An authoring tool for preparing online theorems and proofs with a dynamic geometry environment

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Abstract: With advanced technologies of natural language processing, interactions between computer and human can be very user-friendly. Recently, humans can use their language to communicate to systems of computer-assisted learning. In this paper, an authoring tool has been proposed to help students learn geometry theorems and proofs. This tool is based on Java Sketchpad and regular expression template. With the tool, teachers can edit a geometry proof problem with a client browser and analyse the problem with the knowledge engine. Moreover, the knowledge engine translates the online materials into a XML format and produces a script for drawing a dynamic geometry figure within Java Sketchpad. With an internet browser, students can access these XML materials and manipulate the figure in the dynamic geometry environment when studying theorems and proofs. Furthermore, a preliminary evaluation of the knowledge engine shows that it can understand about 77% of textbook problems.

Keywords: Natural language processing, XML, authoring tool, dynamic geometry environment, geometry proof

Introduction

With the progress of artificial intelligence, the technologies of natural language understanding have been applied to various fields. Less and Cowie [1] designed a natural language consulting interface that helped users to learn UNIX on their own. Chen and Xu [2] proposed a syntactic parser, Grammar-Debugger, which could parse both the grammatical sentences and ungrammatical sentences typically produced by Chinese EFL (English as Foreign Language) learners and to provide feedback in response to their errors. Based on Why2-Atlas, Makatchev [3] presented a natural language inter-talk system which asked students physics questions. Students were asked to give their answers and explanations. In the process of learning, this system would re-analyze the data and give proper feedback for students.

This study tries to provide teachers with an authoring tool that understands geometry proofs in their natural textbook form. Mathematicians and educators all agree that geometry

learning plays an important role in mathematics education and proving geometry theorems is a special skill [4, 5, 6]. In studying geometry theorems and proofs, students have to read many examples from teachers and textbooks before they are able to write down similar proofs. de Villiers [7] suggested that students should discover, believe, and then explain a geometry problem. Students can discover geometric invariants and try to explain them. First of all, we can help students by providing a dynamic geometry environment (DGE) [8, 9] that they can interact with in order to understand the invariants. After enough exploration, the students might believe the propositions. When a proposition becomes meaningful and convincing to students, it means their comprehension is solid. Otherwise, they might not be sure whether the proofs are correct and also forget them easily [10, 11]. Our system analyzes geometry theorem problems and converts them to XML format while automatically producing Java Sketchpad scripts that draw the figures of the theorems in a dynamic geometry environment. Java Sketchpad (JSP) [12] is a software that lets authors publish sketches of Geometer's Sketchpad and user interact with them on the internet. The Geometer's Sketchpad is a DGE available for Macintosh and PC computers from Key Curriculum Press. Students can use Java Sketchpad to distribute interactive, dynamic geometry curricula and activities over the internet.

1. System Design

This section focuses mainly on the online authoring tool and its functions. With this tool (Figure 1), a teacher can edit a geometry theorem that is in natural language and a formal proof that uses both natural language and math symbols. After the theorem is parsed by our knowledge engine, a figure is generated automatically in Java Sketchpad [12]. The teacher can check the theorem and the figure. At the same time, the system will also transform the theorem and its proof into XML format and then store them into a database of proofs. The reading engine can parse the XML files and present the proofs in a textbook format on any internet browser. When students assess learning materials on the internet (Figure 2), they can read the geometry proofs prepared by the teacher. The given conditions of the theorem are also extracted by the system. The construction description of the figure explains how the figure is constructed step by step. Besides, we hope the dynamic geometry figure in this system would be beneficial for students to understand the theorem. By dragging geometric components of the figure, students can understand the meanings of geometric invariant conditions visually.

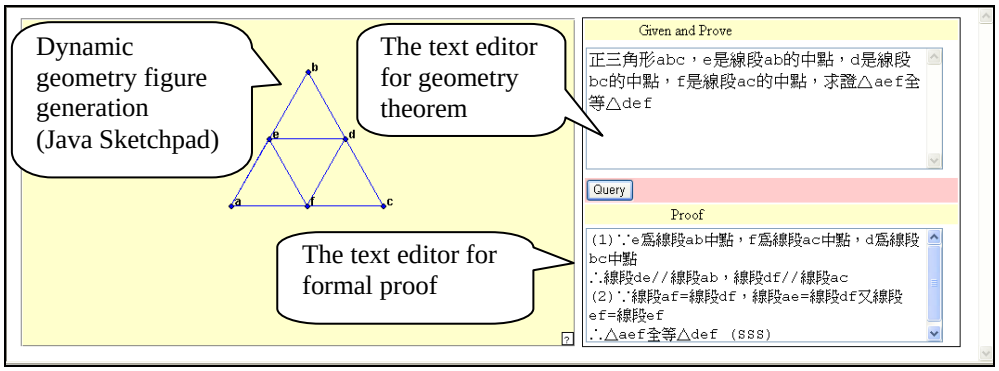

Figure1. Editor interface for the problem of geometry proof

This system architecture is composed of five components: (1)Geometry theorem analyzer: it analyzes geometry proof by retrieving the main properties and attributes of

geometric concepts (2) dynamic geometry figure generator: it produces a geometric script based on the output from geometry theorem analyze (3) XML generator: it represents a geometry proof in XML format (4) XML parser: it analyzes XML documents and format the theorem in a textbook form (5) learning interface: learners read a geometry proof and manipulate the dynamic geometry figure. Figure 3 shows the system flowchart.

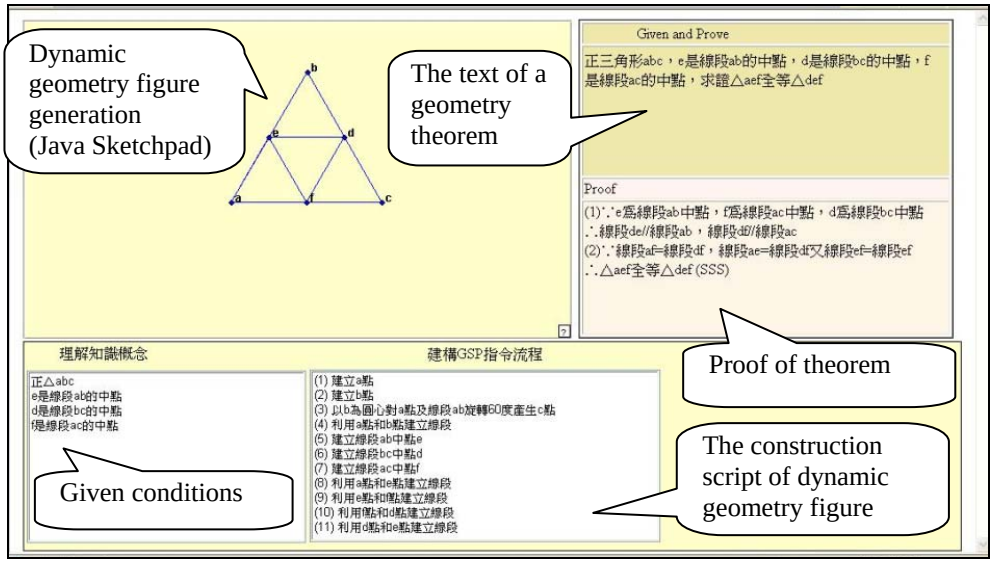

Figure 2. Learning interface

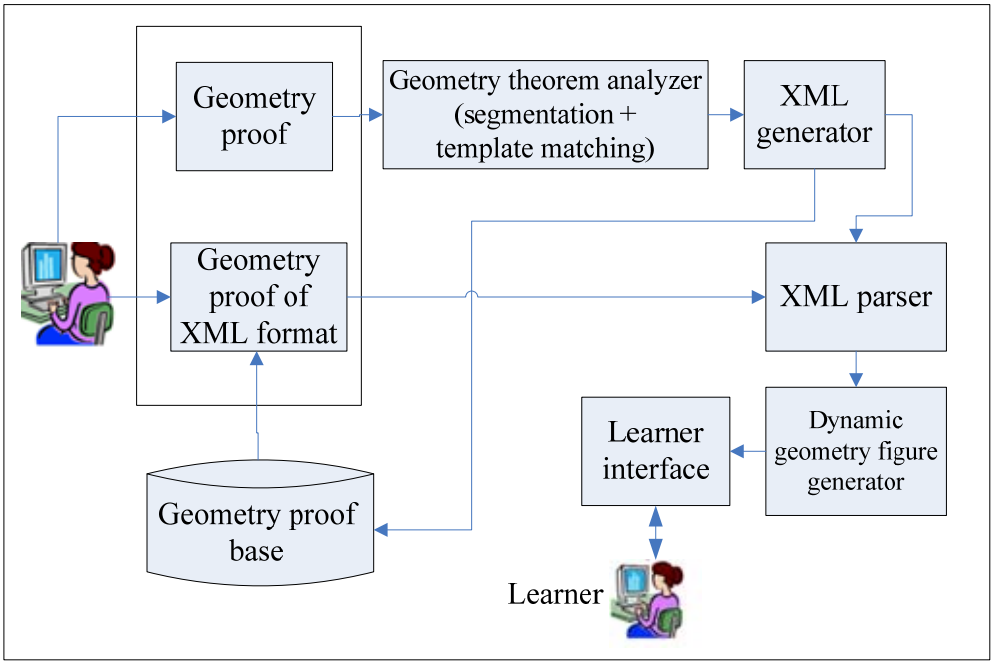

Figure 3. System flowchart

Further discussing the processes of the Geometry theorem analyzer, it firstly segments the geometry proof, and then retrieves the concept attributes in the geometry proof by using the Regular Expression template. For instance, if we have one sentence describing “Point A is the middle point of segment BC”, the sentence will be matched to the midpoint template “(Point) [[Letter]] is (the) middle point (of) (segment)[[Letter]]”. Table 1 lists the result of template matching. Based on the result of template matching, the concepts and their attributes belonging to the geometry proof will be retrieved as shown in Table 2.

Table 1. The template matching of “Point A is the middle point of segment BC”

Geometry proof description	Point	A	is	the	middle point	of	segment	BC
Template	(Point)	[Letter]	is	(the)	middle point	of	segment	[[Letter]]

Table 2. The geometry concept and attributes of “Point A is the middle point of segment BC”

Geometry proof description	Geometry concept	Attribute
Point A is the middle point of segment BC	midpoint	1. midpoint =A 2. line =BC

2. Experiment

In order to evaluate our system in understanding geometry problems and in generating figures, we test the system with problems from three publishers (Nani, ChienHong, KangHsuan). The arrangements of teaching materials follow the recommendations of the Ministry of Education. In junior high school textbooks, there is a great proportion of geometry problems about quadrilaterals and triangles. There are 61 geometry problems here, including 34 on quadrilaterals and 27 on triangles.

2.1 Experiment for proof understanding and figure generation

Table 3 summarizes the evaluation results of our system, where the overall rate of correctness is 77%. The remaining 23% problems that were not understood correctly by the system will be discussed below.

Table 3. Experiment for understanding and figure generation

Type	Quadrilaterals	Triangles	Total
Correct	26	21	47
Incorrect	8	6	14
Total	34	27	61
Rate of correctness	76%	78%	77%

After analyzing the results of the experiment, we have found two factors that can explain the 23% incorrectness rate. First, the original problem text is incomplete on its own and must be complemented by information in an accompanied figure. Second, the drawing power of Java Sketchpad is limited, since it cannot specify the constraints that a pair of segments is equal in length and that two angles are equal in measure. For example, *“In any quadrilateral ABCD, the segment AB is equal to the length of segment CD and the segment, and the segment AD is equal to the length of segment BC and the segment. Prove the quadrilateral ABCD is a parallelogram.”*

By using regular expression template, the system can retrieve the given conditions of the theorem. Because Java Sketchpad can not draw the equal length with the output from template, the system might draw a quadrilateral (Figure 4) which is not a parallelogram. Java Sketchpad can draw a parallelogram (Figure 5) with the translation function only if template retrieves the goal before the given conditions.

Figure 4. A quadrangle ABCD

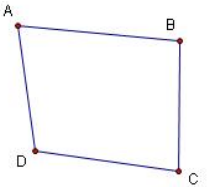

Figure 5. A parallelogram ABCD

3. Conclusion

Students always have different backgrounds and their skill levels are different. In traditional teaching, a teacher's teaching cannot fit all students. Students with high proficiency skills would have less chances of learning something new; on the other hand, students with low proficiency skills are not able to catch up with standard learning steps. Teachers also need to spend plenty of time preparing teaching materials. This study provides an authoring tool for the purpose of distributing theorems and proofs in a dynamic geometry environment. All a teacher needs to do is to enter proofs from textbooks. This system would automatically analyze them with a knowledge engine and translate them into XML format. Since XML documents can be used to exchange information and store data, teachers can share their materials online. The users can use DGE to study theorems and proofs without limitations of time and location.

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