Designing Intelligent Tutors to Adapt Individual Interaction

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Abstract. Present-day efforts in designing technologies to serve and adapt to human needs rather than forcing humans to adapt, embrace intelligent user interfaces as one of ambient intelligence key technologies. This paper elaborates on the design of an adaptive individual interaction in a type of computer-based educational system whose operation is supported by intelligent methods, an emulation of human teacher in the process of learning and teaching. In order to design interaction simple and effortless as well as to adjust learning process and teaching material to individual student, a mechanism for monitoring student's interaction and generating related adaptive interface based on student model is developed. Furthermore, a classification of adaptive hypermedia systems with regard to employed adaptation technology is offered.

1 Introduction

The vision of ambient intelligence (AmI) puts the user, the individual at the center of all developments for a knowledge-based society for all [24], stressing the importance to design technologies for human needs and not forcing humans to adapt. With the growth of Internet, the World Wide Web and computer usage in general, users with a wide variety of background, skills, interests, expertise and learning styles are using computers for quite diverse purposes. For that reason no single user interface, though designed to be both easily learnable and highly efficient, will satisfy every user. Users have different needs as they learn to use an interface, which change as they use a computer and become more familiar with its capabilities as well as the task domain. They have their own preferences and interests as well. This can be seen in some popular web sites which integrate personalization features (to some degree) based on user profiles (for example, Amazon.com, MyNetscape, myCNN and a like).

The emergence of adaptive interface, an interface that dynamically modifies itself during the run-time has provided a satisfactory framework for taking into account users' heterogeneity, by adapting the interface behavior to a user's individual characteristics. Adaptive system generally relies upon user model to adaptively shape its behavior – it collects data about the user (personal characteristics, proficiencies, preferences, interests, attitudes and/or goals (cf. [38]) and then processes them in order to create a model on which to perform the adaptation process. Running a history login allows it to

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keep a history of the communication and to build inferences over the interaction between users and the system during run-time. Within the area of adaptive interfaces a distinction is being made between adaptive and adaptable systems [30], [34]. Adaptable systems allow the user to control the interface customization and adapt their behavior accordingly, while adaptive systems monitor a user's interaction and automatically make adjustments based on the system's assumptions about user needs.

In today's emerging knowledge society for all, knowledge is considered as a foundation of all aspects of society and economy in general and the need for rapid knowledge acquisition is more important then ever. Furthermore, the number of users of computer-based educational systems rapidly grows. Current research efforts mainly address adaptive educational hypermedia systems (AEHSs), hence emphasizing a particular kind of adaptivity that encompasses adaptive presentation, adaptive navigation support and adaptive content selection [6]. However, it can be noted that these techniques still haven't been applied in everyday learning and teaching environments, apart from their development surroundings [3], [25].

Focusing on computer-based educational systems which emulate human teacher in the process of learning and teaching, it is an accepted opinion that their interaction mechanisms have been given inadequate consideration [9], particularly because the majority of existing systems simply predefine the respective interface, without means for its adaptation [28]. Intelligent tutoring systems (ITSs) are computer-based educational systems which attempt to mimic the behavior of a human teacher in order to support the process of learning and teaching in arbitrary domain knowledge [8]. ITSs provide individualized instruction for students, attempting to adjust the contents and the way of domain knowledge perception. Despite the fact there are still only few ITSs in practical use [41], it has been claimed that starting from the 1970's when the first system was developed, ITSs undoubtedly have improved the process of learning and teaching for arbitrary domain knowledge [16], also taking into account individuality of the person being taught. In fact, ITSs still represent the best way to enable one-to-one instruction, since they provide the student her/his own "computer teacher" [32]. This viewpoint is supported by our research concerning ITSs and their generators, authoring shells (ASs) [28] as well, as exemplified in a series of developed systems based on TEx-Sys model [19], [33], [35], [36]. These systems are employed in the process of learning and teaching a number of real subject matter and have been continually evaluated concerning their efficiency of a learning process as well as usability of their user interface (e.g. [18], [20]). Nevertheless, regardless of our expertise and experience as well as the fact that those systems have unquestionably enriched the process of knowledge acquisition, we are still facing difficulties that have to be taken into consideration.

The remainder of the paper is structured in the following way. Section 2 explains our motivation and need for the research on adaptive hypermedia technology with the intention of its appliance in our systems. Section 3 discusses adaptive hypermedia systems (AHSs), highlighting those implementing the most frequently used and evaluated adaptation techniques. A classification regarding implemented adaptation technology completes the presentation of the systems. In order to design adaptive interaction in systems which emulate human teachers, an employment of AHSs adaptation technology is elaborated in Section 4. After a short primer on intelligent tutoring systems and authoring shells, a concept of a student model and adaptation mechanism to be engaged in our systems is presented. Finally, Section 5 provides concluding remarks and outlines further research as well.

2 Motivation

In order to design interaction simple and effortless as well as to adjust the TEx-Sys model founded systems to fit the needs and individual characteristics of all students, we have considered adaptive educational systems, especially those Web-based developed in the last decade. Most of the computer-based educational systems available today could be classified either as intelligent tutoring systems or adaptive educational hypermedia systems. Although ITSs' development started from the seventies, first adaptive hypermedia systems (AHSs) were developed in the early nineties by involving user modeling and adaptation into static "one-size-fits-all" hypertext and hypermedia. They adapt the content or presentation of the system to some relevant characteristics of the user on the basis of a dynamic understanding of each particular user. These systems, with interfaces that look and feel like typical hypermedia documents, became a very natural way of delivering adaptive e-learning courses to the Web, often presented as electronic textbooks or hyperbooks (see classification of AHSs in section 3.1). Consequently, education still remains the widest AHS application area.

Each of these two categories of systems has developed its own adaptation mechanisms, almost independently from each other. Only a curriculum sequencing technology has originally been developed in intelligent tutoring systems and later successfully applied in many adaptive educational hypermedia systems. ITSs also developed an intelligent analysis of student's solutions, interactive problem solving support, example-based problem solving support and later, with the growth of Internet, an adaptive collaboration support. On the other hand, emerging adaptation techniques from AHSs, related to the system's layout as hypertext or hypermedia, appeared to be very effective [12]. Recently, a growing number of ITSs which have accepted and successfully implemented some of the adaptive hypermedia techniques can be found [2].

We aim to design intelligent tutors for students and not make students adapt to the systems. Specifically, in order to improve student's interaction and knowledge acquisition in the family of systems based on TEx-Sys model, we incorporate a number of adaptive hypermedia techniques. To facilitate examination of AHSs' adaptation functionalities, various systems mostly applied in the field of education are analyzed. In the following a cross section of our research in adaptive hypermedia is presented, without pretending to give an overview of all existing systems, but an extraction of AHSs which implement the most frequently used and evaluated techniques. All presented systems are elaborated on the basis of their "live" versions (when possible) instead of relevant elaboration papers.

3 Background Research on Adaptive Hypermedia

In order to be called an adaptive hypermedia system (AHS) the system must satisfy following criteria: (i) it should be based on hypertext or hypermedia, (ii) have an explicit user-model which reflects some features of the individual user and maintains them dynamically, (iii) have a domain model which is a set of knowledge items and relationships between them and (iv) be capable of modifying some visible or functional part of the system on the basis of information stored in the user-model [14]. Few years after developing first single purposes AHSs, their authors began to generalize them into authoring tools for simplifying the development process of new AHSs, usually in the same application area (see Table 1). The creation of the course is usually high level process based on the construction of topics hierarchy in domain model, but some tools go even further and let the authors write some specific adaptation rules, consequently directly involving in adaptation functionality of the system. These authoring tools are commonly used in educational domain but recently authoring tools for the development of on-line information systems, on-line help systems and information retrieval hypermedia can be found.

3.1 Adaptive Hypermedia Systems

Although all adaptive systems are designed to adjust their presentation and functionality to individual needs, wishes and abilities of the user, they significantly differ in (i) what individual characteristics of the user they consider as relevant for the adaptation process, (ii) how do they observe user's actions and gather those information and finally (iii) how do they employ these characteristics to perform adaptation. In the following we present a number of adaptive hypermedia applications distinguishing authoring tools from concrete systems. The majority of them are educational systems, not only selected because of our particular interest in education, but also because of the fact that education is still leading application area of adaptive systems.

AHA![1] [11] is the Adaptive Hypermedia Architecture, a complex but powerful tool for creating adaptive Web-based applications intended to serve many different purposes. Regardless the fact that is mainly used for developing distance learning applications, but in order to preserve generality, adaptation decisions are based exclusively from observing the user's browsing actions, not considering browsing as a learning process.

InterBook[2] [5] is free authoring tool for creating and delivering adaptive electronic textbooks on the Web, not necessarily learning courses. Textbooks written as a word documents are annotated and converted to the HTML documents. Reading material is presented in different windows consisting of several frames, but they all are considered as multiple views on the same page.

KBS Hyperbook system [21] provides a framework for developing and maintaining open, adaptive hypermedia systems in the Internet. It is intended to serve for creating distance learning applications and implements project-based learning. Students are free to choose their own learning goals and the adaptation techniques are based on a goal-driven approach.

[1] `http://aha.win.tue.nl`

[2] `http://www.contrib.andrew.cmu.edu/~plb/InterBook.html`

ELM-ART[3] [7] is one of the first Web-based ITSs, aimed to support learning programming in Lisp. It presents all course materials (topics introductions, examples, problems and tests) in hypermedia form, integrating features of an electronic textbook, of a learning environment and of an intelligent tutoring system. Observations about the user are made by monitoring the problem solutions and by considering test results.

NetCoach [39] is an authoring system that allows creation of adaptive and individual course modules using a simple Web-based interface. Authoring includes creation of the learning material, composition of tests, definition of learning goals, adaptation of a layout and behavior of the interface as well as management of access rights for students and tutors. NetCoach is derived from ELM-ART, so courses that have been developed with NetCoach are ELM-ART alike: all of them are adaptive, adaptable, interactive and communicative.

AdaptWeb [17] is an adaptive environment application for Web-based learning used in a Numerical Methods course. Adaptation mechanism considers three aspects as relevant: the student's current knowledge, the student's program, and the student's navigation preferences.

INSPIRE [31] is an adaptive educational hypermedia system. It allows the learner to select her/his own learning goal and dynamically generates lessons sequence that guides the user toward that goal. System's adaptive behavior exploits student's knowledge state and learning style.

AVANTI [37] is a Web browser which addresses the interaction requirements of individuals with diverse abilities, skills, requirements and preferences (including disabled and elderly people), using Web-based multimedia applications and services. The design and development of the AVANTI browser's user interface supports the concept of User Interfaces for All. Adaptations include the selection of different interaction styles as well as a selection of those attributes of physical interface objects that are appropriate for a given user (e.g. font size, colors, speech parameters).

Table 1. Authoring tools for AHS development

Adaptive Hypermedia Authoring Tool	Adaptive Hypermedia Systems	Publicly Available
AHA! [11]	2L690	Free download
InterBook [5]	ACT-R bookshelf [4]	Free download
KBS Hyperbook [21]	CS1	No
NetCoach [39]	HTML-Tutor, ELM-ART, Peugeot Germany,…	Demo
AdaptWeb [17]	Numerical Methods course	Free download

[3] http://www.psychologie.uni-trier.de/projects/ELM/elmart.html

As a result of our research in adaptive hypermedia we have classified the above systems with regard to their general characteristics, distinguishing authoring tools for creating as well as delivering adaptive systems to the Web (presented in Table 1) from the systems themselves (given in Table 2).

Table 2. General characteristics of a number of AHSs

Adaptive Hypermedia System	Application Area	Title	Publicly Available	Learning Strategies
2L690 [10]	Education	"Hypermedia structures and Systems"	Free access	None
CS1 [21]	Education (Programming)	"Introduction to Java Programming"	No	Project-based learning
ELM-ART [7]	Education (Programming)	"Programming in Lisp"	Free access	Example-based learning
INSPIRE [31]	Education	"Computer Architecture"	No	Experimental learning
AVANTI [37]	Web browser	Domain dependent	Case studies	—

3.2 User Modeling in Adaptive Hypermedia Systems

According to the definition of adaptive hypermedia system stated at the beginning of this section, it is clearly understood that adaptation process heavily relies on individual characteristics of each particular user encompassed in her/his user model, as the necessary prerequisite for the adaptation success [40]. Adaptation mechanisms of present AHSs are usually based on following user features: knowledge, user goals, preferences, background and experience [1]. Although clearly identified as essential requirements for adaptation functionality, some of these features may not be stable over time or easy to deduce from the interaction with a user. Therefore the reliability of the inferred features may vary [23].

User's *knowledge*, although changeable and unreliable, is the most important feature for adaptivity in many adaptive systems and especially in educational systems. User's knowledge is usually represented as an attribute in an overlay user model. This means that the system stores user's current knowledge level about each concept from the domain model and then dynamically updates these values according to observations of the user's browsing actions (AHA!, InterBook, ELM-ART, INSPIRE), passed tests (AHA!, ELM-ART, INSPIRE) and possibly solved problems (ELM-ART) or designed projects (KBS Hyperbook). Throughout her/his interaction with a system, user usually aims to accomplish certain task or goal. In educational systems the user can ask and get *user's goal* from the system. Although user's goal is the most volatile of all her/his features, it is extremely important for adaptation and that's why many systems employ goal–driven approach (INSPIRE, KBS Hyperbook). Adaptive systems often accept some *preferences* of the user, mainly concerning the mode of content presentation. In most cases it is impossible to deduce user's preferences from her/his navigation manners so the user has to directly inform the system about them, thus leading the system towards adaptability (AHA!, ELM-ART). Concerning adaptive educational systems, *learning styles* are also considered as relevant for the success of students' learning process (INSPIRE). AHSs distinguish users according to their *experience* in using hyperspace, meaning how familiar they are with its structure and navigation capabilities (InterBook, ELM-ART). An experience in computer usage in general can be considered too. Similarly, a user's *background* describes her/his previous knowledge about the domain or related topics but acquired outside the system. User's experience and background are usually modeled through the stereotypes. Stereotype user model is sometimes employed for modeling other user's features (AVANTI, AdaptWeb), but the best results in adaptation are achieved by combining these two approaches in such a manner that stereotype user model serves as initiation component of the overlay model (AVANTI, InterBook).

Besides storing the user's individual characteristics, user model is very suitable for storing information about history of user's navigation through the system that is relevant for adaptation, e.g. status of the pages, time the user spent on reading the page, the last visited page in previous session and some other information in respect to content of the page.

3.3 AHS Adaptation Technology

The first issue in the development of any adaptive system is the identification of its adjustable parts, meaning the parts that will look differently or act differently for different users. Due to the fact that hypermedia systems are basically sets of pages connected by links, adaptation of the presented page content, called adaptive presentation and adaptation of links to other pages, called adaptive navigation support is usually enabled [1]. Present AHSs implement various techniques to perform adaptation, often developed especially to fulfill the purpose of the particular system. In the last decade these techniques have grown into very powerful technology that is commonly used in the majority of recent AHSs.

Adaptive Presentation. Although content of a page may be text and multimedia as well, most of existing systems use adaptive presentation techniques to perform text adaptation only (AHA!, INSPIRE, KBS Hyperbook). A main goal of adaptive presentation is to provide different content of the page for each individual user respecting her/his user model. In order to accomplish an idea of providing additional explanation to certain users according their knowledge and interests, AHSs usually use a conditional text technique. Text representing information about some domain concept is presented according to respective user's knowledge level. This simple but quite successful technique sometimes is called inserting/removing fragments (AHA!). To adapt page content, an AHS may store several different explanation variants for the same topic in form of fragment of even whole page. Considering the user model (e.g. category of the user or user's learning style) the system decides which variant to present (INSPIRE). Another way for storing different explanation variants is a frame-based technique. Some newer systems use dimming fragments for adaptive presentation, where less relevant parts of the page content are dimmed or shaded but are still visible.

Adaptive Navigation Support. In an educational hypermedia system there is usually a learning goal for each student representing the knowledge that the student has to learn. To provide adaptive guidance the system has to know not only the student's goal, but also her/his current knowledge level. The *curriculum sequencing technique* is very useful to build the shortest, individually planed trail of learning units leading to the specified learning goal. This technique was originally developed in ITSs but then successfully adjusted and employed in most present AEHSs.

A very simple technique for implementing user's guidance called *direct guidance* can be found in most AHSs in all application domains. It is provided through the "next" button leading the user to the next most suitable page considered user's goal and other parameters represented in the user model (particularly knowledge level in educational hypermedia). *Adaptive link sorting* is another helpful technique for supporting user's navigation. It encompasses ordering the links available from the particular page according to their relevance for the user. Sorting is typical for information retrieval systems, but also successfully used in some educational hypermedia systems (InterBook, ELM-ART).

The basic idea of *link hiding* is simplifying the navigation and supporting the user's orientation by restricting the navigational space (AHA!). Links that are not relevant or not yet ready to be read are disabled (visible but inactive), hidden (transferred to normal text) or even removed from the page content. The goal of *link annotation* technology is to indicate the current state of pages or fragments behind annotated links. It is usually used simultaneously with link hiding techniques. Adaptive link annotation is especially useful in educational hypermedia to indicate the student's knowledge level on particular topics. *Map adaptation* concerns adapting graphical presentation of global and local hyperspace link structure using any of the techniques listed above or their combination.

Classification of AHS Adaptation Technology. In order to review presented adaptation technology, a classification of previously introduced AHSs according to the implemented adaptation techniques is given in Table 3. As shown, numerous

Table 3. Application of adaptation technology in AHSs

Adaptation technology	AHA!	InterBook	ELM-ART	INSPIRE	KBS Hyperbook
Content adaptation	x			x	x
Direct guidance		x	x	x	x
Link annotation	x	x	x	x	x
Link hiding (removing, disabling)	x				
Link sorting		x	x		
Curriculum sequencing			x	x	

reviewed systems apply adaptive navigation support as dominant adaptation technology. Due to the fact that content adaptation is not so frequently used, as most of the systems use one or no adaptive presentation technique at all, the table brings adaptive content presentation as a general technology, not specifying any particular related technique.

First AHSs have been developed independently from each other and usually even unaware of each other. Therefore existing systems considerably differ in their architecture and even more in their functionality, especially adaptation. That makes comparison of existing AHSs very difficult, especially because each of them has been elaborated in a different manner. In the field of adaptive hypermedia there are only few isolated efforts in formal description of systems architecture and adaptation mechanisms as well. We stress the importance of AHAM reference model [13] and a characterization of systems, observations and adaptivity rules in first-order logic [22].

4 Designing Interaction with AHS Adaptation Technology

Since adaptive hypermedia is quite new direction of research within the area of adaptive and user-model based interfaces, many of the systems have not been evaluated to date considering their adaptation functionality. There is still a lack of methodology for adaptivity evaluation [27] and a limited amount of empirical evaluations of adaptive systems has been performed thus far [40]. Nevertheless, they do report the effectiveness of presented adaptation techniques [12], [40] and therefore justify our intention for their employment in our systems.

A brief introduction on intelligent tutoring systems and authoring shells is followed with an outline of adaptive interaction design in the TEx-Sys model based systems.

4.1 Intelligent Tutoring Systems

Intelligent tutoring systems (ITSs) are computer-based educational systems that emulate the human teacher in order to support the process of learning and teaching in arbitrary domain knowledge. The emulation process attempts to mimic the behavior of a human tutor, teaching individually in a one-to-one relationship [15]. ITSs are built on a fairly well established architecture, which relies on four interconnected modules: (i) expert module acting as the domain knowledge unit, (ii) student module comprehending the generated student model based on the learning and teaching process in the domain knowledge, (iii) teacher module guiding the learning and teaching process and (iv) communication module realizing the interaction among student, teacher and knowledge [8]. ITSs provide individualized instruction for the users and accordingly such systems must be intelligent, attempting to adjust the contents and the way of domain knowledge perception. When considering adaptivity, the most important part of a student model is the information which system maintains about the student's relation to the concepts of the domain knowledge, gathered by observing the student's interaction pattern.

As the need to cover a variety of different domain knowledge have arisen since, instead of having a number of particular ITSs for the domains of interest, authoring shells (ASs) [28] have been developed, which are intended to act as generators of specific domain knowledge ITSs. ASs are meant to accommodate to the teachers as well as to the students within an interactive learning environment by supporting teachers in the development of a series of ITSs for arbitrary domain knowledge and conversely, by enabling students to learn, test themselves and be advised on further work. Because of their ability to express the cognitive model of human memory and reasoning [29], in some ITSs and ASs knowledge representation is based on semantic networks, whose basic components are nodes representing domain knowledge objects and links showing relations between objects.

In order to make interaction simple and "transparent" as well as to improve the learning experience, user interface design in these systems plays a fundamental role. Hence the interest is to make ASs and ITSs more acceptable (and usable!) to the users by applying adaptation in order to implement a more intelligent interaction.

Due to an inadequate consideration given to their interaction mechanisms in general, we have developed Adaptive Knowledge Base Builder (AKBB) that supports the communication through interaction styles' adaptation. AKBB supports teachers in the development of specialized ITSs for particular domains of education [19]. Its self-adaptive interface, conformant to individual user interaction, provides three diverse types of interfaces (command, mixed and graphical) with appropriate interaction styles.

Currently we are employing AHS adaptation techniques in order to design adaptive interaction in systems which emulate human teachers in the learning and teaching process, enabling students to learn, test themselves and be advised on further work.

4.2 Designing Individual Interaction in an Intelligent Tutor

In contrary to the classic hypertext pages, which mainly present textual content, user interface of systems based on TEx-Sys model offers nodes representing domain knowledge objects (concepts to be learnt) as well as links showing relations between objects. Each concept is additionally described by its structural attributes that may be text, pictures, presentations and a like. Within the text describing a concept we do not perform content adaptation on individual level, but adaptability in regards to students' university program and for younger pupils respecting their age.

Central part of the interface presents hierarchy of nodes containing teaching material that students are supposed to learn. We consider that on the nodes structure level a high level of adaptivity to individual students can be reached. Engaged technology is essentially adaptive navigation support applied on the nodes instead of classic hyperlinks. Nodes will be adaptively annotated on the basis of recording student's navigation through the nodes structure as well as tests results, aiming to lead the student toward her/his learning goal.

Student Model. We have accepted the methodology of user modeling from the field of AHSs but kept the term 'student model' from previous generations of TEx-Sys model founded systems because users of intelligent tutoring systems are indeed the learners. The student model as the basis of system's adaptivity is an overlay user model. Each student is described by a set of attributes with associated values. We use

Table 4. Student model attributes and their role in interface adaptation of an intelligent tutor

Attribute	Value	Adaptation role
knowledge	%	student's knowledge about a concept
selected	true / false	currently selected node
traversal	[0,2]	visited node and/or its children
relevance	true / false	the next suitable node to select

four attributes, namely *knowledge*, *selected*, *traversal* and *relevance*. For each node from the teaching material structure the system calculates and stores values of those attributes. Student model attributes are listed in Table 4, together with their possible values and short description of their role in system's adaptation.

The *selected* attribute directly detects student's interaction with the system. When a student selects a node, system adaptively annotates selected node by changing node color into purple and then updates the student's model accordingly, that is changes attribute values for selected node and for all nodes directly related to the selected one.

Traversal attribute enables the system to continuously keep record of student's actions that include navigation through the node hierarchy and visiting structural attributes of the nodes as well. For each node traversal value is calculated in the following way: if the student visits the node, traversal value of the node becomes "1", and as the student keeps reading children of that node, traversal value increases in a smaller amount dependent on the number of the children. Maximum traversal value the student can reach reading a content of a lesson is "2". As student usually passes the nodes in the parent-child direction, selection of a child causes the propagation of traversal values of its parent. Traversal attribute is very important for adaptation since a student can access the test at the end of each teaching unit only if she/he has read 70% of presented material expressed in total traversal values of all nodes within that unit.

Recent systems from this ITS family keep tracking the time a student spends on learning particular node, but we argue that time spent on learning can not be consider as a reliable indicator of student's knowledge. The system updates the *knowledge* attribute only on the basis of test results. The test is offered at the end of each teaching unit and consists of dynamically generated questions. This provides trustful information about student's current knowledge level of tested concepts. After test analysis is done, knowledge values propagate through the network of nodes in a way similar to propagation of traversal values.

For presentation of new teaching unit of domain knowledge the system considers student's knowledge tested in previous chapter in the following way. Before presenting new content the system initially increases traversal values of those nodes that have been mentioned in previous units or directly related in the knowledge base to some of the previously mentioned nodes. This improves students learning process by simplifying her/his access conditions for taking the next test.

Respecting the student's learning goal, we use a *relevance* attribute to suggest the most suitable concept for the student to be learned next. Consequently the direct guidance technique is implemented to create an individual learning trail for each student.

Adaptation Mechanism. System performs adaptivity process in four phases: initialization, reconstruction, inference and adaptation (meaning a generation of an interface adapted to individual student). Each phase is realized through its own set of rules.

- The first set of rules operates in initialization phase. When a new student is registered and logged on the system for the first time, the system reacts in running these rules to create her/his student model, assigning default values to its attributes and generating the initial layout of the system's interface.
- Instead of initialization rules (if it is not the first time that a student logs on the system) the second set of rules is executed to perform the phase of reconstruction. Considering previously stored values in the student model, the system reconstructs the state of the user interface from the last student's session.
- The third set of rules concerns inference mechanism. Inference rules define the ways of observing student's actions while she/he is logged on the system and record those actions by updating the user model accordingly.
- In the last phase the system generates an interface adapted to individual learner on the basis of current state of her/his student model. This phase is realized through the fourth set of rules called adaptation rules.

Inference rules as well as adaptation rules are being executed in alternations after each student's action (e.g. selection of a node or a structural attribute of the node) thus providing continuous dynamic update of the student model and generation of a user interface adapted to its new state.

The design is just a high-level outline of the adaptivity mechanism (which hasn't been implemented yet) and consequently its rules are expressed in pseudo-code. As an illustration of the inference phase a rule for monitoring student's navigation and updating traversal values is provided:

```
if node.selected then
  node.traversal := node.traversal + 1;
  n := node.parent.count;
  node.parent.traversal := node.parent.traversal+(1/n);
```

Subsequent to an update of the user model, the system performs adaptation rules to derive new interface features and generate their presentation to the student. In the following the rule for adaptive annotation of nodes is given. All nodes with *traversal>0* are assumed to be visited or known, accordingly being colored blue. Currently selected node is purple-colored. Nodes that have not been visited or learned yet (according to tests results) remain yellow as colored in the initial phase, except the relevant node which is being colored green to suggest the student to selected it next.

```
if node.traversal > 0 then
  node.colour := blue;
if node.selected then
  node.colour := purple;
if node.relevance then
  node.colour := green;
```

We claim that these sets of rules provide a very dynamic and flexible interface adaptation of systems built on TEx-Sys model. Although traversing the nodes in order to learn particular domain knowledge cannot be actually concerned as knowledge, we expect that proposed combination of learning and testing will significantly enhance the process of student's knowledge acquisition. Student's knowledge is evaluated only through tests, with different dynamically generated questions. Therefore, tests are reliable indicators of student's knowledge. Accordingly, immediately after student receives her/his first test, the system gets a trustful base for interface adaptation which simplifies student's learning in further interaction. Nevertheless, the student model initialization, which particularly includes assessment of student's starting knowledge level, remains an open issue. Two approaches are considered; first imposing an entry tests on each course and second using a short introductory lesson ending with a test. Both options have certain limitations so the selection of an appropriate approach will depend on the implementation of particular ITS.

5 Conclusion

Ambient intelligence places the individual at the heart of the development of future Information Society Technologies (IST), emphasizing the need to design technologies for human needs, making interaction simple and effortless. Furthermore, knowledge is the most important resource in such context, hence also dubbed the knowledge society, and the need for its rapid acquisition is more important then ever. On the other hand, although computers are being used at different levels of a teaching process (as subject of teaching as well as tool for supporting the teaching process) despite decades of research their use for tutoring (as the teacher itself) in everyday teaching environment has been quite limited. Intelligent tutoring systems (ITSs), as computer-based educational systems which emulate one-to-one human tutoring process, must consider a student as an individual just like a human teacher would do. In order to improve the effectiveness of a learning process, ITSs have to be adaptive, adjusting the teaching material and the way of its presentation to the student's needs, wishes and abilities. Recently, development in the field of adaptive hypermedia (AH) produced a number of possibly effective adaptivity techniques that could be applied in ITSs to improve their interaction mechanisms.

Despite our expertise and experience in the conceptualization and development of systems based on TEx-Sys model and the fact that they have unquestionably enriched the process of knowledge acquisition at our Department, we are still facing some difficulties. Systems still do not employ any intelligence in the presentation of teaching material but only in the generation of test questions. Consequently, in order to adjust the learning process and teaching material to an individual student, a mechanism for monitoring student's actions and generating adaptive user interface based on those observations is developed and presented in this paper. Adaptation process relies on student model as well as on dynamic updating of its attribute values during the individual interaction. A system mainly performs adaptive navigation support, adjusting the adaptive hypermedia techniques to its own interface. Student's knowledge deduced from tests, is simplifying student's further interaction, consequently improving the process of knowledge acquisition. In order to have better insight in applied AH adaptive technology, background research is summarized in two classifications, first based on user modeling methods applied in a number of recent systems, as well as a second one based on commonly used adaptivity techniques.

Future work will be focused on the employment of such adaptation mechanism in authoring shells (ASs) facing the possibility that such approach has to be refined in order to fit existing architecture. A series of experiments will follow to examine the effects of adaptivity on learning process, as well as to obtain results concerning evaluation of efficiency, accessibility and usability of developed solution. Additional work will also encompass a research of Kolb's learning theory [26] as well as the possibility of learning styles consideration in the interface adaptation on the TEx-Sys model founded systems.

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