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Adaptive Presentation for Effective Web-based Learning of 3D Content

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Abstract

In this paper we focus on incorporating adaptive presentation and 3D visualization into Web-based learning environments to enhance learners' learning outcomes, especially to facilitate learners' spatial reasoning on geometric topics in computer graphics. This system is called CooTutor (Coordinate Tutor). According to educational media studies, "Media and Method" are the main concerns of developing such a system. In CooTutor, interactive 3D media is used to present spatial relations effectively to the learners. Instructional methods and strategies are embedded in its adaptive mechanism by incorporating ITS (Intelligent Tutoring Systems) techniques. Since geometric transformation is the example domain of our study, learners' spatial ability is used as an index for adapting the presentation. To achieve better abstraction and flexibility, we have chosen to separate the concept sequencing from the underlying learning materials. We believe that Web-based learning could take more advantages of available computing power to enhance learning by realizing innovative instructional design, as in the case of 3D interactive presentation.

1. Introduction

Web-based learning (WBL) paradigm has shown its economical benefits on enabling learners to learn at any time and any place. Though WBL brings us convenience and efficiency, many factors affect the effectiveness of this type of learning. If the use of WBL is merely to treat computers as replaceable media, unfortunately there may exist no difference on learning between WBL and other means. Educational media studies have argued around the *effectiveness of different media on learning* for a long time [3][10]. The lesson we learned from these studies is clear that there is no magic bullet to enhance learning. Even by using novel technology e.g. WBL, instructional methods are still the main considerations inevitably.

Spatial Geometric Transformations (or SGT for short) is fundamental for learning advanced computer graphics. SGT is about how to represent and compute 3D transformations (e.g. scaling, rotation and translation) of objects in the spatial coordinate system. From the view of learning, this topic possesses two unique attributes:

(1) Spatial reasoning is required. To learn complex geometric transformation (e.g. a series of rotations with respect to several axes), learners must construct mental images of spatial relations in their mind, and subsequently manipulate the mental images to assist thinking. Theoretically this is related to each individual's spatial ability. Besides, instructors also face the problem that it is difficult to clearly describe these concepts without suitable communication tools.

(2) Multimedia presentation is needed. For in-depth understanding of this topic, multi-symbol systems are required inherently. At least, the mathematical matrix representation, text-based description, and diagrams for illustrating spatial relations are all required.

The requirements of these two attributes (or criteria) may not be easily met in a typical classroom and in the scenario of lecture-based learning. On the other hand, WBL could fulfill these requirements by adopting multimedia presentation with modern computers' capabilities.

We take "Media and Method" as the central principle to design effective WBL. From the media aspect, we argue that computer graphics technologies, especially those in computer animation, could greatly benefit SGT learning. Abstract concepts could usually be better explained through instantiation and visualization with examples. Text books and typical pedagogical means usually choose to clarify them by pictorial diagrams. However, when the concepts are related to dynamic processes, what the best textbooks could offer is only a series of static frames. The difficulty of representing dynamic spatial information could be nicely solved by employing 3D computer graphics as the educational media.

From the method aspect, the ITS (intelligent tutoring systems) field has developed many techniques to personalize the contents presented to different learners. For effective knowledge acquisition, students with different knowledge background, skill levels, and preferences should receive fit-to-size learning material. In our example, adaptive presentations based on individual's spatial ability [1] will be used to enhance the learning effects on the topic of SGT.

Our approach takes a middle road between *computers as (passive) media/tools* vs. *computers as (active) tutor*, as well as *learner-centered construction* vs. *tutor-centered instruction*. In this paper, we will describe the system architecture realizing our approach. A novel adaptive mechanism incorporating interactive 3D media with a Web-based, client-server architecture will be proposed in the following sections.

2. Review of Learning with Media

The term "media" could be defined from different aspects with wide extents. Examining the characteristics of media could help us to understand media in depth. These characteristics are *technology*, *symbol systems* and *processing capabilities* [10]. Failing to distinguish these characteristics usually makes researchers and educators perplexed in discussing related issues.

The debate of the effects of learning with various media has been undergoing for a long period of time. The critical point is that *whether the use of different media influences learning or not*. It is worth to note Clark's point that only instructional methods benefit learning but media do not [3]. On the other hand, Kozma argued that "media and method are inseparable" [10]. For example, hypermedia could not be easily replaced by other technologies such as TV or books because of some of their unique characteristics.

The idea of using computers as cognitive media in education has been proposed by researchers based on various observations. The explanations for how cognitive media could help learning are not quite the same [4][11], but most studies notice the debate we just mentioned. The consensus is clear that media should be used meaningfully and related to the needs of learning particular domain directly.

Some researches consider computers as cognitive tools. This implies that computers are tools to assist learners to accomplish cognitive tasks [8]. Different descriptions of computer's role in education—cognitive 'media' and cognitive 'tools'— could be observed. Most people agree that computers' capabilities are powerful and unique. As media, computer systems can store, deliver, and represent contents. As tools, computers can help people to think, reason, and create ideas.

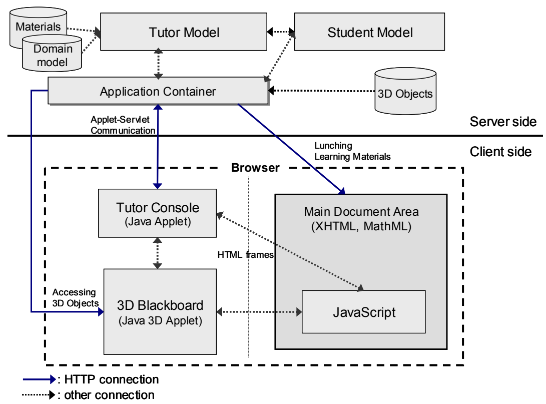

Figure 1. CooTutor system architecture

Adaptive and intelligent educational systems usually take a model-based approach to employ computer's capabilities to enhance learning. Student model is the cornerstone enabling adaptive tutoring fitted to the individuals' needs. By incorporating appropriate student model, adaptive computer systems could play a more active role in addition to being passive media/tools. We believe that the active and passive roles of computers are equally important in achieving the goal of building effective educational systems. In the literature, some researchers have already noticed the potential of using multiple representations in intelligent educational systems [9].

3. CooTutor System

The CooTutor (Coordinate Tutor) system proposed in this paper is an adaptive Web-based learning environment with interactive 3D media for SGT learning. How to design the architecture considering both the media and method is the main issue that we concern in this section.

3.1. System architecture

Since CooTutor is developed to be used on the Web, it inherits the server-client structure in the design of its system architecture, as illustrated in Figure 1. At the client side, the *main document* area is used to present main contents such as textual and mathematical materials. By embedding JavaScript codes inside, we enrich the document with scripts of 3D presentations (e.g., scripts of 3D models and animation). These codes are activated during the process of user interaction and then associated 3D content is visualized in the *3D* *blackboard* module at run-time. In CooTutor, these functionalities are implemented by using Java 3D technology and FastScript3D toolkits [7]. In addition, the tutor model and the student model shown in Figure 1 are designed for adaptivity which is established by the collaboration and communication between server and client.

3.2. User interface with interactive 3D media

The user interface of the system, as illustrated in Figure 2, consists of three parts: the *tutor console*, *main document* area, and the *3D blackboard*.

The tutor console takes the responsibility of client-side management including lunching learning materials, observing learners' behavior (e.g. how learners interact with 3D blackboard), and further communicating with the server. The tutor console acts like a control center residing at the client side to assure that this media-rich environment works compactly.

The 3D blackboard is the module that provides 3D visualization and interactivity for better knowledge delivery. The term, *interactive 3D media*, is used to emphasize its capability of presenting 3D content via interactive means.

It is worth noting that pure 3D representation would be not adequate for learning. Since each type of representation has its own merit in presenting concepts, we cannot ignore the needs of using textual and mathematical symbols in the context of science education. They are usually used as tools for formal description and communication. In CooTutor, by incorporating suitable interactions between different media in this system, the integration of multiple representations becomes more meaningful and compact for learning.

Two kinds of interactions are designed for learning. One is the interaction between 3D blackboard and learners. Learners are allowed to navigate the scene by dragging the mouse with different modes, e.g. zoom, pan and rotate, to obtain a good view for better understanding of 3D content. The other is the interaction between main documents and the 3D blackboard. By which learners read the textual content in the main document area, and then they can manipulate objects presented in 3D scenes by adopting interaction objects (e.g. buttons, input fields) embedded in the Web pages. The linkages between textual descriptions and 3D visualizations are made according to the needs of presenting particular topics. By the theory of anchored instruction [12], the main document area thus offers the context of learning. The interaction between different representations allows learners to explore the scene and do experiments freely. This type of user interfaces provides an environment for learner-centered construction.

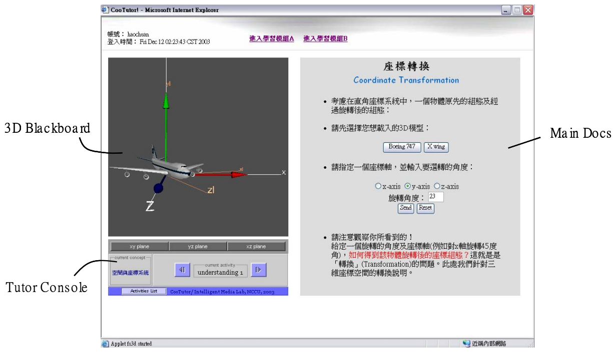

Figure 2. User interface with 3D blackboard

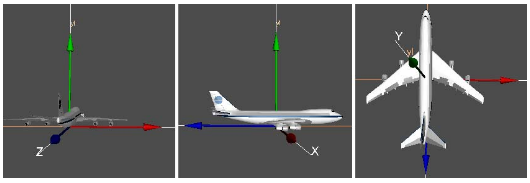

Figure 3. Describing spatial relations with 3D navigation

Figure 3 shows how CooTutor presents spatial relations by using 3D blackboard. Learners are allowed to change the viewpoint for better understanding of the spatial configuration. Comparing to conventional static 2D presentation appeared in text books, this design is recognized powerful in reducing ambiguity in explaining spatial concepts.

4. Adaptivity in CooTutor

Figure 4 shows the adaptive mechanism of CooTutor. Three main levels exist: *concept sequencing*, *material selecting* and *client-side tuning*.

4.1. Adaptive presentation

Server-side decision making is divided into two levels. First, we sequence the concepts in accordance with learners' knowledge status. The objects to be sequenced at this level are not learning materials directly, but concepts. Therefore, this phase is also called *concept sequencing*. After determining what concept should be delivered, *material selection* proceeds. Appropriate learning materials are subsequently selected to illustrate the concept. This is similar to the two levels of curriculum sequencing (i.e. knowledge sequencing and task sequencing) mentioned by Brusilovsky in [2].

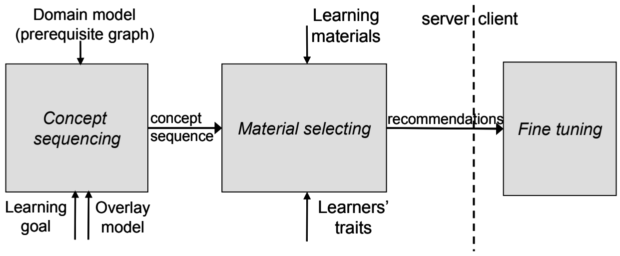

Figure 4. Adaptivity in CooTutor

Different aspects of adaptivity are considered in each level. For the level of concept sequencing, we account for learners' prior knowledge. That is, we consider what concepts should be delivered next. For the level of material selection, we will take learners' traits and preferences into account and select the kind of learning materials and presentation that would benefit particular learners most.

4.1.1. Domain modeling. Domain knowledge in CooTutor is organized as a prerequisite graph, a directed acyclic graph (DAG) similar to that proposed in [5]. Vertices in the prerequisite graph represent concepts in the domain. Edges in the graph represent the *conjunctive* relations. For example, assume that we are given a prerequisite graph G=(V, E), where V is a set of vertices and E is a set of edges. For three vertices, $u, v, w \in V$, we have $(u, w) \in E$, and $(v, w) \in E$. This indicates that both concepts *u and v* should be known (i.e. learned) before learning concept *w*. Note that these vertices are concepts, *not* learning materials. When the nodes are learning material, disjunctive relations are usually designed for attaining multi-paths content sequencing. However, such a model with disjunctions is usually too complex for authoring and its computational complexity of adaptivity increases rapidly [5]. When the domain knowledge is modeled at a more abstract level, it is reasonable to adopt conjunctive prerequisite graph, as used in CooTutor, to find the feasible concept sequence for learning targeting a specific objective.

4.1.2. Concept sequencing. Figure 5 shows the algorithm for concept sequencing in CooTutor. Given a goal concept, the task is to find out a best sequence of concepts according to prerequisite relations between concepts and the overlay student model. Overlay model used in CooTutor is to represent learners' known concepts as a subset of the domain model. Whether a concept is known by the learner is determined by pre-test. The goal could be specified by learners or inferred by the system. By employing the *topological sort* algorithm for graphs, we could assure that the resulting sequence conforms to the constraint

```
Concept_Seq ( GoalConcept g, DomainModel dm,
   OverlayStudentModel sm )
{
   List topo_order ← Topological_Sort(dm);
   List seq ← topo_order – {'known' concepts in sm};
   for-each (concept c in seq)
   {
        if (exist a path from c to g in dm)
           retain c in seq;
        else
           remove c from seq;
   }
   return seq;
}
```

Figure 5. Concept sequencing algorithm

Table 1. Some features of learning materials

Features	*Values*
Main representation	3D-based, 2D-based
Activity type	Experiment, Lecture
Level of details	Basic, Medium, Supplementary
Abstractness	Abstract, Concrete

of all prerequisite relations. Once the concept sequence is derived, re-sequencing is needed only when the goal is changed.

4.1.3. Material selection. Learning materials could be typical Web pages, 3D-integrated pages, PDF documents, etc. Each content object is indexed by features shown in Table 1.

We use *stereotyped user model* and *similarity measures* (i.e. distance between objects) to select learning materials.

In CooTutor, information of *learners' spatial ability*, *experience to 3D content* and *interaction pattern with the system* etc. are considered to trigger stereotypes. For example, if a learner has low spatial ability, no experience on 3D manipulation, and long staying period in previous tutoring sessions, the system could trigger the stereotype containing following vectors:

<main_representation = 3D-based, Activity type= lecture, level_of_details = supplementary>

<interactivity = limited>

The first vector specifies the "ideal" features of learning materials to the learner. CooTutor measures the similarity between each available learning material and the ideal query. Distance functions used by clustering algorithms in machine learning are employed here. Then the system could generate an ordered list of recommendations to the learner. Since the learner is not experienced in 3D manipulation. The second vector further disables the functionality of free navigation of 3D blackboard in order to prevent the leaner from being perplexed and disoriented in 3D scene.

4.1.4. Client-side tuning. Client-side computing is necessary in CooTutor. Learners' browsing patterns observed by the tutor console module could help to determine *how learners interact with 3D objects*, *if learners are satisfy with the recommendations*, etc. When learners finish learning a concept and proceed to the next one, such information is encoded in HTTP requests to refine the original student model. It is also possible to tune the presentation (e.g. change the order of recommendation) directly at the client-side.

4.2. Integration of adaptivity and interactivity of 3D media

In CooTutor, we consider the integration and balance of *learner-centered construction* (interactive 3D media) and *tutor-centered instruction* (adaptive presentation) an essential issue. First, how learners interact with media is observed as a source of student modeling. Second, the system measures learners' spatial ability to select learning materials with suitable representations.

4.2.1. Spatial ability. Spatial ability is a psychometric construct that is considered essential to activities related to spatial reasoning such as engineering activities and scientific thoughts. *Purdue Visualization of Rotations Test* is integrated in CooTutor to assess such competence [1]. Learners with different spatial ability should receive contents with different types of representations. For example, if 2D-based (i.e. texts and diagrams) and 3D-based explanations (i.e. interactive 3D media) are both available for describing a concept, we could scaffold learners with low spatial ability by adopting 3D visualization. For learners with enough spatial reasoning skills, letting the learner practice to form and manipulate the mental image with 2D-based representation is reasonable. In this design, the theory of cognitive scaffolding is also considered for more effective learning.

Recent experimental result shows that learners with high spatial ability had a more positive attitude on 3D content than learners with low spatial ability [6]. We argue this does *not* imply that the system should merely offer learners with low spatial ability 2D-based presentation. Because learners may lack meta-cognitive skills to determine what types of content would be beneficial. The proper solution is to limit the complexity of 3D manipulation. So we incorporate the functionality of limiting interactivity as we have mentioned previously.

5. Conclusions and Future Works

We have described our approach of incorporating adaptive presentation as well as interactive 3D media to realize specific instructional design. An interdisciplinary theoretical background based on educational media, pedagogy, psychometry etc. is used to design CooTutor. We suggest that "Media and Method" is a noticeable principle on developing computer-based educational systems. The objective of this research is to construct a Web-based environment for learning spatial concepts effectively.

The main future work is to evaluate the system under a real learning scenario. Especially, the relations between spatial ability, media types, and SGT learning need to be clarified further by adequate experimental proof.

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