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Testing Visual Abilities of Machines - Visual Intelligence Tests

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***Abstract*—**Intelligence tests are series of tasks designed to measure the capacity to make abstractions, to learn, and to deal with novel situations. Testing of the visual abilities of the shape understanding system (SUS) is performed based on the visual intelligence tests. In this paper the progressive matrices tests are formulated as tasks given to SUS. These tests require good visual problem solving abilities of the human subject. SUS solves these tests by performing complex visual reasoning transforming the visual forms (tests) into the string forms. The experiment proved that the proposed method, which is part of the SUS visual understanding abilities, can solve a test that is very difficult for human subject.

***Keywords*—**Shape understanding, intelligence test, visual concept, visual reasoning.

I. Introduction

INTELLIGENCE tests are series of tasks designed to measure the capacity to make abstractions, to learn, and to deal with novel situations. The class of intelligence tests called the visual intelligence tests includes tasks that deal with visual forms (shapes). These tests 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 [1], [2].

SUS 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 objects. A shape understanding method described in this paper takes into account geometrical properties of the visual object, properties of digital representations of the visual object, perceptual properties of the visual object and symbolic representations of the visual object. Current research, which is part of the shape understanding method, considers shape as a geometrical figure that has all parts clearly visible, that means there is no small parts of the figure that can not be uniquely interpreted. Existing methods of shape analysis are mostly concerned with shape recognition [3], [4], [5], [6], [7]. Visual systems applying shape as their knowledge are called the model-based object recognition systems and have been used extensively by vision researchers [8].

In the previous research on the application of the visual intelligence tests to test the abilities of SUS to understand the visual tasks, the different visual intelligence tests were analyzed and applied for testing [9]. In this paper the progressive matrices tests are applied to tests abilities of SUS to understand the visual tasks.

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II. Undestanding of the Visual Object

Shape understanding method [10], [11] 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 [10], [11], [12], and [13]. In this paper a 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 (Fig.1a), the quadrilateral class L^4 (Fig.1b), the convex curve polygon class M (Fig.1c), the convex curve class K (Fig.1d), the concave polygon classes $Q_{L^5}(L^3)$ and $Q^2_{L^5}(2L^3)$ (Fig.1e,f), the concave curve class $Q^1_{M^1}(M^1)$ (Fig.1g), the thin class $\Theta^3_{L^3_E}([l,m,m])$ (Fig.1h).

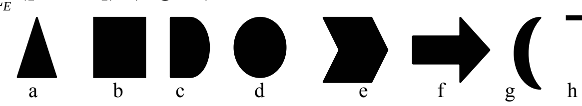


Fig. 1 Exemplars from the convex polygon class

III. Progressive Matrices Test

In this paper the progressive matrices tests are formulated as tasks given to SUS. Two types of progressions or relationships are established, one in the horizontal and one in the vertical direction. The examinee is required to pick the choice that correctly fills the missing entry in the lower right-hand corner of the matrix.

Progressive matrices tests can be divided into four groups depending on the main strategy used for finding the solution.

In the next chapters the tests that belong to each group are briefly described.

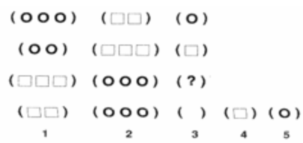
IV. The Test Type of Arithmetical Operations AO

The test type of arithmetical operations AO consists of eight patterns of two different types of figures that code the arithmetical operations such as addition or subtraction. Each of eight patterns consists of two different figures that are meaningful for arithmetical operations. Let the first figure is denoted as F1 and the second figure as F2. The number of figures F1 in the pattern Pi is denoted as mi, whereas the number of figures F2 in the pattern Pi is denoted as ni. The test pattern can be represented as follows:

P1(m1F1,n1F2) P2(m2F1,n2F2) P3(m3F1,n3F2)
P4(m4F1,n4F2) P5(m5F1,n5F2) P6(m6F1,n6F2)
P7(m7F1,n7F2) P8(m8F1,n8F2) P9(m9?,n9?)

Two rows are used to find the relationships between numbers of figures F1 and F2 and the third row is used to find the solution. The relationship is expressed by the following equations: (m1-n1)+(m2-n2)=(m3-n3), (m4-n4)+(m5-n5)=(m6-n6), and the final solution by solving equation (m7-n7)+(m8-n8)=(?). For example for the test in Fig.2a we have m1=3, n1=0, m2=0, n2=2, m3=1,n3=0, m4=2, n4=0, m5=0, n5=3, m6=0, n6=1, m7=0, n7=3, m8=3, n8=0. Inserting into equation we obtain:

(3-0)+(0-2)=(1+0), (2-0)+(0-3)=(0-1),
(0-3)+(3-0)=(0,0).


a

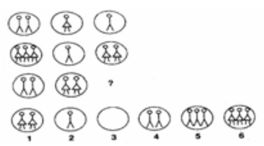

b

Fig. 2 Examples of test type of arithmetical operations AO

V. The Test Type of Abstraction ECW

In the test type of abstraction ECW there are selected attributes that are changes across the rows/columns. The test consists of eight figures for which one of its visual features such as size, color or thinness varies across the rows. Let figures in the row/column are denoted as F1, F2, F3. The visual features that differ across the rows/columns are denoted as f1, f2 and f3. The test pattern can be represented as follows:

F1(f1) F1(f2) F1(f3)
F2(f1) F2(f2) F3(f3)
F3(f1) F3(f2) ?

From this pattern the solution is easy to obtain and is given as F3(f3). The pattern shows the configuration where the changes are made across the rows. In order to have a configuration where the changes are made across the columns the matrix needs to be transposed. For example, in Fig. 3b the size of the figure is changing across the rows. In this example F1='circle', F2='circle with pattern' and F3='circle with two patterns' and the selected feature is the size: f1='small', f2='medium' and f3='large'. The possible solution we are looking for is F3='circle with two patterns' and f3='large'. The possible answer is given as six figures and the final solution is found by matching the possible solution with all answer figures.

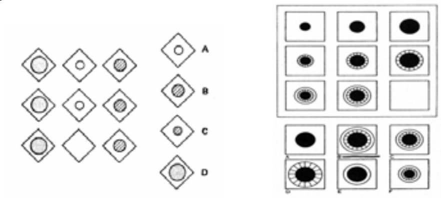


Fig. 3 Examples of tests type of abstraction ECW

VI. The Test Type of Geometrical Addition GA

The test type of geometrical addition GA has two different figures in column one and column two (in rows one or two) that makes the figure in column three by applying the geometrical operators. The test pattern can be represented as follows:

F1 F2 F3
F4 F5 F6
F7 F8 ?

Two rows are used to find the relationships between figures F1 to F6 and figures F7 and F8 in the third row are used to find the possible solution. The relationships can be written as F1*F2=F3, F4*F5=F6, F7*F8=?, where '*' denotes the geometrical operator. Fig. 4 shows the figure in the first column that is the geometrical sum of the figures in the second and the third column.

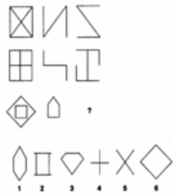


Fig. 4 Example of the test type geometrical addition GA

VII. The Test Type of Finding Relationships FR

In the test type of finding relationships FR figures are arranged in such a way that two sets (the six figures are used to find the general rules of prediction and two figures are used to find the possible solution. In order to have a solution the test needs to have at least two features in common for each three figures. The test pattern can be represented as follows:

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.

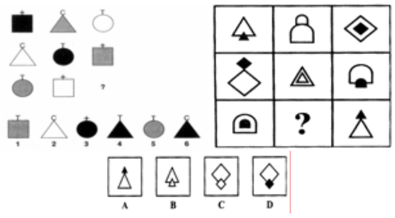
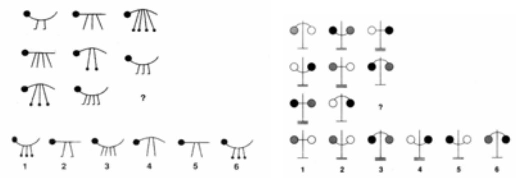


Fig. 5 Examples of the test type finding relationships FR



a b

Fig. 6 Examples of the test type finding relationships FR

The solution to the test can be given in the interpretational steps. Examples of the interpretational steps for the test shown in Fig.6a are given as follows.

Test in Fig. 6a.

$C(K^1,\Theta(c(h),s(l),b,s(l),c(h)))$ [K,h,l,b,l,h]

$C(K^1,\Theta(s,s,b,s,b,s,s)$ [K,s,s,b,s,b,s,s]

$C(K^1,\Theta(c(d),s(k),b,s(k),b,s(k),b,s(k),c(d)))$ [K,d,k,b,k,b,k,b,k,d]

$C(K^1,\Theta(s,s,b,s,b,s,b,s,s)$ [K,s,s,b,s,b,s,b,s,s]

$C(K^1,\Theta(c(d),s(k),b,s(k),c(d)))$ [K,d,k,b,k,d]

$C(K^1,\Theta(c(h),s(l),b,s(l),b,s(l),c(h)))$ [K,h,l,b,l, b,l,h]

$C(K^1,\Theta(c(d),s(k),b,s(k),b,s(k),c(d)))$ [K,d,k,b,k,b,k,d]

$C(K^1,\Theta(c(h),s(l),b,s(l),b,s(l),b,s(l),c(h)))$ [K,h,l,b,l, b,l,b,l,h]

?

1. $C(K^1,\Theta(c(h),s(k),b,s(k),b,s(k),c(d)))$ [K,h,k,b,k,b,k,h]
2. $C(K^1,\Theta(s,s(l),b,s(l),s))$ [K,s,l,b,l,s]
3. $C(K^1,\Theta(c(h),s,b,s,b,s,b,s,c(h)))$ [K,h,s,b,s,b,s,b,s,h]
4. $C(K^1,\Theta(c(d),s,b,s,c(d)))$ [K,d,s,b,s,d]
5. $C(K^1,\Theta(s,s,b,s,s))$ [K,s,s,b,s,s]
6. $C(K^1,\Theta(c(h),s(k),b,s(k),b,s(k),c(d)))$ [K,h,k,b,k,b,k,h]

[K,h,l,b,l,h] [K,s,s,b,s,b,s,s] [K,d,k,b,k,b,k,b,k,d]
[K,s,s,b,s,b,s,b,s,s] [K,d,k,b,k,d] [K,h,l,b,l, b,l,h]
[K,d,k,b,k,b,k,d] [K,h,l,b,l, b,l,b,l,h]

1[K,h,k,b,k,b,k,h] 2[K,s,l,b,l,s] 3[K,h,s,b,s,b,s,b,s,h]
4[K,d,s,b,s,d] 5[K,s,s,b,s,s] 6[K,h,k,b,k,b,k,h].

After removing letters K and b we obtain the following form:

[h,l,l,h] [s,s,s,s,s] [d,k,k,k,k,d]
[s,s,s,s,s,s] [d,k,k,d] [h,l,l,l,h]
[d,k,k,k,d] [h,l,l,l,l,h]

1[h,k,k,k,h] 2[s,l,l,s] 3[h,s,s,s,s,h] 4[d,s,s,d] 5[s,s,s,s] 6[h,k,k,k,h].

Sequence h,k..., s,l,..., h,s,…, d.s,…, needs to be removed. The result is 5[s,s,s,s].

In the present paper the progressive matrices tests are used to test visual understanding abilities of the shape understanding system (SUS). The shape understanding system that is implementation of the shape understanding method is based on the concept of shape classes.

VIII. The String form Representation

In SUS the symbolic names are used represent the archetypes of the shape class. The symbolic names are transformed into the string forms. 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 class is expressed as M1L3A 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.7 (L3A, L4R, M1L3A, M1L4R, M2L4R) are all of the type P.

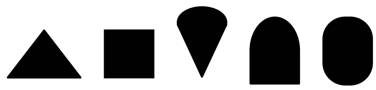


Fig. 7 Exemplars of the class type P

IX. 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 8).

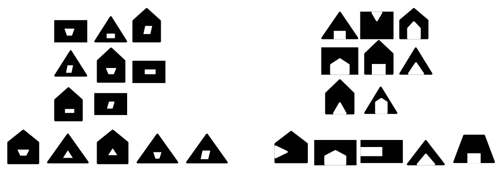


Fig. 8 Examples of tests and answers

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 $\wp_i^S$. 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|.

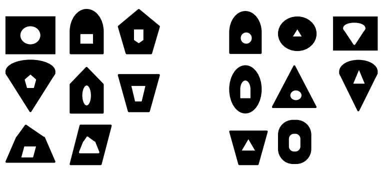
A. Representation and Generalization

The symbolic name η_i , $i = 1,..8$ that is obtained during visual reasoning refers to one of the symbolic representations and is transformed into a basic form. The basic form includes symbols that refer to the symbolic names (general level of description). For example, the symbolic notation $Q^2_{L^4_R}(2L^3_A)$. is transformed into the string form Q<L4>[R]|<L3>[A]<L3>[A].

Symbolic names are described with reference to the level of details. The levels of details need to be taken into account during translation of the symbolic names into strings. 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 n-th level of details can be written in the string form as follows:

$$jA_1^0 \ldots \_\ jA_1^H \mid \ldots \mid jA_i^0 \ldots \_\ jA_i^H \mid \ldots \mid jA_1^0 \ldots \_\ jA_n^H \mid .$$

Examples of the test for one and two levels of details are given in Fig. 9.



a b

Fig. 9 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 for the test 1. A_1|L3_*|L5_*|, and
the test 2. A1|K_*_*|K_*_*|.

During generalization the symbol is dropped from the left to the right. For example, for the test in Fig 9a the first level of generalization (the first row) is A|L4|L5|. For the test in Fig.9b the first level of generalization (the first row) is A_1|M_1|K_1| and the second level of generalization is A|M|K|.

X. Test Difficulties

In conventional item analysis, when the difficulty of an item is assessed, a p-value is derived. This p-value represents the proportion of people in the sample who have responded correctly to the item. In this research it is assumed that the level of difficulty of the test depends on the number of perceptual elements of the test. The perceptual elements denote the number of different parts of the test figures, the level of details, the level of generalization and the number of features.

The number of different parts is computed taken into account a figure as a whole or its parts. For example, in the Fig. 10a there are eight concave figures and three different convex parts. The number of different parts for the tests in Fig. 10 is a.n=11, b.n=11, c.n=13, d.n=14. The level of details is described by the level of meaningful parts that are used to find the relationships in the test. For example, in Fig. 10a for the relationship {F1,F6,F8} there is the level of details equal 0 and for the relationship {F3,F5,F7} there is the level of details equal 1. This is denoted as L(0,1). For the test in Fig. 10b the relationship is given as L(1,1). The number of features denotes the number of parts on the same level of details. For example, for the test in Fig. 10c the number of features f=1, and for the test in Fig. 10d the number of features f=2 . The level of details refers to the class description and indicates the level of iteration in the concave and cyclic class. For the test in Fig. 10 level of generalization G=0, for the Fig.13a,b G=1 and for Fig 14c, G=2. For the tests given in Fig. 10 level of difficulties of the test is E0 a. L(0,1), f=1, l=1, G=0 n=11 b.L(0,1), f=1, l=1, G=0, n=11, c.L(0,1), f=1, l=1, G=0, n=13, d.L(0,1), f=2, l=1, G=0, n=14. It was assumed that level of difficulties in solving the test depends on the combination of all perceptual elements of the test items. Depending on the variation of the perceptual elements of the test the three levels of difficulty were distinguished: the easy level, the medium level and the difficult level. When the easy level can be relatively easy to establish based on the combination of all perceptual elements of the test items, the medium and the difficult levels were established based on the subjective filing of difficulties of the task. The problem of the levels of difficulty in the context of the task solved by human subject is very complex and the further research is needed to find the final solution. Examples of tests with different levels of difficulty are shown in Figs. 10-14.

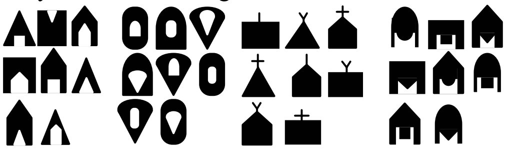


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Fig. 10 Tests of the level of difficulty E0

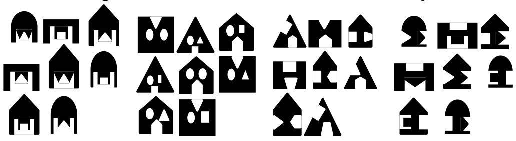

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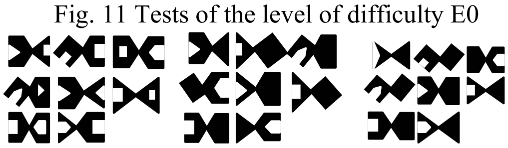
Fig. 11 Tests of the level of difficulty E0



a b c

Fig. 12 Tests of the level of difficulty E1

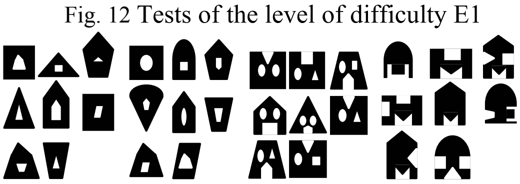


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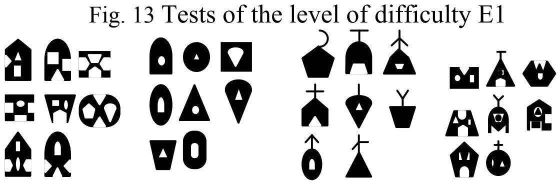
Fig. 13 Tests of the level of difficulty E1



a b c d

Fig. 14 Tests of the level of difficulty E2

XI. Experiment and Discussion of the Results

The shape understanding system (SUS) [14] is implemented in C++ under Windows 2000 on 3.06 GHz Pentium computer. In this paper understanding abilities of the shape understanding system were tested based on the intelligence tests (progressive matrices test). The SUS intelligence tests are formulated as the tasks given to the system. In this experiment the progressive matrices test was used and 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 consists 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 2D visual objects on a 256 x 256 pixel picture plane. The test is presented to SUS as the sequence of the eight figures (a 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 different levels of difficulties of the test were tested.

Testing ability to solve the test of the different levels of difficulties was performed on the test of the type FR. The levels of difficulties were established based on the combination of the all perceptual elements of the test items. The tests were grouped into three groups: the easy, the medium and the difficult. The easy level (E0) was found by analyzing of the perceptually relevant features of the figures. Because the number of the combinations of the perceptual elements was big, at this stage of research, the medium and the difficult level were established based on the subjective filing of difficulties of the task.

Tests with 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 Figs. 10-14. During the performance, time that was needed to solve the test was used as a measure of the level of difficulty.

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.

Experiment shows that ability of SUS to solve visual task can be measured by visual intelligence tests. Progressive matrices test type FR, requires good abilities of visual understanding and make it relatively easy to design the tests that has the different levels of difficulties. However, when the easy test (easy levels of difficulty) can be designed based on the combination of all perceptual elements of the test items, the medium and the difficult tests were designed based on the subjective filing of difficulties of the task. In the designing of the test the different abilities such as abilities to make generalization seems to depend both on the properties of figures as well as the SUS abilities to perform generalization. These problems are complex and the further research is needed to find the final solution.

The time performance of the test solving 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 time that was needed to obtain the symbolic names is characteristic for the perceptual abilities of SUS. The symbolic names are obtained during a reasoning process and the reasoning process is part of all tasks that are performed by SUS. The time in which problem solver solves the test seems to be indicator of the test difficulty, however the differences between the levels of difficulty are not very significant. The results obtained show that SUS solves these tests in the different ways in comparison to the human subject. 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. It can be explained by this that

SUS has very good abilities to interpret the visual objects as one of the shape class. Each shape class has its representation that makes it possible to perform complex visual reasoning.

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.

XII. Conclusion

In this paper understanding abilities of the shape understanding system (SUS) were tested based on the adoption of the intelligence tests.

Intelligence tests are series of tasks designed to measure the capacity to make abstractions, to learn, and to deal with novel situations.

In this research testing of the visual abilities of the shape understanding system (SUS) was performed based on the visual intelligence tests (the progressive matrices tests). The designed progressive matrices tests had the different levels of difficulties. The results show that SUS solves these tests by performing complex visual reasoning transforming a visual form (test) into a string form. 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.

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