Automated Synthesis Tableau Calculi in Intelligent Web-based Education Systems

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Abstract—The paper proposes some applications the automated synthesis of tableau calculi in intelligent web-based education systems (WBES). We propose architecture of an intelligent web-based education system that use automated synthesis of tableau calculi. Current solutions mostly use only one deduction system for target logic. In case of the semantic web ecosystem it is description logics (DLs) deduction system based on tableau or hyper-tableau. This paper also examines some disadvantages of using the automated synthesis tableau calculi in WBES. We analyze how to use the method in an intelligent analysis of student’s solutions.

Keywords—Automated synthesis, Tableau calculi, Technology enhanced learning, Web-based education systems.

I. INTRODUCTION

Automated reasoning plays an important role in Intelligent web-based education systems (WBES). Today’s intelligent education systems on the web require not only one sort of deduction system, for example, tableau system for a description logic [2] or only tableau system for a modal logic [8]. Particularly, intelligent web-based education systems in the future need synergy of different reasoning mechanisms. For example, intelligent web-based education system for student modeling and assessment in intelligent tutoring of software patterns [7], may needs at the same time deduction system for intuitionistic logics and description logics. To implement and practically use, at the same time, deduction systems based on tableau, for mentioned logics, in such education system [7], is practically very hard task. Also, integration several deduction systems into BWES is not easy task.

To overcome such problem we describe, in this paper, benefit of possible usage automated synthesis tableau calculi [3] [4] in intelligent web-based education systems. Idea is based on automated generation inference rules depends on syntax and semantics of logic as input in the deduction system [4].

Next section describes the idea of automated synthesis tableau calculi by using a description logic case study. Section III covers application automated synthesis tableau calculi in web based education environment. Section IV covers benefits of using automated synthesis in intelligent analysis of student’s solutions. Section V concludes the paper.

II. AUTOMATED SYNTHESIS TABLEAU CALCULI

In this section we shortly describe automated synthesis tableau calculi. We demonstrate how to apply automated synthesis to learning material expressed as description logics concept inclusion axioms (GCI) [2] and first order logic (FOL) formulas.

The semantic tableau (truth tree) is proof procedure in first order logic and other decidable logics [1]. It is also applicable to wide range of other non-classical logics [1]. Tableau calculus is a set of tableau inference rules [4].

Automated synthesis of tableau calculi is a method [3] [4] for automated generation tableau inference rules for a given logic. According to [3] [4], the method works as follows:

1. The user defines semantics of a given logic such that certain well-definedness conditions hold [4].
2. The method automatically reduces the semantic specification of logic to Skolemised implicative forms that are then rewritten as tableau inference rules [4].

The method [3], [4] can be applied to description logics [2]. Some of them are logical basis for Web Ontology Languages (OWL) [5]. Ontologies play an important role in intelligent technology enhanced learning systems on the semantic web [2], [5], [9]. The ideas of automated synthesis tableau calculi may be applied to automated generation tableau calculi for ontologies.

A. An Example of automated synthesis tableau calculi

Suppose that a teacher wants to maintain learning material divided in chapters and chapters divided in lessons. For example, learning material in mathematical logics can be divided in chapter classical logic and non-classical logic. Chapter classical logic consists of two sub-chapters: propositional logic and first order logic, while chapter non-classical logics consists of two sub-chapters: modal logics and temporal logics. The chapters can be interpreted as unary predicates in logic. We also state that concepts modal logics
and temporal logics are disjoint concepts. In ALC DL [2] the chapters are concept names. This description of learning material can be encoded into ALC DL as concept inclusion axioms as follows:

\[ \text{ClassicalLogic} \subseteq \text{FirstOrderLogic} \cup \text{PropositionalLogic} \]  
\[ \text{NonClassicalLogic} \subseteq \text{ModalLogics} \cup \text{TemporalLogics} \]

where concepts ModalLogics and Temporal logics are disjoint as follows:

\[ \text{ModalLogics} \cap \text{TemporalLogics} = \emptyset \]

At the same time, the learning material in mathematical logics can be expressed as FOL formulas, with one free variable, as follows:

\[ (\forall x)(\text{ClassicalLogic}(x) \rightarrow \text{FirstOrderLogic}(x) \cup \text{PropositionalLogic}(x)) \]  
\[ (\forall x)(\text{NonClassicalLogic}(x) \rightarrow \text{ModalLogics}(x) \cup \text{TemporalLogics}(x)) \]  
\[ (\forall x)(\text{ModalLogics}(x) \land \text{TemporalLogics}(x) \rightarrow \emptyset) \]

The automated synthesis tableau calculi, in both cases, will accept a ALC DL [2] language and FOL language, respectively and generate inference rules for the logics and later applies it in order to check satisfiability of learning material.

### III. Application Automated Synthesis in Web-based Education Environment

Many intelligent technology enhanced learning systems have an expert knowledge in their structure. They use different reasoning techniques in order to improve usage of the system in preparation courses [4], testing student’s knowledge [11], collaborative learning [17].

Architecture of web-based education systems, that uses automated synthesis, is shown on Fig. 1. Components of the proposed architecture are:

1. Educational servers.
2. Servers for automated synthesis.
3. Learners/Teachers.

**Educational servers** consist of wide range of educational software and web-based educational services. For example, it includes software system for student modeling and assessment in intelligent tutoring of software patterns [7] or software for modeling learning courses [14]. Finally, educational servers can exchange information received from automated synthesis servers.

**Servers for automated synthesis tableau calculi** are connected with educational servers in order to generate reasoning rules if any educational software requires reasoning services, independent of logic formalisms that an educational software use. For example, in case of learning material in mathematical logics, explain in previous section, education server A (see Fig. 1) may require generation deduction rules for FOL because learning material is expressed in FOL as shown in formulas (4), (5) and (6), while educational server B (see Fig. 1) may require deduction system for a DL, because learning material is expressed as DL axioms, as shown in formulas (1), (2) and (3).

Finally, educational servers A and B may require generation inference rules for different class of the same logic. For example, server A may require inference rules for ALC DL [2] logic while server B requires inference rules for ALCO DL [4].

**Learner/Teacher** side of the architecture includes participants in education process

#### A. Benefits of Usage Automated Synthesis in intelligent WBES

This section outlines benefits of using automated synthesis tableau calculi in WBES. We analyze the problems from integration point of view two different WBES and its requirement for using different deduction methods for different mathematical logics.

There are several problems when we use only one reasoning algorithm in traditional intelligent web-based education systems:

1. The usage of an intelligent WBES depends on reasoning systems developed for appropriate logic. In traditional application of a reasoner (theorem provers) in WBES [10], input for reasoner depends on expressive power of logic. For example, if a user wants to check consistency of a knowledge base expressed in a certain modal logic then the user of WBES must use certain modal logic theorem prover developed for the logic. In case of application automated synthesis tableau calculi, the engineer does not care much about logic expressivity and its deduction system. The method generates inference rules for wide range of logics instead of usage appropriate reasoning rules already implemented for the target logic. For example, if a user or educational servers, A or B or both at the same time (see Fig. 1), asks for checking satisfiability of learning content expressed in propositional logic or first order logic then in both cases they can use the same deduction method i.e. automated synthesis instead of using two different theorem provers. If a user decides to use separated theorem problem then the user must consider which one is necessary in order to solve inconsistency/satisfiability task. A disadvantage of architecture proposed in this paper is that deduction method [4] does not cover all mathematical logics and there is work in progress that will cover as much as possible class of
logics [3] [4]. We propose that process of software implementation intelligent WBES should not be strongly dependent of deduction system which users pane to apply.

2. It is very hard to integrate different intelligent WBES and use appropriate reasoning algorithms.

An integration different intelligent learning system is not easy task and needs a lot of knowledge and experiences. For example, integrate WBES for learning design patterns [7] and QTI-FAR system for assessment students [12] is desirable. In that case, how to solve the problem when these two WBES should use different deduction systems like, modal logic and description logics and at the same time exchange deducted information. Bridging the gap between different WBES platform can be overcome with a server for automated synthesis tableau calculi. The server for automated synthesis will deliver necessary information to WBES for learning design patterns [7] by generating inference rules for description logics, while QTI-FAR [12] will use generated inference rules for modal and description logics.

IV. AUTOMATED SYNTHESIS TABLEAU CALCULI IN INTELLIGENT ANALYSIS OF STUDENTS’ SOLUTIONS

Intelligent analyzes of student’s knowledge is deeply analyzed in [10] [11] [7]. The authors focused on application description logics based reasoning in WBES and did not consider application other sort of logics i.e. deductions systems, for example deduction system for a decidable part of first order logic.

We use driving license test example in QTI-FAR framework (see Fig. 2) [12] in order to demonstrate ability of using automated synthesis instead of simple tableau algorithm for target logic. This framework [11] [12] is about applying intelligent reasoning techniques to improve design and implementation of questionnaire systems based on the IMS Question and Test Interoperability (QTI) standard [13]. We call such systems QTI assessment systems, or just QTI systems. Driving license exams typically include multiple-choice questions (see Fig. 2). To pass the exam, candidates must answer correctly to almost all questions.

In QTI-FAR [12], a candidate submits his answer to the question by clicking the Answer button. At that point, the item gets check-marked in the list on the right side of the screen (see Fig. 2). The list shows the candidate's progress in the test (the assessment items answered are check-marked). At the same time, a modal feedback is generated at the bottom of the screen. It shows the current number of correct and incorrect answers, as well as the number of items answered. The candidate can answer the question just once, which means that he cannot change the answer to an already answered item. Upon answering all items, the candidate can run response processing to generate a detailed score report (see Fig. 2) [12]. The QTI-FAR can uses automated synthesis tableau calculi to check the satisfiability of the answer, which a student submitted. Selecting an answer to such a question implies that the selected answer is true, and all other answers are false. However, in case of driving license training, simple true/false questions/answers are insufficient for estimating the efficiency of the candidate's knowledge and skills, due to the following shortcomings:

1. Candidates cannot provide correct answers if questions have logical errors, in the sense that some issues contradict each other,
2. Two syntactically different answers may have the same meaning,
3. Whether one answer is subsumed by other answer?
4. How to assess answer of the form “probably”, “necessary” as elements of modality in modal logics?

To fulfill above requirements during testing students knowledge, QTI-FAR requires a DLs [11] and modal logics [15] reasoning services. It is not enough to use only a DL reasoner because the reasoner cannot conclude with modal predicates like possibility, necessary [15]. The deduction method can generate inference rules for modal and description logics. It depends on the question i.e. students answer. The deduction method will check satisfiability of student’s answer based on input logic. It improves test systems because it is possible to include questions and answers with modal predicates and at the same time use the same deduction method. Also, it is possible to include predicates in propositional logic if a student’s answer should be marked as true of false. Automated synthesis of tableau calculi cannot be applied to logic that does not have finite model property [3] [4]. Instead of that, to assess student’s knowledge we propose to use description logics extended with description graphs (DG) [16]. For instance, one can define relations among drivers, cars, road signs, as in Fig. 2, using graphs. In a similar way, DG rules can be used to define many different pedagogical strategies and difficulty levels for questions and question answering. It is possible to define more then one DG rule connected to one or more questions. Hyper-tableau algorithm can be called in order to assess student’s knowledge if questionnaire system is designed by using DG [16].
V. CONCLUSIONS AND FUTURE WORK

The paper proposes benefits of using automated synthesis of tableau calculi in intelligent web-based education systems. We also give an example how to use the deduction method in intelligent analysis of student’s solution when assessment system needs more than one inference engine. Future work will be focused on application automated synthesis tableau calculi in annotation learning content on the semantic web.

REFERENCES


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