUS is shown in Fig. 6. In this paper only the solver expert for progressive matrices test is presented. The test is solved by following algorithm.

Algorithm: General test solving algorithm

1. Make the visual reasoning and find the symbolic name for each figure in the test during the visual reasoning
2. Invoke the SymbolicNamesTestConverterExpert to find the basic symbolic name representation
3. Invoke the StringFormConverterExpert to find the test string form
4. Invoke the TestIdentificationExpert to find the type of the test
5. Invoke the specialized test solver experts to find the solution
6. if solution not found invoke the TestGeneralizationExpert and goto 4.
7. END.

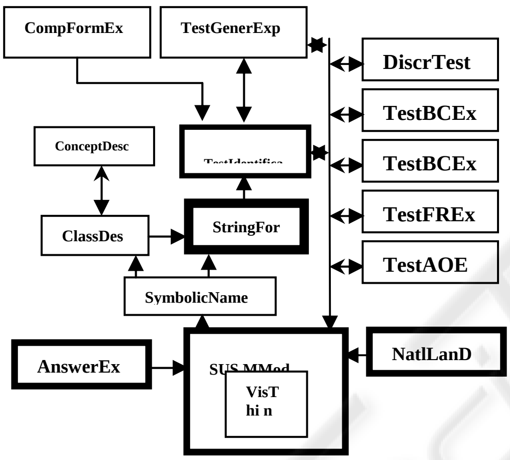


Figure 6: Schema of the SUS peripherals modules for performing the task solving the visual intelligence test

The TestIdentificationExpert and the specialized test solver expert implements algorithms for solving the test. In the next chapter an algorithms that are implemented in the TestIdentificationExpert and two test solver experts (TestAOExpert and TestFRExpert) are described.

5.1 TestAOExpert

The TestAOExpert implements solution for the test type AO. The test AO is given in the form of the eight figures that are transformed into the symbolic names and next into the string forms. In this paper the string forms of the tests is restricted to the type S given in the form Sn|A|1X|…|iX|…|nX|. The test AO is given in the form:

1.Sn1|A|1X|…|iX|…|n1X
2.Sk1|A|1X|…|iX|…|k1X
3.Sm1|A|1X|…|iX|…|k1X
4.Sn2|A|1X|…|iX|…|n2X
5.Sk2|A|1X|…|iX|…|k2X
6.Sm2|A|1X|…|iX|…|k2X
7.Sn3|A|1X|…|iX|…|n3X
8.Sk3|A|1X|…|iX|…|k3X

Fig. 7 shows two tests that consist of exemplars from cyclic classes. Example of the test given in Fig 7 is as follows:

1.A3|K1C|K1C|K1C| 1.A2|K1C|K1C|* |* |
2.A2|L4R|L4R |* | 2.A2|L4R|L4R |* |* |
3.A1|K1C|* |* | 3.A4|L4R|L4R |K1C|K1C|
4.A1|K1C|* |* | 4.A1|K1C|* |* |* |
5.A3|L4R|L4R |L4R | 5.A1|L4R|* |* |* |
6.A2|L4R|L4R |* | 6.A2|L4R|K1C|* |* |
7.A2|K1C|K1C|* | 7.A2|K1C|K1C|* |* |
8.A1|L4R|* |* | 8.A1|L4R |* |* |* |

The possible solution found by SUS for test 1: A1|K1C|* |* | and for test 2: A3|L4R|K1C|K1C|* |.

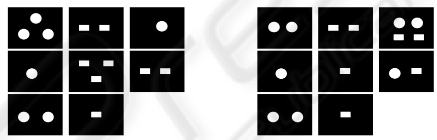


Figure 7: Example of tests type AO

The two rows are used to find the relationships between numbers of figures F1 and F2 and the third raw is used to find the solution. The relationships: (m1-n1)+(m2-n2)=(m3-n3) and (m4-n4)+(m5-n5)=(m6-n6) are used to find if the test is type AO. At first the type of string is checked and if the type of test is S the relationships are checked. If both conditions are fulfilled the test is type AO. The TestIdentificationExpert implements part of algorithms that check if the algorithm is type AO. If so, the TestAOExpert is invoked to find the solution. In the first stage of the algorithm the test is checked if it is of type AO, next the possible solution is found and finally the possible solution of the test is matched with the given answers.

The TestIdentificationExpert implements an algorithm to check if the test type is $\Im^{AB}$. In the first stage the type of the test symbols $\Theta(\wp_{ij}^{T})$ is computed. The test AB is given as the set of strings $S_n^j \mid A^j \mid X_1^j \mid ... \mid X_i^j \mid ... \mid X_n^j \mid$, where $X_i \in \{\eta_1, \eta_2\}$ denotes the symbolic names of parts of the figures of the tests. The type of the test symbols $\Theta(\wp_{ij}^{T})$ is the number of the different symbolic names $\eta_1, ...\eta_i,...\eta_m$ in the test $\wp_{ij}^{T}$. The type of the test symbols $\Theta(\wp_{ij}^{T})$ is computed by counting the number of the different symbolic names.

Compute type of the test symbols $\Theta(\wp_{ij}^{T})$

begin
For i=2 to n
begin

$if\ \ \wp_{ij}^{T} \neq '*'\ \ than\ \wp_{ij}^{T} = X$

For j=0 to 7
begin

$if\ \ \wp_{ij}^{T} = X\ \ than$

begin

$L_{\Theta} = \wp_{ij}^{T},\ \Theta = \Theta + 1,\ \ \wp_{ij}^{T} = '*',$

end
end
end.

An algorithm 'Check_if _test_ type_is_ type $\Im^{AB}$' is implemented as a part of the TestIdentificationExpert.

Check_if _test_ type_is_ type $\Im^{AB}$

begin

1. For each object in the test pattern $o_i \in O_T$ the visual name η_i^{T} is obtained and transformed into a string $\wp_{ij}^{T}$ (Sn|A|1X|…|iX|…|nX|)

2. The type of the test symbols $\Theta(\wp_{ij}^{T})$ is computed

3. $if\ \ \Theta(\wp_{ij}^{T}) > 2$ than goto END.

For i=2 to n
Begin
For j=0 to 7
Begin

$if\ \ \wp_{ij}^{T} = L_0\ \ than\ \ n_{ij} = 1\ \ else\ \ n_{ij} = -1$

end
end
For j=0 to 7
begin

$$S_j = \sum_{i=2}^{n} n_{ij}$$

end

if $S_0 + S_1 = S_2$ and $S_3 + S_4 = S_5$ then $\Im^{AB} = 1$

END
end.

TestAOExpert implements an algorithm to compute the solution 'Compute_solution_test_ $\Im^{AB}$'.

*Algorithm: Compute_solution_test_* $\Im^{AB}$

begin
1. For j=0 to 7
begin

$$S_j = \sum_{i=2}^{n} n_{ij}$$

end

$S = S_6 + S_7$

2. Decompose S into the type of the class, next into symbolic names X1..Xh and next into form of possible solution S|A|1X|…|iX|…|hX
3. For each object from a set of given answers A, $u_i \in A$ obtain the visual name η_i^{A} and transform it into form Sn|A|1X|…|iX|…|nX|
4. Find the final solution by string matching between the string of the given answers and the possible solution
end.

5.2 Test FR Expert

The TestFRExpert implements algorithms that give solution to the test FR. In order to have solution the test needs to have at least two features in common for each three figures. The figures are arranged in such a way that six figures are used to find the general rules of prediction and two figures are used to find the possible solution. The following pattern (letters F1…F8) shows the figure in the test

F1 F2 F3
F4 F5 F6
F7 F8 F?.

There are two configurations used in the test. The simple configuration CS is given as three sets of the three figures {F1, F2, F3}, {F4,F5,F6}, {F7,F8, F?}. The most common configuration CMC is given as {F1,F6,F8}, {F3,F5,F7}, {F2, F4, F?}. Each test given in the form of the CMC configuration can be transformed into CS configuration. Example of the transformation is given in Fig. 8.

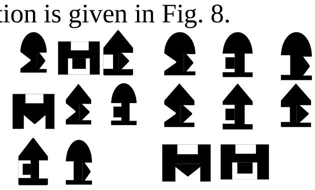


Figure 8: Transformation of the test given in the CMC form into the CS form

5.3 Features

Test is solved by selecting features for both configurations {F1,F6,F8} and {F3,F5,F7}. The feature is any symbol in the string representation …|X1|…|Y1|.... The relationships can be formulated in the form of one, two or more than two features. Fig. 9 shows a test that has relationships expressed in the form of the one feature (Fig. 9a) and two features (Fig. 9b).

A1|M2L4R|M1L4R |	Q1|M1L4R|Q1|L4R|M1 |
A1|M1L4R|M2L4R |	Q1|L4R |Q1|L4R|L4R|
A1|M1L3A|M1L3A |	Q1|L5M |Q1|L4T|L3A|
A1|M1L4R|M1L3A |	Q1|L4R |Q1|L4T|L3A|
A1|M1L3A|M1L4R |	Q1|L5M |Q1|L4R|M1 |
A1|M2L4R|M2L4R |	Q1|M1L4R|Q1|L4R|L4R|
A1|M1L3A|M2L4R |	Q1|L5M |Q1|L4R|L4R|
A1|M2L4R|M1L3A	Q1|M1L4R|Q1|L4T|L3A|

Solution for the first test is A1|M1L4R|M1L4R| and for the second test is
1.Q1|L4R|Q1|*|M1|
2.Q1|L4R|Q1|L4R|M1|.

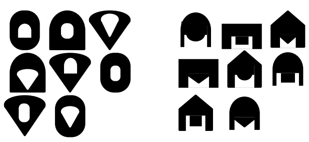


Figure 9: Tests that have relationships expressed in the form of the one feature (a) and two features (b)

In this paper algorithm is presented in the context of the most common configurations. This form is used to design the algorithm for finding the solution to the test. The test which has solution can be written as follows:

1. …|X1|…|Y1|...		1. X1|Y1
2. …|X2|…|Y2|...		2. X2|Y2
3. …|X3|…|Y3|...		3. X3|Y3
4. …|X2|…|Y3|...		4. X2|Y3
5. …|X3|…|Y1|...	or in short	5. X3|Y1
6. …|X1|…|Y2|...		6. X1|Y2
7. …|X3|…|Y2|...		7. X3|Y2
8. …|X2|…|Y3|...		8. X2|Y3

The test can be given in the compatible form that means each eight rows have the columns that are representative of the same type of classes. The test given in the compatible form can be represented as follows:

1A1|1A2|…|1Ai|…|1An|
2A1|2A2|…|2Ai|…|2An|
3A1|3A2|…|3Ai|…|3An|
4A1|4A2|…|4Ai|…|4An|
5A1|5A2|…|5Ai|…|5An|
6A1|6A2|…|6Ai|…|6An|
7A1|7A2|…|7Ai|…|7An|
8A1|8A2|…|8Ai|…|8An|

The test is formulated as the pattern of the eight strings. For simplicity the type of compatible test can be written in the form of the one string. Examples of the different one string representation of the different tests are as follows: Sn|A|1X|…|iX|…|nX|, S1|A|1_S1|1_A|1_X|, Sn|A|1X|2X|…|hX|1_1Q1|1_1G|1_R|…|1_hQ1|1_hG|1_hR|.

The incompatible test can be represented as follows:

1A1|1A2|…|1Ai|…|1An1|
2A1|2A2|…|2Ai|…|2An2|
3A1|3A2|…|3Ai|…|3An3|
4A1|4A2|…|4Ai|…|4An4|
5A1|5A2|…|5Ai|…|5An5|
6A1|6A2|…|6Ai|…|6An6|
7A1|7A2|…|7Ai|…|7An7|
8A1|8A2|…|8Ai|…|8An8|

The transformation from the incompatible form into the compatible form is performed by the CompatibilityFormExpert. The transformation from the incompatible form into the compatible form involves both type of the classes and the symbolic names. At first the type of the class for each row is compared to find if it can be transformed into the compatible form. If the incompatible form can be transformed into the compatible form at first the types of class for each row are matched with the test general type of the class. The test general type of class is the type that makes it possible to fit structure of all strings. The general type can be generated or stored as a template. For example, the test Sn can contain string type Qn|G|1R|…|iR|…|nR|, An|C|1W|…|iW|…|nW| or both type of strings. For the type Snj|A|1X|…|iX|…|nX| the algorithm is as follows:

```
For j=1 to 8
begin
if nj<n2 than
begin
for nj+1 to n2
begin
jX='*'
end.
```

Example of the test type Sn is as follows:

Q2	L4R	L3A	L4R	*
Q1	L3A	L4R	*	*
Q2	L5M	L3A	L4T	*
Q3	L3A	L3A	L4T	L5M
Q1	L5M	*	*	*
Q2	L4R	L3A	L4R	*
Q3	L5M	L3A	L4R	L5M
Q2	L4R	L3A	L3A	*

Similarly the procedure can be applied for the test type S11_S given as:

$$S_n|A|1\_S^1_{m1}|1\_A^1|1\_X^1_1|..|1\_X^1_{m1}|...|1\_S^n_{mn}|1\_A^n|1\_X^n_1|..|1\_X^1_{mn}|\text{In}$$

the test we assume that n, m1 and mn are <5. In the test where the different types are included the numbers of features are limited by the perceptual abilities of SUS. The TestIdentificationExpert implements an algorithm to check if the test is of type $\Im^{FR}$. Procedure combi_n_m(n,k) computes the k combinations from the set of n numbers. Procedures ComputeSUM3() and ComputeSUMP1_P2() compute the number of the relationships between the characteristic features of the test.

ComputeSUM3()
Begin
S=0;

$if\ \wp_0^S = \wp_1^S\ than\ S = S+1$

$if\ \wp_0^S = \wp_2^S\ than\ S = S+1$

$if\ \wp_1^S = \wp_2^S\ than\ S = S+1$

$A_{ik}^Z = S$

End.

ComputeSUMP1_P2()
Begin
S=0

$if\ \wp_0^S = \wp_5^S\ than\ S = S+1$

$if\ \wp_0^S = \wp_7^S\ than\ S = S+1$

$if\ \wp_1^S = \wp_3^S\ than\ S = S+1$

$if\ \wp_2^S = \wp_4^S\ than\ S = S+1$

$if\ \wp_2^S = \wp_6^S\ than\ S = S+1$

$A_{ik}^{S1} = S$

S=0

$if\ \wp_0^S = \wp_4^S\ than\ S = S+1$

$if\ \wp_1^S = \wp_5^S\ than\ S = S+1$

$if\ \wp_1^S = \wp_6^S\ than\ S = S+1$

$if\ \wp_2^S = \wp_3^S\ than\ S = S+1$

$if\ \wp_2^S = \wp_7^S\ than\ S = S+1$

$A_{ik}^{S2} = S$

End.

The Checkif Test _is _type FR () algorithm checks if the test type is type $\Im^{FR}$.

Checkif Test _is _type FR ()
begin

$s_i = 0$

For i=0 to n
begin
For j=1 to 7
begin

$if\ \wp_{i0}^T = \wp_{ij}^T\ than\ s_i = s_i + 1$

For i=0 to n
begin

$if\ s_i = 8\ than\ remove\ i-th\ column$

end
for k=1 to 2
begin
m_N=combi_n_m(n,k)
for i=0 to n
begin
for j=0 to 2
begin

$a = C_{i0},\ b = C_{i1},\ \wp_j^S = \wp_{aj}^R \oplus \wp_{bj}^R$

end
ComputeSUM3()

for i=0 to n
begin

$if\ A_i^Z = 0\ than$

begin
S=0
for j=0 to 7
begin

$a = C_{i0},\ b = C_{i1}$

$\wp_j^S = \wp_{aj}^R \oplus \wp_{bj}^R$

end
ComputeSUMP1_P2()
end
end
for i=0 to n
begin

$if\ (A_{ik}^{S1} = 5\ and\ A_{ik}^{S2} = 5)\ than\ \Im^{Fr} = 1$

end
end

The expert SolveTestAA implements an algorithm SolveTestAA(). An algorithm finds the solution and transforms it into the string form.

SolveTestAA()
begin
s1=0, s2=0
for i=0 to n
begin

$if\ A_{i0}^{S1} = 5\ than$

begin

$\wp_{s1}^{SA} = \wp_i^R$, *s1=s1+1*
end
$if \;\; A_{i0}^{S2} = 5 \;\; than$
begin
$\wp_{s2}^{SB} = \wp_i^R$, *s2=s2+1*
end
for i=0 to m_N
begin
$a = C_{i0}$, $b = C_{i1}$
$if \;\; A_{i1}^{S1} = 5 \;\; than$
begin
$\wp_{s1}^{SA} = \wp_a^{R1} \oplus \wp_b^{R1}$, *s1=s1+1*
end
$if \;\; A_{i1}^{S2} = 5 \;\; than$
begin
$\wp_{s2}^{SB} = \wp_a^{R1} \oplus \wp_b^{R1}$, *s2=s2+1*
end
end.

6 EXPERIMENT AND DISCUSSION OF THE RESULTS

The method of shape understanding was implemented as a shape understanding system (SUS). The shape understanding system (SUS) (Les 2004) is implemented in C++ under Windows 2000 on 3.06 GHz Pentium computer. In this paper understanding abilities of the shape understanding system are tested based on the intelligence tests. The SUS intelligence tests are formulated as the tasks given to the system.
In the experiment the progressive matrices test was used. In this experiment the task was formulated as: ‘find the object o_k, $k = 1,..5$ that fills the missing entry in the matrix $v_{i,j}$, $i, j = 1,..3$: $[\exists o_k : o_k \otimes v_{i,j}, \;\; for \;\; i, j = 1,..3 \;\; k = 1,...,5] \Rightarrow o_k \rhd \sigma$ The progressive matrices test consist of the eights matrix objects and five objects from which one was to be selected. The digital objects were obtained by generating exemplars from selected classes or by digitizing 2-D visual objects on a 256 x 256 pixel picture plane. The selection criterion is that the selected object fills the missing entry in the matrix. The test is presented to SUS as the sequence of the eight figures (the test) and the five figures as the answer. At first the symbolic names are obtained for each figure and next the test was performed by module called the test solver. During the testing stage the following tasks were tested: testing the general abilities of the SUS, testing the generalization abilities of SUS and testing the different levels of difficulties.
For testing general abilities of SUS the tests AO and FR were used. In this experiment SUS needed to identify the type of test and next to find the solution. Solving these two different types of tests required the proper identification of the type of the test. In this experiment the algorithms that were used to identify the type of the test were implemented as the part of the TestIdentificationExpert. In this experiment ten tests of the type AO and ten tests of the type FR were used. Examples of tests of the type AO are shown in Fig 10 and examples of tests of the type FR are shown in Fig 8 and 9. The solution in the form of the symbolic name that was found by SUS was compared with the solution that was obtained during the analysis of the test. The result obtained by SUS was in agreement with results obtained during the analysis of the test.

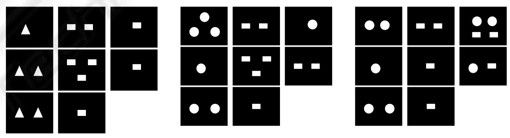


Figure 10: Examples of the tests of type AO

Testing ability to solve the test of the different levels of difficulties was performed on the test of the type FR. In this experiment the tests were grouped into three groups: the easy, the medium and the difficult. The level of difficulty of the test was found by analyzing of the perceptually relevant features and tested for small sample of human subjects. Tests with the different levels of difficulty were presented to SUS as a sequence of the eight figures. In this experiment 30 tests of the type FR were used. Examples of the tests used in the experiment are shown in Fig. 9-10. During the performance, time that was needed to solve the test was used as a measure of the level of difficulty.
An ability to make generalization was performed on two groups of tests. In the first group the first level of generalization was tested, whereas in the second group the second level of generalization was tested. The tests were given as a series of figures and solution was determined based on the properties of

the test. Each group of tests consisted of five tests. Examples of the test are shown in Fig. 11. Results obtained by SUS were in agreement with results obtained during the analysis of the test.

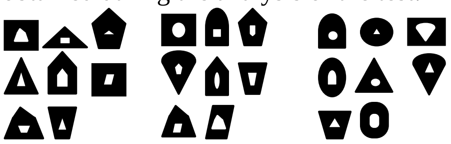


Figure 11: I level of generalization and (a,b) [f1] and II level of generalization (c) [f1]

Progressive matrices test requires good abilities of visual understanding. SUS needs to find the representation that shows only relevant features of the test. At first each figure is converted into symbolic names and next into strings. Strings, after refinements, are used to find the final solution. Testing general abilities of the SUS required identifying the type of the test and next finding the solution. In the experiment two different types of tests were used: the test of the type AO and the test of the type FR. Solving these two different types of tests required the proper identification of the type of the test. Although a number of types of tests could be large the method that was proposed would incorporate identification of the different types of tests. It would require implementing the proper algorithm in the TestIdentificationExpert. The algorithms for identification of the type ECW and the type GA were elaborated and partially tested. The result shows that proposed algorithm that was implemented as the part of the TestIdentificationExpert gives a very good results in identifying and solving visual tests. The results indicated that the visual tests can be performed in two steps: the test identification and finding the solution. The human subject also seems to perform the test solving in two steps. However, finding the type of the test does not guarantee that the human subject will be able to solve the test.

Testing ability to solve the test of the different levels of difficulty was performed on the tests of the type FR. The time performance depended both on the reasoning process that led to obtaining the symbolic names and the time in which the test solver solved the test given in the string forms. The reasoning process is part of all tasks that are performed by SUS and the time that is needed to obtain the symbolic names is characteristic for the perceptual abilities of SUS. The main indicator of the level of difficulty is the time in which problem solver solves the test. In the SUS for all tests presented there is indication that time performance depends on the level of difficulty. The time performance of the task seems to be indicator of the test difficulty, however the differences between the levels of difficulty are not very significant. Human subject solves these tasks in the different way. The levels of difficulty are an indicator of the human ability to solve the visual task. The tests that were ranked difficult were not solved by all human subjects. Although in the testing of the human subject a small sample was used the result indicates that there is a big difference in solving these tasks by human and by SUS. The main reasons seem to be that SUS has a very good string representation of the task. Even the test which was classified as difficult was solved by SUS. It indicates that for each tests that can be represented by the string representation shown in this paper the level of difficulties can be measured by time of performance of the test. In comparison to the human subject who after training process has its performance very depending on the level of the test difficulty, the SUS performance vary only in the time that is needed to process the bigger number of calculations.

An ability to make generalization was performed on two groups of tests. All tests were solved by SUS assuming that the generalization was performed in ordered manner that means it takes into account the known structural features of the exemplar. Generalization requires knowledge of the class description as well as knowledge of the geometrical properties of the visual figures. In the case of SUS the symbolic name that is the result of the visual reasoning includes description of the class that refers to the geometrical properties of figures. The hierarchical structure of the shape classes make it possible to perform generalization based on the string representation. The combinatorial manners that do not distinguished between the types of the class descriptions require interpretation of the string which was selected. The proposed method makes it possible to perform complex generalization based on the hierarchical structure of the shape classes.

7 CONCLUSION

In this paper understanding abilities of the shape understanding system (SUS) are tested based on the adoption of the intelligence tests. The intelligence tests are formulated as the tasks given to the system. Performance of the SUS was compared with the human performance of these tasks. The results show that the SUS is able to perform visual tasks that are performed by the human observer during intelligence tests. The tests were based on the

progressive matrices test which requires the good visual problem solving abilities of the human subject. SUS solves these tests by transforming the visual form into the string form. The proposed string form makes it possible to perform complex visual reasoning.
The experiment proved that the proposed method, which is part of the SUS visual understanding abilities, can solve the test that is very difficult for human subject.
The main novelty of the proposed method is that all tasks performed by SUS applied their internal representations called the visual concepts. The visual concept in the case of the visual test refers to the string representation of the test pattern.

REFERENCES

Bhanu, B., and Faugeras, O.D. (1984). "Shape Matching of Two-Dimensional Objects." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 6(2): 137-156.

Colaruso, R., and Hammil, D. (2003). Motor Free Visual Perception Test. New York, Academic Therapy Publications.

Gardener, M. F. (1996). Test of Visual-Perceptual Skills, Psychological and Educational Publicatios.

He, Y., and Kundu, A. (1991). "2-D Shape Classification Using Hidden Markov Model." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 13(11): 1172-1184.

Kartikeayan, B., and Sarkar, A. (1989). "Shape Description by Time Series." *IEEE Transactions on Pattern Analysis and Machine Intelligence* 11(9): 977-984.

Les, Z. (2002). "Shape Understanding System: Understanding the thin object." *An International Journal Computers and Graphics* 26(6): 951-970.

Les, Z., and Les, M. (2003). "Shape Understanding system: Understanding of the Convex Objects." The Journal of Electronic Imaging 12(2): 327-341.

Les, Z., and Les, M. (2004). "Shape Understanding System-the System of Experts." International Journal of Intelligent Systems 19(10): 949-978.

Les, Z., and Les, M. (2005). "Shape Understanding System: Understanding of the Complex Object." The Journal of Electronic Imaging (in print) 14(2).

Les, Z., and Les, M. (2005). "Understanding of a Concave Polygon Object in Shape Understanding System." Journal of Computer and Graphics 29(3): 365-378.

Lu, C. H., and Dunham, J.G. (1993). "Shape Matching Using Polygon Approximation and Dynamic Alignment." *Pattern Recognition Letters* 14: 945-949.

Pal, N. R., Pal, P., and Basu, A.K. (1993). "A New Shape Representation Scheme and Its Application to Shape Discrimination Using a Neural Network." *Pattern Recognition* 26(4): 543-551.

Pope, A. R. (1994). Model-based Object Recognition, a Survey of Recent Research, Department of Computer Science, The University of British Columbia.

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