COGNITIVE MODELS IN PLANIMETRIC TASK TEXT PROCESSING

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A B S T R A C T

A new cognitive approach is proposed for understanding the texts of planimetric tasks and for visualizing the task conditions to complement the syntactic-semantical sentence parsing. Two main difficulties in understanding texts of plane geometry tasks are observed: the ellipticity and vagueness of texts. To overcome the difficulties in understanding the task conditions it is proposed constructing cognitive models of objects and relations between them. The proposed cognitive approach is incorporated in an integrated system for automatic solving planimetric tasks with the natural language interface. The interactive visualization has been developed in the system. It depicts the syntactic and semantic structures as a result of natural language text analysis and searching for task solution. This visualization allows the users to obtain explanations associated with any elements of the images and to correct the tasks' texts in dialog with the system. The destiny of the system is to serve for training schoolchildren in the domain of Euclidean geometry. The cognitive approach proposed can be a first step to automated analyzing plane geometry texts, in perspective, as a cognitively controlled parsing.

1. INTRODUCTION

An integrated intelligent system to solve natural language planimetric tasks is considered. The system embodies some intellectual characters: it contains and uses the problem domain knowledge (plane geometry), it has a natural language interface and understands texts of geometric tasks. The solver of the system works based on heuristic search for solution. Visualization in this system is aimed at showing as much as possible all the stages of the system's functioning and giving in the "point and click" manner explanations about the content and genesis of any element of the drawing.

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Drawing the conditions of geometrical tasks is a key problem in the system (for students too). The difficulty in analyzing and understanding the text is induced by various reasons. One reason is the ellipticity of the text. The resolution of ellipses in the texts of planimetric tasks is considered by us in (Kurbatov, Naidenova and Ganapol'skii, 2019).

However, there are difficulties in understanding texts without ellipses too. These difficulties are caused, first, a vague text language that is not logically and linguistically clear. Secondly, these difficulties are induced by the necessity to attract general geometric knowledge related to objects and relationships in the texts of tasks. Thirdly, some difficulties are explained by the need to choose from several building options, or to formulate additional considerations (conditions) for drawing. The latter circumstance requires the involvement, in the process of drawing, various assumptions and logical conclusions.

An example of a lack of text clarity might be the task: "two circles of radii r and

R (r < R) are located such that one of their internal tangents is perpendicular to one of their external tangents. Find the area of the triangle formed by these tangents and one of the internal tangents".

Some examples of involving the common geometric knowledge are:

1. "Three circles, the radii of which are 1, 2, and 3, touch in pairs externally. Calculate the radii of two circles, each of which touches to three given circles". (Here it is required understanding how to build two additional circles).

2. "Through point R, lying on the continuation of diagonal AC of quadrangle ABCD and the middle of sides BC and CD, are drawn two straight lines crossing sides of AB and AD, respectively, in points E and F. Prove that the straight lines EF and BD are parallel". (In this task, it is necessary to take into account that through two points you can draw only one straight line, and two straight lines should intersect at point R).

3. "Find the corners of an equilateral triangle if its altitude is half the bisector of angle at the base". (Here you have to decide what altitude is meant).

4. "A square is inscribed in the other square. Calculate a smaller angle between the sides of the squares if their areas are related as 2:3". (It is important to consider the position of the vertices of the inscribed square).

There are the tasks for which drawing their conditions is possible only after their solution. For example: "Is there a rectilinear polygon in which the length of one of its diagonals equals the sum of two other diagonals?"

Call these difficulties cognitive expectations. Cognitive expectations are apparently quite common when generating natural language texts. That is why we come to the idea of involving in the analysis of texts cognitive graphics and relations pre-formed in the system of solving planimetric problems. We can use them during the visualization of a task condition in dialogue with a user. The user can be a high school student, a teacher, and a schoolboy.

Despite the fact that the problems of resolving ellipses are widely discussed theoretically, most of works address only to a special type of ellipses, namely the verb ellipses (VE) and exclusively for English (Kenyen-Dean, Cheung, and Precup, 2016), (Liu, Gonzalez and Gillick, 2016), (McShane and Babkin, 2015; 2016). These ellipses refer to the omission of a verb phrase whose meaning can be reconstructed from the context. The structure of this ellipsis consists of two parts standing in a sentence on the right and left of the "dash". An example: "one had the power of the Sun, the other – the Moon".

To resolve multiple ellipses, a new method is advanced in (Shuster, Nivre and Manning, 2018). An example of multiple ellipsis is: "the prices growth amounted to 11.9% in 2003, in 2009 – 4.4 %, in 2014 – 7.5%.

It should be noted that the question of how to restore the full structure of elliptical part of a sentence has not been fully solved in the conventional approach based on syntactical-semantic parsing sentences. Linguists have already realized the restriction of the syntactical-semantic approach to resolving ellipses in which syntax is separated from semantics (Jurafsky, 1993, p. 3). In (Zhao, 2016), the following answers are compared to the basic questions in the framework of generative linguistics and cognitive approach:

- Is ellipsis a syntax unit?
- Is the meaning of ellipsis determined only by its antecedent?
- Is reconstructing the missed part in a sentence equivalent to understanding the ellipse in it?

Generative linguists answer these questions in the affirmative. Adepts of cognitive linguistics tend to answer in the negative. Thus, P. W. Culicover and R. Jackendoff, (2006, p. 414) state that there is no additional syntax structure corresponding to the missing words in the sentence and, therefore, the study of ellipses based on grammatical rules does not make sense.

The cognitive approach states that the meaning of the missed part of a sentence depends greatly on the meaning of the whole sentence. Understanding ellipsis does not mean that we first have to restore it, and then to turn to understanding the whole sentence. In fact, understanding the sentence also entails understanding the ellipsis in it. The meaning of the ellipsis is defined both by the explicit part of a sentence and by the knowledge of the subject area, including linguistics, pragmatics, encyclopedic knowledge, context etc.

Generative linguistics is not interested in the real human mental processes taking place in ellipsis resolutions. Cognitive linguists suggest that the design of meaning is a conceptual process (Langacker, 2009) and language itself does not encode meanings, but only gives a hint at their design (Evans and Green, 2006, p. 162).

2. MATERIALS AND METHODS

2.1. Description of the system for automated solving planimetric tasks

The main concept of the system for solving planimetric problems has been developed in (Khakhalin et all., 2012), (Kurbatov, Fominykh and Vorobyev, 2019) and its general scheme is given in Figure 1. The concept of "integrated system" covering natural language interface, heuristically oriented solver and conceptual visualization is described in (Lobzin et all., 2015).

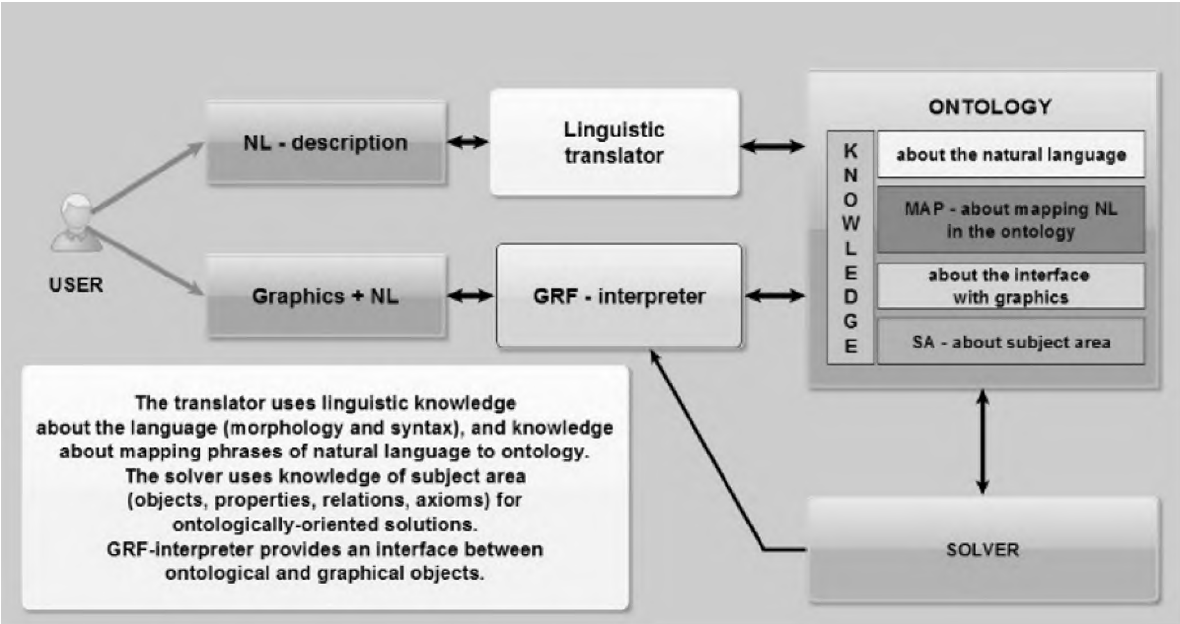

Figure 1. General scheme of the system

The system consists of the following blocks: "Ontology", "Solver", "Linguistic translator", "Graphics+NL", and "GRF interpreter" modules for drawing and explaining the results accompanied by the NL-explanation of the solution process.

The ontology serves for representing knowledge necessary for functioning all the subsystems of the system.

The task of the linguistic translator is to construct the conceptual description of a given geometrical situation in terms of concepts and relations of the ontology.

The solver takes the ontological description of task and searches for solution modifying the solution's intermediate semantic representation.

We use the semantic hypergraphs' language for the ontology representation. This language is an extension of semantic networks and it provides a suitable basis for naturally representing n-dimensional relations. For the Ontology's implementation, DBMS Progress has been used. In more details, the system ontology is described in (Kurbatov and Vorobyev, 2016).

The linguistic translator performs several processes: traditional grammar and semantic analyses, and semantic interpretation of planimetric task texts. The grammar analysis covers morphological and syntactic analyses. The semantic interpretation consists in "translating" text's fragments into corresponding ontological structures.

Processing NL-texts of planimetric tasks is based on the linguistic concept of paraphrasing (Apresian et all., 2010). With the help of the paraphrasing, subject-oriented text is translated into canonical structures directly displayed in the ontology. In the aspect of our fixed subject area, it is assumed that there are some standard (canonical) NL-descriptions of objects and relations.

The solver uses two components: heuristic and logical ones. The examples of heuristic rules are: reducing a task to its algebraic formulation; using the geometric concept of "locus of points"; searching for some cognate task; focusing on objects having maximal number of known and derived constituents; using empirical guesses; using statistical data; limiting the depth of search; beginning with the simple actions; using the symmetry; the trial and error method; using inductive reasoning, and some others.

The operations are performed on

semantic structures (SemS) (Mel'čuk, 2018). There are two kinds of operations: basic operations or construction axioms and general operations. Examples of basic operations: construction of straight line passing through two already constructed (given) points; construction of circle having the center in an already constructed point and radius equal to the segment connecting some already constructed points; construction of the intersection of two already constructed figures; selection of an arbitrary set of points belonging to one of already constructed figures. General operations realize the construction implemented with the use of basic operations and, possible, other general ones.

The interactive visualization provides the incremental control of syntactic and semantic structure formation and displaying the process of searching for task's solution. It is always accompanied by the explanation of elements of drawings and system solutions. The system allows to modify all the graphical images with keeping tasks' conditions. Figures 2 and 3 show the syntactic and semantic structures for the following task:

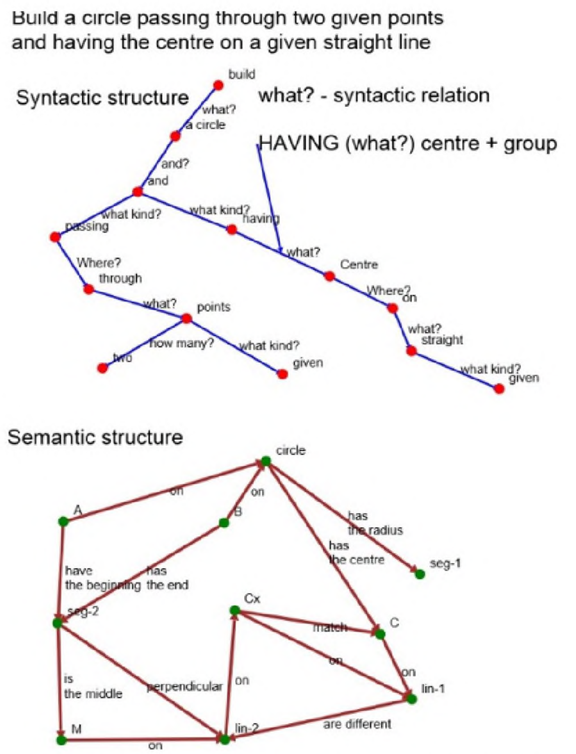

Figure 2. Syntax and semantic structures

"Build a circle passing through two given point and having the center on a given straight line".

It is possible by clicking on an object, for example, on word "*build*" or link "*what?*", to obtain the information about the characteristics of selected issue and the grounds for its creation (appearance).

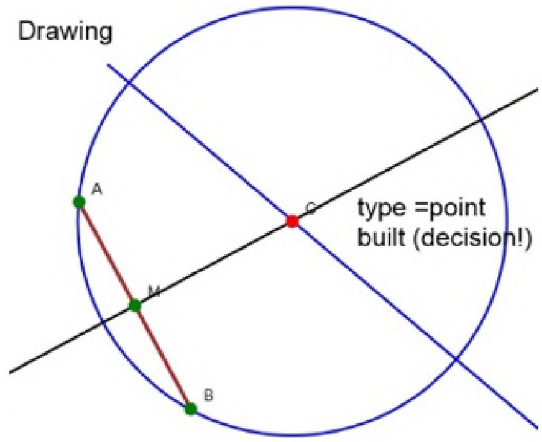

Figure 3. Drawing dynamically formed by the system as the solution protocol

The system visualization simplifies greatly debugging the ontology.

Each semantic and syntactic structure has its presentation in the ontology. This presentation is transformed into the natural language text taken by the program of visualization. Based on linguistic processing and solution search, a protocol is extracted from the ontology that forms a text file with a visualization program.

The interactive visualization is implemented based on javascript. Libraries JSXGraph (JSX Graph Reference) and MathJax (MathJax Documentation) were used to support graphics and mathematical formulas.

2.2. Cognitive models of objects and relations

The process of binding objects extracted from texts can be supported by cognitive models of objects and relationships between them. Cognitive scheme is designed to make syntax analysis of texts more effective, especially in cases of ambiguity and ellipses. Therefore, the cognitive scheme will combine three components:

• Semantic component in the form of a specific relationship between objects (typical geometric situation);

• Syntactical component associated with the semantic component, on the one hand, and with the corresponding fragments of text, on the other hand;

• Visual component in the form of a drawing of the corresponding geometric situation.

Semantic component can be expressed by using the system ontology.

We also assume that cognitive structures correspond to profound structures of geometrical situations outlined in the texts and define the structures of noun phrases (NPs), prepositional phrases (PPs), and verb phrases (VPs). Cognitive approach deals with modeling processes occurring in the human brain during solving the complex thought problems. In the case of geometric constructs, the cognitive process is associated with thinking about concrete objects (Sechenov, 2008). Cognitive models reflect the following relationships:

- object carries out some actions;
- object is subjected to actions of other objects;
- object has different relationships (spatial, temporal) with other objects;
- object can be compound;
- object can be a part of another object;
- object has properties (call them actant ones) related to the actions that object carries out (intersects – intersecting, touches – touching) or the actions performed on it (has been constructed – constructed, has been inscribed – inscribed). Thus, the actant properties are directly reflected in the morphological forms of words describing them;
- the relationships between the properties of one object or between the properties of different objects.

The cognitive models of objects and actions are created, in our approach, in an incremental mode using geometry school textbooks. Tables 1 and 2 depict some fragments of cognitive model "Bisector". An example of interacting NP and VP with cognitive scheme is given in Figure 4.

3. RESULTS

3.1. Dynamic visualization of cognitive models

Within the proposed approach, it is possible to use the tool of interactive dynamic visualization to create the initial drawing representing the task conditions and implicit relationships hidden in them. Now the ontology will be involved in constructing the draft of task condition.

Consider the cognitive scheme and its visualization for the following task: *Two circles are internally touch each other in a point A. From the center of greater circle, it is drawn radius OB touching the smaller in point C.*

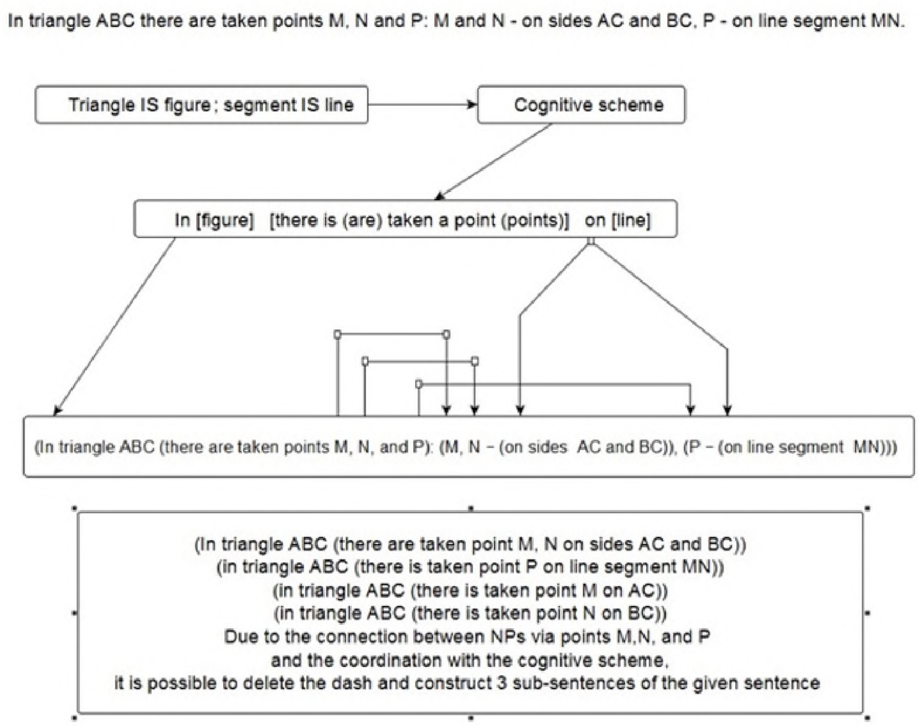

Figure 4. An example of interacting VP and NPs with a cognitive scheme

Table 1. Noun Phrases including "Bisector"

Bisector	Hyperlink to object (to NP)		Hyperlink to object (to PP)
Bisector of		angle	
Bisector of		angle	in (of) triangle
Bisector of	acute	angle	in (of) rectangular triangle
Bisector of	inner	angle	in (of) triangle
Bisector of		angle	at base of isosceles triangle
Bisector coming from		vertex	of inscribed triangle
Bisector of		angles adjacent to one side	in (of) parallelogram
Bisector of			in (of) triangle
Bisector of	inner	angle	in (of) parallelogram
Bisector of		angle	in (of) convex quadrilateral
Bisector of		angle	in (of) rectangle

Table 2. Verb Phrases including "Bisector"

Bisector	Hyperlink to action	Hyperlink to object (to PP)
Dividing	To divide	Side of triangle
Perpendicular	To be perpendicular	Median of triangle
Splitting, cutting in	To split, to cut in	Side of parallelogram in segments
Intersecting	To intersect	Bisector of triangle
Intersecting	To intersect	Circle
Restricting	To restrict	Area of quadrangle
Coming across	To come across	Circle in points
Containing	To contain	Points of intersection
Lying on	To lie	Straight line

We need the cognitive scheme "internally touching two circles" (Figure 5). The dynamic visualization program generates all possible variants of this situation, but it keeps the condition of "internally touching" (as an invariant one). The ratio between the lengths of the circles' radii and the reciprocal positions of their centers will be changeable. The center of the larger circle may be outside or within the smaller circle. So, we have two possible drawing of the current situation.

Now we take into account the other condition of the task: from the center of greater circle, it is drawn radius OB touching the smaller in point C. We turn to the cognitive scheme "to draw a tangent to a circle" (Figure 6). From this scheme, it will be known that the tangent is located outside the circle and has only one common point with it. Since the tangent line is simultaneously the radius of the larger circle, this radius should lie outside the smaller circle. Therefore, the center of the larger circle should lie outside the smaller circle. We have two variants of drawing consistent with the previous conclusion. Since there are no more conditions limiting the choice, we can take any option. Then the angle is selected the magnitude of which is unknown (Figure 7).

In the process of text analysis, the drawing satisfying a task conditions is created incrementally. This means that the solution of tasks begins together with this process.

The use of an interactive cognitive-oriented visualization is reflected in Figures 5, 6, and 7. After the "Start building" step, the user can modify the drawing (moving elements by mouse or requesting a system modification of the drawing). However, this action requires the organization of a dialogue with the system in the process of work.

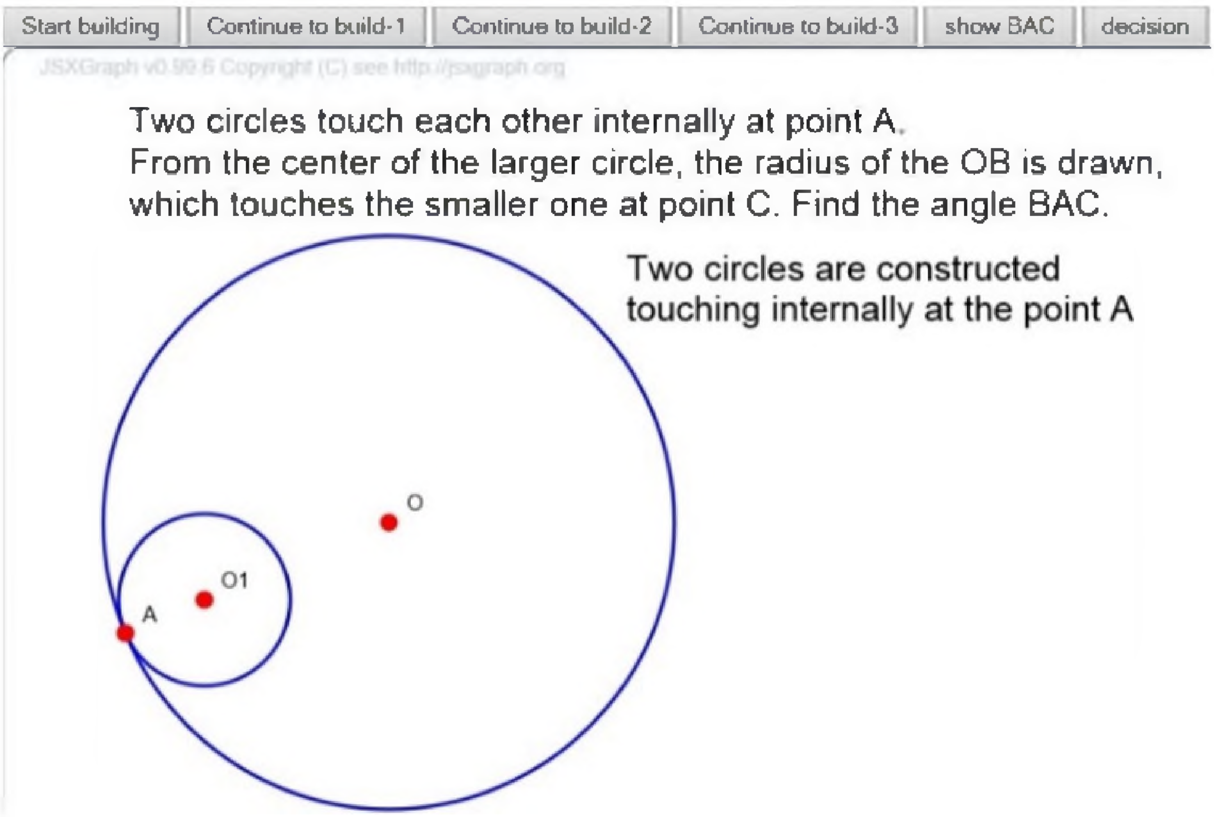

Figure 5. The draw of task after "Start building" (screen shot step)

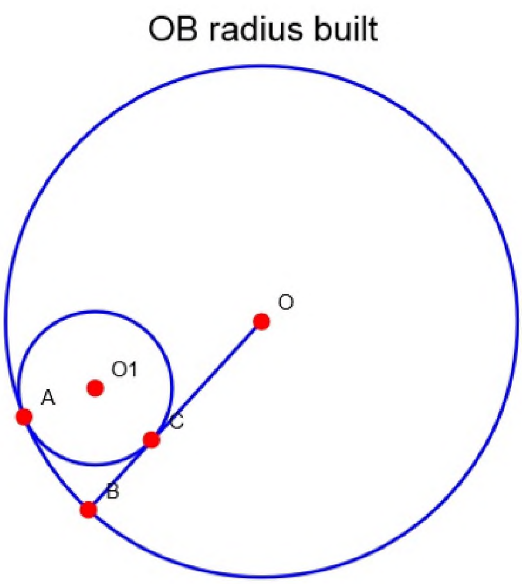

Figure 6. The draw of task after the step "Continue build-2"

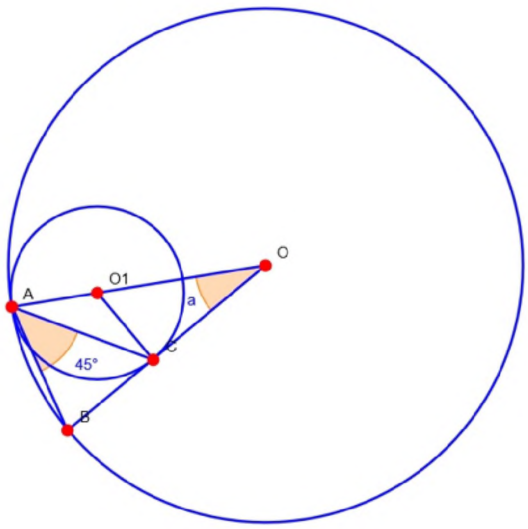

Figure 7. The draw of task after the step "Decision"

3.2. Using cognitive schemes in dialog with the users

Let a task be given: "two circles of radii r and R (r < R) are located such that one of their internal tangents is perpendicular to one of their external tangents. Find the area of the triangle formed by these tangents and one of the internal tangents". Figure 8 is the drawing corresponding with this task.

Suppose that the system fails to understand completely the text of this task and cannot construct the correct drawing of the task condition.

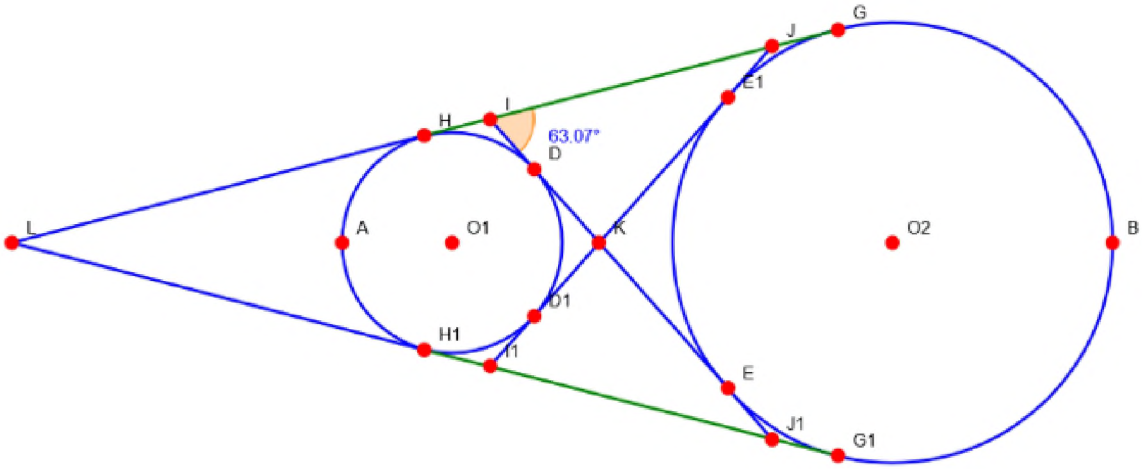

Figure 8. Drawing the initial cognitive structure

The proposed solution is advanced as follow:

1. The task text is used for extracting available cognitive model (for example, via the key words);

2. This model includes:

• semantic cognitive structure;

• the drawing of cognitive semantic structure;

• the natural language description of this drawing.

The drawing of cognitive structure (scheme) is showed to the user via a dialog (by means of simple commands (operations)). The user changes the drawing. The cognitive semantic structure and the task text are changes, in parallel, automatically.

After entering the changes, the system shows the new formed task text to the user.

If the user supports the text, then the new cognitive semantic structure is transmitted to the system solver.

The initial cognitive semantic structure is described as follows:

circle crcl -1 has radius variable r
circle crcl -2 has radius variable R
variable r smaller than variable R

circle crcl-1 has external_tangent line pr-1

circle crcl--1 has_external_tangent line pr-2

circle crcl--2 has_external_tangent line pr-1

circle crcl--2 has_external_tangent line pr-2

circle crcl--1 has intenal_tangent line pr-3

circle crcl--2 has_internal_tangent line pr 4

poin L on line pr-1
point L на line pr-2

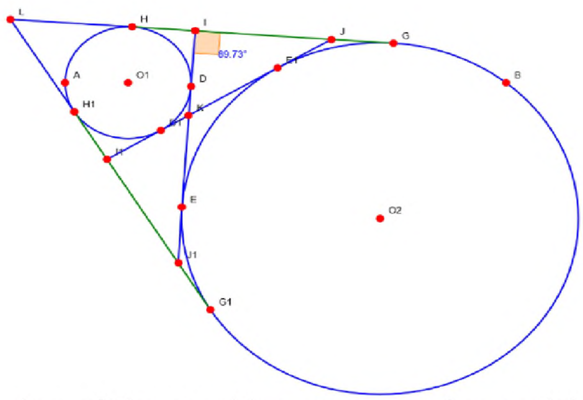

Figure 9. The drawing of the cognitive structure after applying the command about perpendicular lines

Natural language description of the drawing: "two circles of radii r and R (r < R) have internal and external tangents".

With the use of the command "selected straight lines are perpendicular" the drawing is changed (it is really working example). The result is in Figure 9.

With the use of the command (operation) «Find the area of triangle IJK" the task condition is made more exact.

Selecting objects can be done by a click of the mouse.

For example, the click on segment D1E1 gives some message and the segment is included in the list of selected objects (Figure 10).

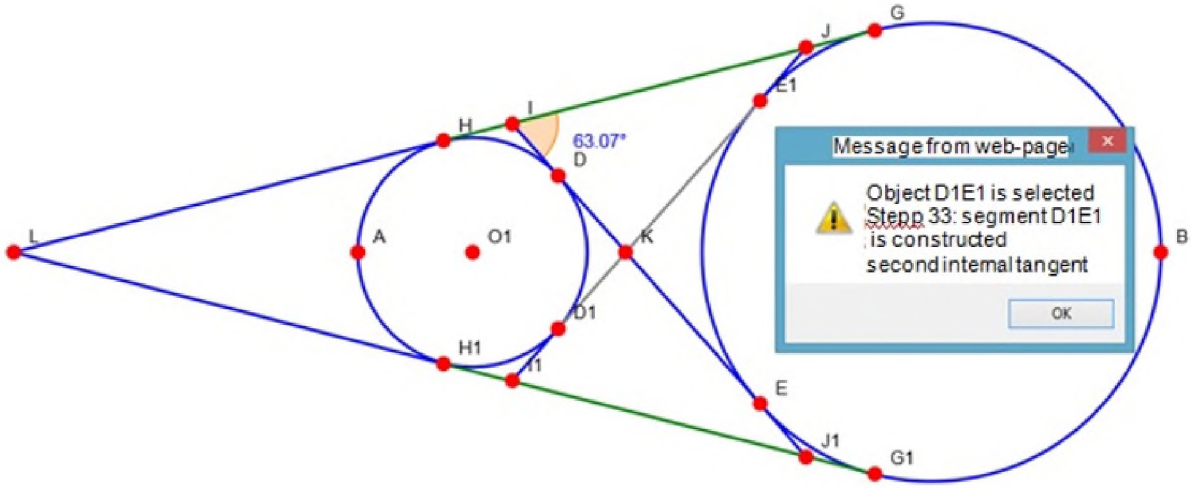

Figure 10. The message appears after selecting segment D1E1

Obtaining messages via the click is only particular case of the click-calling functions. These functions can provide a lot of possibilities: dialog, appeal to the ontology, editing the knowledge.

After supporting the cognitive scheme by the user, the initial text of cognitive scheme "two circle of radii r and R (r < R) have internal and external tangents" is completed by the following text:

"one of the internal tangents is perpendicular to the external one. Find the area of triangle formed by the internal tangents and this external tangent".

And after supporting the changed text of cognitive scheme by the user, the semantic structure is completed by the following fragment:

line pr-1 perpendicular line pr-3
triangle IJK has the area ?

And finally, the changed semantic structure is passed to the solver.

The commands form the main objects (points, straight lines, circles...) and the relationships between them (to belong, to be perpendicular, to be parallel, to intersect, ...). These operations call directly the library functions jsxgraph as well as create the commenting arrays (step descriptions and their explanations).

Of course, a step-by-step view of forming the drawing included in a cognitive structure is also provided, as well as a number of service functions - "freeze" the drawing, viewing auxiliary constructions (invisible on the drawing to avoid bulkiness), etc.

For example, you can make visible all auxiliary builds, here's an example (Figure 11): In the process of text analysis, the drawing satisfying a task condition is created incrementally.

The use of an interactive cognitive-oriented visualization is reflected in Figures 8-10. The user can modify the drawing (moving elements by mouse or requesting a system modification of the drawing). This action means the organization of a dialogue with the system in the process of work.

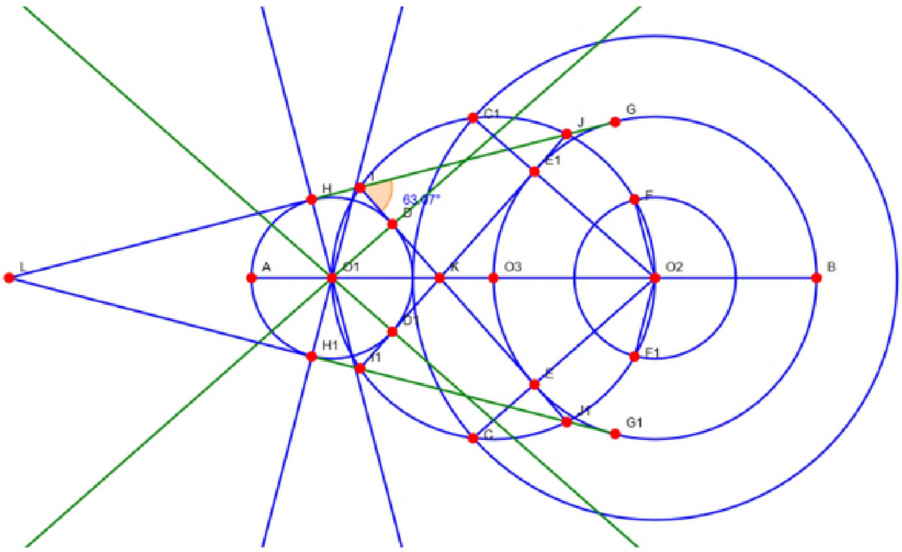

Figure 11. Auxiliary straights and circles needed to build tangents using known algorithms

4. DISCUSSIONS

We resume the features of cognitive models as follows:

• Each cognitive model (scheme) can be displayed as a drawing;

• Visualized dynamic cognitive model determines invariant relationships between its objects as like as all their possible configurations;

• Visualized cognitive models allow to list all the implied objects and relationships between them and to restore elided or hidden elements in the task text;

• The interaction of cognitive schemes implies narrowing the search for task solution.

Tuning system parameters, modifying heuristics and eliminating explicit defects are carried constantly.

Introducing the concept of cognitive model of geometry objects and actions implies that the structure of automated analysis of geometric texts can be considered, in perspective, as a cognitively controlled parsing.

The cognitive models imply also the possibility to synthesize a text describing a geometric situation and compare this text with the text to be analyzed.

5. CONCLUSIONS

The essential role of cognitive approach for understanding natural language texts of planimetric tasks and displaying task conditions in the form of a drawing is shown. A structure of cognitive schemes to represent planimetric objects, relations between them and planimetric constructions is proposed. Two kinds of difficulties in understanding the task texts are described: the ellipticity of texts and their vagueness. It is proposed the dynamic visualization of cognitive schemes and using them in dialog with the user to create the draft of task condition and to restore the task text.

The organization of natural language dialog between the system and the users at all the steps of the system's functioning is the aim of our future investigations.

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Conflict of interests

The authors have not a conflict of interest.

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