Authoring Storyline-based Adaptive 3D Virtual Learning Environments

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Abstract: Adaptive three-dimensional (3D) Virtual Leaning Environments are interesting for the e-learning domain as they have great potential resulting from the capabilities offered by 3D Virtual Environments in combination with the opportunities offered by adaptive systems. However, their breakthrough is hindered by the difficulty of their development. This paper presents a development approach that allows course authors to create adaptive 3D virtual learning environments without the need to be an expert in 3D or using programming or scripting languages. In particular, the paper elaborates on the principles used for the authoring approach, as well as on the different aspects that need to be supported, i.e. the pedagogical aspects, the adaptation aspects, and the requirement to support the specification of an adaptive storyline which should be followed by learners.

1 INTRODUCTION

3 dimensional (3D) virtual environments are defined as three-dimensional (3D), multisensory, immersive, real time, and interactive simulations of a space that can be experienced by users via three dimensional input and output devices (Burdea, 2006). This kind of environment is often used for entertainment, but can also be used in the context of education. For certain subjects and for certain types of learners using a 3D Virtual Learning Environment (3D VLE) may be much more appealing and motivating than the use of classical learning material, e.g., to simulate the effect of physical laws (Cobb et al., 1998); to simulate social environments and allow people to practice social skills (Adams et al., 2008); or to learn about history (Di Blas et al., 2003); Dede et al., 2003). Equipping those 3D VLE with adaptive capabilities could offer even more advantages (Chittaro and Ranon, 2007). For instance, adaptivity allows the 3D VLE to adapt dynamically (i.e. at run time) to the individual learner and to the progress that the learner makes during the learning process. It could mediate the distinction between education and entertainment, which could improve the learner's experience and motivate him better. Furthermore, adaptivity may be used to prevent the learner form being overwhelmed in the 3D VLE. For instance, it may be more effective to guide a learner through the 3D VLE according to his or her background and learning goals, or only show the learner the objects that are relevant for his current knowledge level, or adapt the environment to his learning style. Also adaptivity may be used to decrease the risk that learners are distracted too much and are therefore not able to focus on the actual learning task (De Troyer et al., 2010).

As the major goal of a 3D VLE is education, involving teachers or educational-schooled people is very important. However, with the current development tools for 3D virtual environments, it is very difficult to involve these people actively in the development process, as they usually don't have background in programming or in 3D. One way to overcome this drawback is to provide authors an authoring tool that enables them to turn existing 3D virtual environments into *adaptive* 3D virtual *learning* environments. With such a tool, the authors should be able to manipulate the 3D VLE contents to fit it to the context of the course and to the learners, and specify the required adaptive behaviour. The usability of such a tool will be a critical factor in its adoption.

Our work is based on the acquired experience in the context of a EU FP7 STREP project GRAPPLE

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(GRAPPLE, 2008). It aimed at the construction of a generic adaptive learning environment that can be used/accessed at home, school, work, or on the move. GRAPPLE includes authoring tools that enable teachers to specify adaptation strategies for the contents and activities of their courses. The project considered classical learning materials, as well as simulations and virtual reality. Based on our experience in the GRAPPLE project, we found it is important to allow authors to provide a storyline for an adaptive 3D VLE that learners can follow during a course. This finding is supported by work done in the context of educational games, where narration helps the player to be more involved in the game and, as a result, to increase the expected learning outcomes (Salen and Zimmerman, 2003). Furthermore, narrative aspects can play an important role to deliver the instructional message and appropriate goals (Laurillard, 1998).

The rest of the paper is structured as follow. In section 2, we consider work related to authoring 3D environments in the context of e-learning and educational games. Section 3 explains the basics of adaptive 3D VLEs. In section 4, our authoring approach for adaptive 3D VLEs is explained, and section 5 proposes the architecture for the associated authoring tool. Section 6 presents conclusions.

2 RELATED WORK

This section reviews related work dealing with authoring adaptivity in 3D virtual learning environment and video games.

There exist different Virtual Reality (VR) development environments that enable advanced authors in VR to create 3D virtual learning applications. Some of them are specific for certain 3D virtual environments. Examples are (3Dxplorer®, 2002); (OpenQwaq, 2007); (Creator®, 2007). Another interesting example is the Sloodle project (Livingstone and Kemp, 2008) which is based on integrating learning and teaching across SecondLife (SecondLife, 2003) which is an online 3D virtual world, and Moodle (Moodle, 2002) which is a course management system. However, in the context of authoring tools to deliver adaptive 3D VLE, there is little available. For this reason, the related work mentioned in this section will also discuss narrative, adaptivity and authoring tools developed in the context of educational games.

An authoring toolkit called <e-adventure3D> is presented in (Torrente et al., 2008). The authoring tool has a scene editor that supports authors to define and configure size (width and depth), texture and roughness settings of the 3D virtual environments. Furthermore, the author is able to define the camera and lights settings, which will be considered as user guidance in the 3D virtual environment. The authoring tool also provides an editor to define the interactive elements inside the 3D virtual environments. The end-user will be able to interact with such predefined elements by carrying out some tasks and actions. Also the editor allows the author to place the interactive elements in a scene. Furthermore, the author can scale, rotate and/or translate them to fit correctly in the scene. Additionally, a 3D avatar representing the learner is available and which "*can engage in interactive conversations that can be graph-shaped if cycles are needed or tree-shaped otherwise. The editor includes a graphical facility to create these structures easily*." (Torrente et al., 2008).

It should be noted that in <e-adventure3D>, game authors are not able to specify which kind of users interactions should be monitored, as this is limited to what has been implemented in the game API. Note that being able to monitor user interactions is important for being able to adapt the 3D virtual environment at run time. Another shortcoming is that adaptation resulted from monitoring the user interactions can only be performed in future execution of the game, not in real time. Furthermore, the authoring tool is used for only two predefined environments: closed environments and connected virtual rooms.

In (Marchiori et al., 2012), WEEV (Writing Environment for Educational Video games) is explicitly considering three elements or tasks to create narrative *point-and-click* educational games: (1) the author needs to define the actors, which are the interactive elements in the game. In other words, actors are the 3D objects upon which the player can perform an action and interact with them; (2) the virtual game world or so-called *gamespace* should also be defined. The virtual world includes the different interactive elements and non-interactive elements of the educational game; (3) the game story must be edited separately to define the player's interactions and the game feedback. The WEEV authoring tool is implemented as three editors to support the author in defining the main three elements: Simple Actor Editor, World Editor and Story editor. A domain specific visual language is used for the World and Story Editors. The Actors Editor enables authors to view a list of all the actors in the game in a specific panel. Furthermore, the author is able to select a new actor form a "resource library" containing different graphic resources. The World Editor allows the author to define the game world. On the other hand, the Story Editor is used to define the story-flow of adventure games. In general, a story is represented "…*based on a state-transition diagram, where each state represents a point in the game story and each transition an interaction by the user with the system, which moves the story along*." (Marchiori et al., 2012). The basic elements of the proposed game story flow language are: (a) *state* which represents the status of the game, (b) *transition* which is used to define a player action which moves the state of the game to next one, (c) *feedback* which is associated with the transition element to display effects or feedback when a transition happen. Furthermore, the proposed domain specific visual language provides specific features to integrate educational characteristics like content adaptation. For instance, the author can create an explicit representation of student assessment, hints for guidance and adaptation of the game story. Adaptation can be defined for the story-flow of the game depending on the student profile. The story-flow can have more than one initial state. The initial nodes of the story-flow are associated with different adaptation profiles in the game, for instance, "easy", "medium" and "hard" difficulty levels.

Researchers in (Gaffney et al., 2010) described an authoring tool (ACTSim) which is developed to allow educators with non-technical background authoring situational simulations. Situational simulation focuses on teaching learners how to perform targeted task (Alessi and Trollip, 2001). Their approach designs adaptation aspects in two ways. First, a tagging mechanism allows authors to define multiple properties for so-called adaptive dimensions (Wade, 2009) which include role of the learner, learning outcomes, categorization of the dialogue nodes and the related subjects. This is done by providing a highlight function in the authoring tool which allows the author to know how the dialogue model will be adapted. Secondly, triggers are used which allow the authors to define adaptation depending on educational principles of assessment, feedback and reflection. The ACTSim authoring tool supports the two approaches to design adaptive simulation. A good principle of the approach is not adhering the authors to compose complex rules in order to provide adaptation. An evaluation was conducted for the proposed authoring tool and the result was promising.

3 ADAPTIVE 3D VLE

In order to be able to discuss the principles used for our authoring approach, we first need to present the basics of adaptive 3D VLEs. First, we will discuss the different components that make up a 3D VLE. Next, we discuss the adaptation possibilities for 3D VLEs.

3.1 3D VLE Anatomy

Before we discuss how to drive adaptation for 3D VLE, it is important to know what are the 3D VLE components on which adaptation can happen. Conceptually, we can distinguish the following components and associated functionality in a 3D Virtual (Learning) Environment: (1) The *virtual scene* that corresponds to the 3D space which will be populated with the 3D virtual objects. (2) *Virtual objects* are objects which have a visual representation having colour and material properties, a size, a position in the space, and an orientation. (3) *Object behaviours* that are the behaviours associated to the virtual objects. Behaviours may reflect real life behaviours like rotation, walking, etc. (4) *User interactions* as users are able to interact with the virtual objects. For example, a user may pick up an object and drag it to some other place in the space (if the object is moveable). (5) *User navigation* which is related to the way the user can move in the 3D space, e.g., walking, running or flying. The user navigates by a so-called avatar. The user's avatar can be represented explicitly (by an object) or implicitly in which case the viewpoint of the camera is used to show the user's position. (6) *Communication* as nowadays, more and more 3D virtual environments are also collaborative environments in which remote users can interact with each other, e.g., talk or chat to each other or perform activities together. In this research, we concentrate on single-user environments. (7) *Sound* can be important component in simulations to enhance the feeling of reality or simply to simulate some sound. Sound/speech can also be used as an instruction and feedback mechanism during the learning process. More explanation about 3D VLE components is presented in (De Troyer et al., 2010) and (Kipper and Palmer, 2000); (Bowman and Hodges, 1999).

3.2 Possible Adaptation Techniques for 3D VLE

Different adaptation techniques and mechanism are proposed to be applied to 3D virtual objects. For instance, the work presented in (Chittaro and Ranon, 2007) presents adaptation techniques which are basically limited to 3D contents representations. On the other hand, the authors in (Dos Santos and Osório, 2004) propose the so-called Intelligent Virtual Agent to provide adaptive navigation towards interesting 3D virtual objects. However, adaptation can be applied beyond 3D material representation or user navigation. In principle, adaptation can happen for each component of a 3D VLE. An adaptation can be limited to a single component of the 3D VLE, but it can also involve different components of the 3D VLE. We defined two different adaptation categories (De Troyer et al., 2010). The first category includes adaptations that apply on a single component, i.e. possible adaptations for objects, behaviours, interaction, and for navigation. We call these *adaptation types*. For instance, there are adaptation types related to 3D virtual objects such as *semi-display, changeSize, changeMaterialProperties*, *changeVRRepresentation*, etc. For the moment, we did not consider any adaptations types yet for the scene or sound. Communication is also not considered because we focus on single-user 3D VLEs. The second category is related to more high-level adaptations that involve more than one component. These kinds of adaptations we called *adaptation strategies*. For instance, adaptation strategies that can be applied to group of 3D virtual objects are *filterObjects, markObjects, displayAtMost, displayAfter,* etc. More examples about adaptation types and strategies can be found in (De Troyer et al., 2010).

4 AUTHORING AN ADAPTIVE 3D VLE

In general, the purpose of an authoring tool is to enable authors defining a course at a high level of abstraction and without resorting to programming or scripting languages. In the same way, the purpose of our authoring tool is to allow authors to define an adaptive 3D VLE without the need to be experienced in 3D/VR and to know programming languages. In principle, this involves authoring the 3D virtual environment, as well as the adaptivity and the pedagogically relevant aspects of the course. We will not consider the authoring of the 3D virtual environment itself, as for this many tools are available (e.g., Google SketchUp (GoogleSketchUp, 2000)), 3D Studio Max (Murdock, 2003)). The purpose of our authoring is to add storyline, adaptivity and pedagogical aspects to an existing 3D virtual environment.

The approach taken for adaptivity is an author-driven approach which means that during the design of the adaptive course, the author needs to specify explicitly when and how the content needs to be adapted. The advantage of this is that it gives the control to the author. On the other hand, the disadvantage is that it requires the author to keep track, at design time, of all possible adaptation scenarios. However, we believe that supporting authors with appropriated tools can overcome this disadvantage.

In the following sections, we first present the (high level) requirements that we formulated for our authoring approach. Next, we discuss the models and principles used for the authoring approach. Finally, we provide more details on the three most important steps of the authoring process.

4.1 Requirements

Based on our previous work done in the context of the GRAPPLE project, we derived some important features to be considered in authoring adaptive and educational 3D virtual environments. The most important features can be summarized as follows:

- *Pedagogical-oriented:* As we are dealing with 3D virtual *learning* environments, we want to provide means to take into consideration some pedagogical aspects when specifying an adaptive 3D VLE (i.e. the course). This is achieved by enabling authors to create pedagogical relations between the different learning concepts.
- *Adaptive-specific*: As we are dealing with *adaptive* 3D virtual learning environments, we want to provide means to specify the adaptivity of a 3D VLE using a high level of abstraction. The idea is to provide a number of different (pre-defined) adaptation types and strategies to allow the author to express the adaptivity.
- *Teacher-oriented*: One of the major goals is allowing teachers and pedagogically schooled people to be directly involved in the authoring process of the adaptive 3D VLE. This requires that the authoring approach should be at a high level of abstraction, and using terminology that is understandable by this type of users.
- *Storyline-oriented*: We have observed (during evaluations performed in the context of the GRAPPLE project (Ewais and De Troyer, 2014))

that when using a 3D VLE, there is a need to guide the learners through the learning material offered in the 3D VLE in a way similar as this is done for classical text-based learning material (where some kind of sequence is enforced or advised). For instance, the author may want to express that the learners first should get a guided tour through the virtual environment highlighting the most important learning objects, next they should focus on performing some activities related to one learning concept, and so on. However, while for classical learning material a personalized "sequence" could be achieved by specifying adaptation rules only, our previous work done in the context of the GRAPPLE project has shown that this is very difficult to be achieved for 3D VLEs only with the use of adaptation rules. To allow expressing such a "sequence", we will use the concept of *storyline* (taken from game development).
- *Web-based:* A web-based authoring tool will allow easy access to the tool independent of the platforms or PCs that are used by the authors.

4.2 Models & Principles

In general, classical adaptive systems maintain different kinds of information in different models (Paramythis and Loidl-Reisinger, 2003). We also follow such an approach. Authoring an adaptive 3D VLE goes as follows. First a *Domain Model* (DM) (Hendrix et al., 2008) describing the concepts that should be considered in the course, needs to be created. Learning resources and materials are associated with these learning concepts.

We also use a *User Model* (UM), which is used to maintain the learner's characteristics, learning background, and his learning progress.

Next, pedagogical relationship types should be defined between the different learning concepts. An example of a pedagogical relationship type is the prerequisite relation that expresses that one concept is a prerequisite to master the other concept. These pedagogical relationships are defined in the *Pedagogical Model* (PM). The PM also expresses at a high-level how the User Model should be updated (at runtime) based on what the learner does in the learning environment. After that, the author defines the actual adaptivity behaviours (*Adaptation Model*) for the 3D VLE. For this a rule mechanism is used. Adaptation rules are basically if-then rules. The if-part specifies the conditions to be satisfied for performing the adaptation, while the then-part specifies the adaptation actions. These adaptation actions are expressed in terms of the adaptation types and strategies (see section 3.2) to be performed on the 3D VLE components. In our approach, the adaptation rules are defined in context of two sub-models: *Adaptive Storyline Model* (ASLM) and *Adaptive Topic Model* (ATM). We first explain the purpose of these two models.

As indicated in section 4.1, to define the actual course, the author will use a storyline. This storyline defines the steps that the learner should follow during his learning process. The storyline can be adaptive, i.e. the actual flow can adapt at runtime e.g., depending on the learner's knowledge about specific concepts. The storyline and how it should adapt is defined in the Adaptive Storyline Model. A storyline consists of number of *topics*; each topic is dealing with a number of 3D virtual objects. The topics are connected with so-called *storyline adaptation rules*. These adaptation rules specify the adaptive behaviour of the storyline. Figure 1 depicts the sub models in the adaptation model.

Next to the adaptivity expressed for the storyline, more adaptivity can be expressed for the topics. A topic is defined by means of an Adaptive Topic Model. In this model, the 3D virtual objects involved in the topic are specified, as well as the actual adaptation actions that have to be applied to them. Moreover, it specifies when the adaptions need to be applied. Also here, a rule mechanism is used.

In the rules, the conditions are not only based on the learner's preferences or learning background and learning progress (maintained in the User Model) but also on the activities performed by the learner in the 3D VLE (e.g., number of interactions with a certain object, the behaviours performed). This type of information, which may not always be directly related to the learning, is added to be able to control the learner's behaviour in the 3D VLE, e.g., to avoid that he wastes too much time by playing around or to help him when he has problems in navigation or interacting with objects. This information is stored in the so-called *3D VLE Activity History Model*. It is important to mention that not all the user activities inside the 3D VLE are monitored. But the more information is kept about the activities of the learner in the 3D VLE, the more this information can be taken into account to adapt the 3D VLE to the individual learner. Note that some data from this 3D VLE Activity History need to be translated into User Model data. For instance, it needs to be defined what activities need to be performed in the 3D VLE by the learner to raise the knowledge level of a certain learning concept.

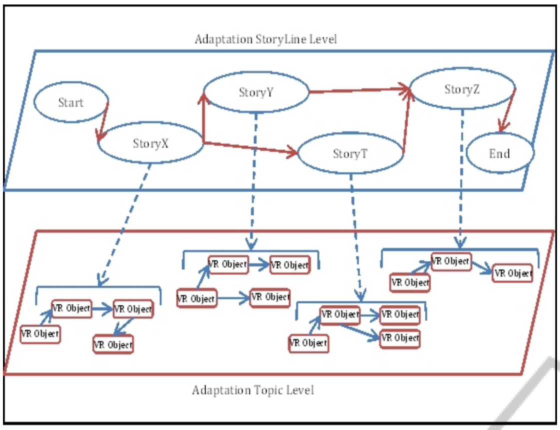

Figure 1: Two-level specification of the Adaptation Model.

Maintaining the User Model and the 3D VLE Activity History at runtime is done by the adaptive delivery environment. Figure 2 depicts the different models used in our approach to perform the adaptation process inside a 3D VLE and how they are related to the authoring process, respectively the adaptive delivery process. It is actually the Adaptive Engine that will figure out when to use which adaptation rule. It is also the Adaptation Engine that sends updating instructions that are related to the User Model according to user activities performed inside the 3D VLE. The Adaptive Engine is also responsible for selecting the appropriated 3D resources (based on the adaptation rules) and sending them to the delivery environment (client side). Actually, the exact content of the course is composed on the fly by the Adaptation Engine.

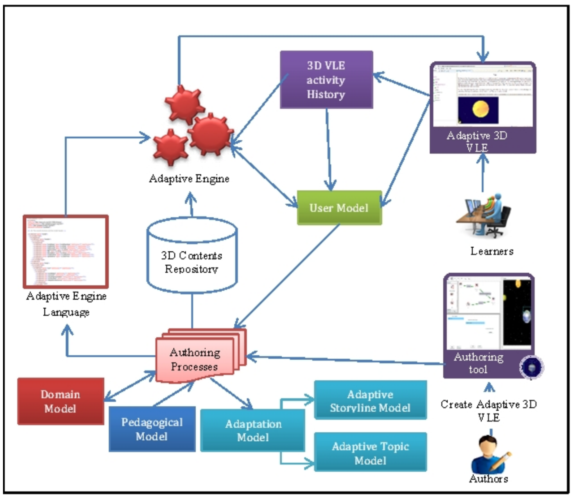

Figure 2: Conceptual Framework for Adaptive 3D VLE.

In the next three sections, we will elaborate on the three most important aspects of the authoring process, i.e. authoring the Pedagogical Model, the Adaptive Storyline Model, and the Adaptive Topic Model.

4.3 Authoring Pedagogical Aspects

The Pedagogical Model (PM) is used to define the pedagogical structure of the learning concepts, as well as to indicate how the learner's knowledge (captured in the User Model) should be updated based on the learner's activities inside the 3D VLE.

A typical *Pedagogical Relationship Type* (PRT) is the *prerequisite*. When a learning concept A is a prerequisite for learning concepts B, this means that the learner needs to study concept A before he can start with concept B. Other PRTs like *Defines, Illustrates, Interest, Propagates_knowledge* and *Update_knowledge* can also be used to define relationships between the different learning concepts.

After defining Pedagogical Relationships Types between learning concepts, the author can specify the *Pedagogical Updating Rule* (PUR) for each PRT. PURs are responsible for defining how the User Model needs to be updated based on the activities performed by the learner. PURs are *condition-action* rules. At runtime, the PURs are triggered on accessing (visiting) learning concepts. The action part of a PUR defines the updates that will happen. For instance, the *interest*-PRT has a PUR that for visiting a 3D learning concept will update the user's interest level of the target 3D learning concept. The following is an example of Pedagogical Updating Rule associated to the *interest*-PRT:

```
IF    (UserID.3DLearningConceptA.
knowledge = 'GOOD')

THEN  (UserID.3DLearningConceptB.
interest= 'HIGH')
```

Note that, rather than requiring the authors to specify the learning sequence for the learning concepts in all possible cases, the authors only have to provide the PRTs between the different learning concepts and the adaptive engine will be able to dynamically derive the required learning sequence.

4.4 Authoring Storyline Adaptation

As already explained, an adaptive storyline enables the delivering of the topics in an adaptive sequence. To achieve this, *storyline adaptation rules* are used. A storyline adaptation rule is associated with a topic, the source topic, and is used to control the transition to the next topic, the target topic. Such a rule consists of two parts: a *condition* part and an *action* part. The condition part is used to specify when the learner can be directed from the current topic (the source topic) to the next topic (the target topic). The condition is, in general, based on two aspects: the learner's current knowledge level about the current topic and the suitability of the next topic for the learner. To simplify tracking the learner's knowledge and topic suitability, every topic in the storyline has two parameters: *topic knowledge* and *suitability*. A learner can acquire knowledge about the topic in a topic by navigating and interacting with the 3D objects (concepts) related to the topic. The knowledge level about the topic is incrementally increased by acquired knowledge about the related concepts. The author needs to define how the topic's knowledge level can be increased. Once the learner's knowledge about the current topic crosses the specified threshold (given in the condition part of the rule) and the target topic is suitable for the learner then the learner will be able to progress to the target topic. This is specified in the condition part of the topic adaptation rule. For instance, in this way, the author can specify that a beginner should not be able to go to a topic for advanced learners.

In the action part of the storyline adaptation rules, the author specifies the adaptation strategies (see section 3.2) that should be applied on 3D virtual objects (learning concepts) of the target topic. For example, the author could specify the *interactionAtMos*t adaptation strategy in the action part of a storyline adaptation rule to specify the maximum number of times the learner can interact with the 3D virtual objects (concepts) inside the target topic.

Let us illustrate the adaptive storyline by the following example. An author creates TopicX, TopicY, TopicZ, TopicR, and TopicT. Those topics consider the different issues to be discussed in the course. Every topic should include a number of learning concepts. The author can determine that learners with basic knowledge (beginners) should follow a larger number of topics than the learners with good knowledge (advanced). For instance, two possible storylines are envisaged. An advanced learner should have the following flow of topics: Topic X-> Topic Y -> Topic Z. After having completed topic Z, he will finish the course. On the other hand, learners with beginner level should follow a larger number of topics, as they need to master more concepts in order to master the topic: Topic X-> Topic Y-> Topic T-> Topic Z. In the same way as reading a course book, students with advanced knowledge can skip sections or even chapters. To realise this, the following topic adaptation rule can be associated with Topic X:

```
IF(user.TopicX.knowledge>
Required_Value)&&
(user.TopicY.suitability=TRUE)
THEN   navigationWithRestrictedBehaviour
<ConceptA,ConceptB,ConceptC>
<disableRotationBehaviour>
```

This rule states that the learner can progress from TopicX to TopicY when his knowledge about TopicX is above "Required_Value" (defined by the author) and his suitability for TopicY is TRUE. In addition, the action part specifies that in TopicY, the user can navigate through the environment but he will not be able to see rotation behaviours that are related to the ConceptA, ConceptB , and ConceptC.

4.5 Authoring Topic Adaptation

Inside a topic, the author can specify when and how the content and structure of the 3D VLE needs to be adapted. This is done using adaptation rules. For instance, the author can define an adaptation rule to change a 3D virtual object's properties based on the learner's activities inside the 3D VLE. To achieve that, an *event-condition-action* rule mechanism is used. The event-part is related to specific events related to the user's activities inside the 3D VLE, e.g., interaction with a 3D virtual object by mouse clicks or navigating close to a 3D virtual object. The event-part will be responsible for triggering the rule, but the condition-part must be satisfied in order to actually perform the action-part of the rule. The condition-part can deal with the learner's preferences, his learning background, and progress but also with previous activities performed by the learner in the 3D VLE. These last types of conditions are added to be able to control the learner's behaviour in the 3D VLE, e.g., to avoid that the learner wastes too much time by playing around. The following is an example of such a rule.

As an example, we explain an adaptation topic rule called *SemiDisplay3DObject* between Concept C and Concept D (see Figure 3). This rule will be evaluated once the learner comes close to (the 3D virtual representation of) concept C. As a result, the condition part of the rule will be evaluated which is in this case related to 3D VLE Activity History. Remember that the condition part can refer to user activities history inside the 3D VLE but also to his preferences, knowledge level, etc. If the condition part is true, then the so-called *semidisplay* adaptation type will be applied to concept D.

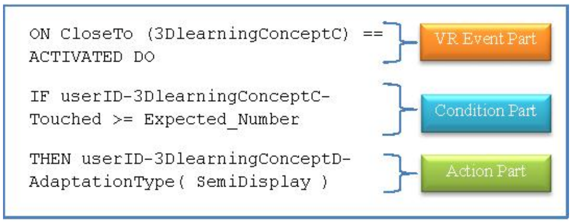

Figure 3: SemiDisplay3DObject adaptation topic rule.

Such a rule could be defined to draw the learner's attention to another 3D object instead of wasting his time by interacting with one single 3D virtual object.

5 ADAPTIVE 3D VLE AUTHORING TOOL: ARCHITECTURE

In this section, we present the architecture of the authoring tool. The main modules are shown in Figure 4. The *Web services toolkit* allows the authoring tool to connect with other external models such as the User Model and the Domain Model. Moreover, it allows the author to use local and/or external 3D modelling repositories used to store 3D materials and resources.

The actual interface to the user (i.e. author) is composed of two sub-environments. The *Data Models Environment* facilitates the preparation process for the required data models in the authoring process. The other sub-environment is called the *Pedagogical and Storyline Visual Environment* and provides access to three editors, which use visual languages to define respectively the Pedagogical Model, the Adaptive Storyline Model and the Adaptive Topic Model. Every sub-environment has different editor tools which are linked together using a unified user interface style. Furthermore, a Visualization Tool (previewer) is integrated in the authoring environment to allow authors to preview 3D VLE and to display actual effects of customized adaptation types and strategies upon 3D VLE components.

The Data Model Environment is composed of five editor tools: the *Pedagogical Relationship type Editor* to define PRTs; the *3D Learning Object Editor* to specify the required 3D learning objects; the *3D Adaptation States Editor* to create or modify adaptation types and adaptation strategies that will be applied to 3D objects; the *3D Learning Materials Editor* to associate adaptation types and strategies to

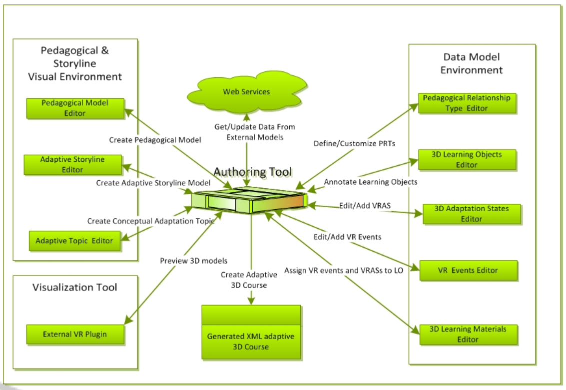

Figure 4: Overview of the 3D VLE authoring tool Architecture.

specific 3D learning objects; and the *VR Events Editor* to define or customize the VR events specifications (for instance, the proximity area for the '*close to*'-event can be set/changed with the VR Events editor). It is important to note that these editors are targeted to more VR experienced users. Novice authors only need to use the *3D Learning Materials Editor* to indicate which 3D objects they will use. The other editors in this environment are needed to specify more details related to PRTs, 3D virtual objects, adaptation types and strategies, and VR events. But in general, defaults can be used. The resulting data models are the input for the Pedagogical and Storyline Environment.

The Pedagogical and Storyline Environment has three visual editors, which are the *Pedagogical Model Editor*, the *Adaptive Storyline Editor* and *Adaptive Topic Editor*. We have opted for visual modelling languages, as our authoring tool is teacher-oriented and should be accessible by novice authors. The languages themselves will be described elsewhere.

Based on all information entered, the authoring tool can generate a 3D course in an XML format that can be parsed by an adaptive engine like AHA! (De Bra et al., 2003) or the adaptive engine used in the GRAPPLE project. However, this XML file can also be translated by means of XSL and XSLT into some other format.

6 CONCLUSIONS

Adaptive 3D virtual learning environments offer many advantages for learning. However, their breakthrough is impeded by the lack of authoring tools. In this paper, we have presented an authoring approach and associated tool architecture for these kinds of virtual learning environments. The approach and tool is based on experience obtained from our work done in the GRAPPLE project.

The approach is based on a number of principles that have been discussed in the paper. We have mentioned the different components of a 3D virtual learning environment and discussed how they can be adapted for satisfying the needs of a learner. We have motivated the need for a pedagogical component in the authoring process, as well as the need for a storyline-based authoring approach. The first requirement is achieved by enabling authors to define pedagogical relationships between the different learning concepts. To satisfy the second requirement, they are able to define a storyline inside the 3D VLE using a 2-layer approach. Adaptation rules can be associated with both layers, in each layer focussing on a different level of adaptation.

We are currently working on developing a prototype for the authoring tool. Furthermore, an empirical evaluation will be considered to validate the usability aspects of the authoring tool.

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