A HIPERMEDIA MODEL FOR AN ADAPTIVE LEARNING

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ABSTRACT

We present SEM-HP, an evolutionary model for the development of adaptive hypermedia systems. Hypermedia systems allow the documents to be linked so the information can be browsed in a non-linear way, providing advantages from an educational point of view. Nevertheless, they can cause disorientation and lack of comprehension, which is reduced by adaptation to the user and orientation support. SEM-HP allows a semantic representation of the knowledge offered by the system, along with different navigation modes that aim to maximize the understanding of the offered material, by showing only the proper information to the reader, taking into account his experience, knowledge and preferences. In addition, it supports evolutionary mechanisms that keep the hypermedia system consistent when it is modified.

KEYWORDS

Hypermedia, user adaptation, semantic networks, e-learning.

1. INTRODUCTION: A SEMANTIC NAVIGATION STRUCTURE

Hypertext and hypermedia are nowadays very common terms when speaking about new technologies in information presentation and access. This is because they have shown to be a powerful tool for representing documents and information, as well as for communicational and educational processes in different fields, especially since the appearance of the World Wide Web. The main reasons of this success are two: in the one hand, the attractiveness for the user of the visual aspects and the variety of media (audio, video, images, text…) with which the information is presented in the hyperdocuments, and in the other hand, the possibility to access the information in a non-sequential order. The latter reason assumes the existence and adoption of the criterion of association of ideas and concepts as the basis for organizing the documents [Bush, 1945]. Nevertheless, despite their advantages, comprehension and disorientation problems may arise if an inadequate navigational structure is initially used.

We often observe that links in a hyperdocument have been introduced in a capricious or random way, and they scarcely show information about the destination of the link, and about the relation that the destination document has with the current document. To prevent this kind of problems, which are very frequent in the creation of hypermedia systems (HS), SEM-HP model [García-Cabrera et al., 2002] proposes a navigational structure in which the semantic is explicit. This structure is a semantic network called Conceptual Structure (CS), which shows the concepts of the conceptual domain captured in the HS, and the semantic relations among them (conceptual relations). In this structure, the hyperdocuments (information items) are linked to the concepts by means of functional relations. In this way, the concept to which the contents of each item are related is visualized in the navigation structure itself. In addition, the functional relation that links an item to a concept is labelled with a role that classifies the content of the item in categories such as example, exercise, introduction, antecedent, etc. Besides the role, the items have other properties such as difficulty level, date of creation, author, language, etc. The CS will be the basis of the HS, and later the tutor will be able to select different subsets and to define different ways of navigating them. A repository of learning resources can be created, allowing them to be reorganized and reused for future different courses.

Figure 1 shows a CS whose knowledge domain is the object-oriented paradigm. The set of concepts (shadowed circles) consists on the main ideas of this paradigm, C={Class, Object, ADT, Inheritance, Message, …}, and the items, I, are pieces of information that describe the concepts, for example the item I15 explains an opinion about the usage of simple inheritance and the item I10 contains examples of instance methods in different programming languages.

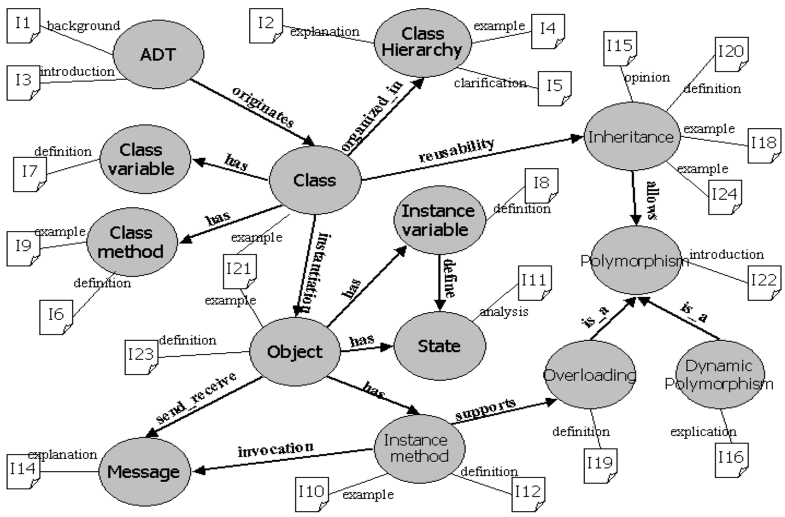

Figure 1. Example of Conceptual Structure

2. ORIENTATION SUPPORT: PERSONALIZED VIEWS

The knowledge domain of the HS will be frequently complex and large, therefore is it possible that, in some moment in the navigational process, a reader can find himself lost, not knowing how he got to the current document and how to return to a previously visited document. In traditional navigational systems, it is necessary to superimpose orientation support methods on the link structure; because the link structure does not provide information such as if a link is close to another one followed before, or how many links get to the current document. In our case, the CS constitutes by itself an important mechanism to improve the user orientation, but, even then, it could be not enough if the CS is too large.

In order to solve this problem, SEM-HP model allows the tutor to define different views of the whole CS. Each view is called Conceptual Structure of Presentation (CS_P) and captures a subset of the knowledge domain represented by the initial CS. This permits to assign to each reader the CS_P that captures the knowledge in which he is interested, without complicating the navigation with items not interesting for him.

The process followed by the tutor to create a new presentation consists in hiding in the CS the concepts, items and conceptual relations he considers not related to the current view. The system automatically keeps the integrity of the CS_P, for example, if after hiding a relation some concepts get disconnected, they are also automatically hidden. In the same way, when a concept is hidden all the items associated to it and all the relations starting or arriving to the concept are also hidden.

The tutor will be in charge of defining the subdomains in which the HS is divided, as well as of labelling each CS_P with the subdomains it represents and in which proportion it represents each one (a CS_P can be labelled to represent partially one or more subdomains). He can also determine the experience degree or degrees, both in navigation and in the subject to which the CS_P is addressed. For example, he will presumably associate a high experience in navigation to a presentation if it has many conceptual and functional relations. In the same way, a presentation in which most items have a high level of specialization will probably require high experience in the subject. The labelling of the CS_P will permit the system to determine automatically which CS_P best adjusts to each reader, thereby providing a personalized navigation structure.

3. KNOWLEDGE ACQUISITION

Knowledge acquisition is a key element in any learning process. Because of this, a mechanism that allows the system to infer the reader's knowledge state at every moment is needed. Adaptive systems (AHA, ELM ART, SQL Tutor or KBS Hyperbook) introduce personalized navigation and content presentation based on the knowledge the user has [Dolog et al., 2003]. In our model, SEM-HP, the reader's knowledge state is stored, along with other information (experience, preferences, interests, etc.), in a user model, and is represented by the knowledge degree $K(i_j)$ that the reader has about every item i_j in the HS. We consider five different knowledge degrees, expressed by the semantic labels "null", "low", "medium", "high" and "total". The mechanism used to obtain the user knowledge is based in a set of knowledge and update rules [Medina-Medina et al., 2002b], defined by the tutor.

The update rules increase the reader's knowledge after he assimilates the content of an item. Initially the update rule $Ru(i_j)$ associated to the item i_j sets to "total" the knowledge degree about that item after its contents are studied. Obviously, the author can modify this rule, choosing other types of update on i_j and even adding updates to other related items. For example, when studying the definition "instance method" (item I12) in Figure 1, the reader also learns something about the definition of "class method" established in I6, so the tutor can specify the knowledge about I6 to be updated when I12 is understood. The structure of the update rules and the possible update predicates are shown in figure 2.

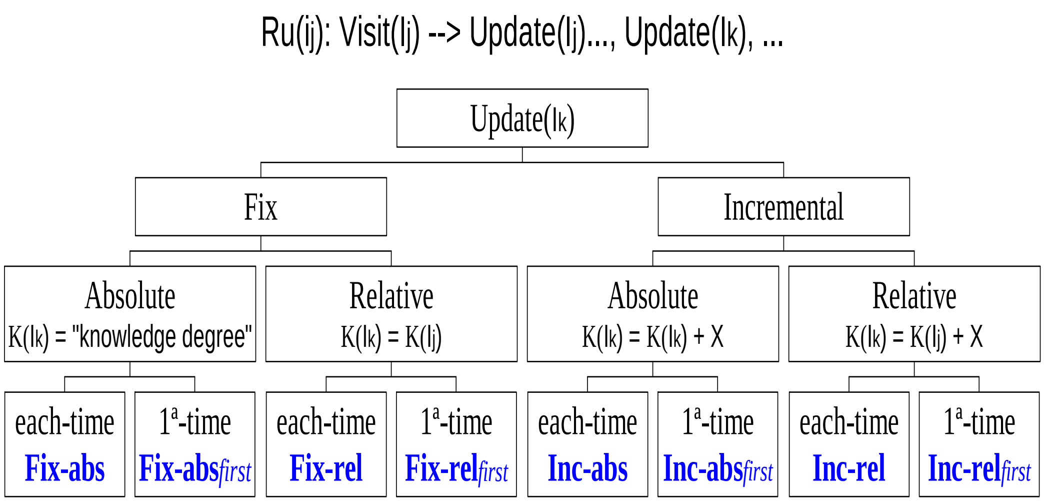

Figure 2. Update rules

The knowledge rules $Rk(i_j)$, associated to an item i_j, define a set of knowledge restrictions which determine if i_j is visitable, and if that visit is advisable. An item can have several associated knowledge rules $\{Rk^1(i_j), ..., Rk^n(i_j)\}$, and if there is more than one the reader must satisfy at least one of them. Restrictions in each rule can be divided in two types: accessibility restrictions ($Restriction^A$) and idoneity restrictions ($Restriction^I$), which determine respectively when the reader is ready to understand the information in an item, and when an item is too simple or redundant for the reader so he should not waste time visiting it. Hence, each $Restriction^A$ determines the minimum knowledge degree the reader must have about an item to be permitted to access another item ($K(i_k)\geq$"knowledge degree"), while $Restricción^I$ determine the maximun knowledge degree that the reader must have about an item so the visit to another item is advisable ($K(i_k)\leq$"knowledge degree").

In this way, while the user navigates, the system updates his knowledge in the following way: every time he visits an item the system checks if his knowledge state is adequate for correctly understanding the contents of that item, that is, if he satisfies the associated accessibility restrictions. In affirmative case, the visited item's update rule is executed, so the reader knowledge about certain items is increased.

4. MODES OF NAVIGATION

Depending on his circumstances and particular interests, the reader will wish to browse the information in a different way. Because of this, SEM-HP model offers four different navigation modes, allowing the reader to choose at every moment the one that best suits him. In addition, in each type of navigation, the system applies a set of adaptation techniques [Brusilovsky, 1996], which allow adjusting the navigation structure in function of the mode of navigation and the specific characteristics of the reader. Table 1 lists the four supported navigation modes, along with a short description.

Table 1. Modes of navigation in SEM-HP

Mode	Description
TRADITIONAL	All the items are accessible.
BY CONCEPT SUMMARY	The system composes a summary of each concept, using the items connected to it.
RESTRICTED BY KNOWLEDGE	Only the items that the reader is prepared to understand are accessible.
BY CONCEPTUAL RELATION	The navigation must adjust to the links between concepts.

4.1 Traditional Navigation

This type of navigation allows the reader to select, in any order, the items in the provided navigation structure. This way of browsing the information is the closest to the navigation scheme to which the users of web systems are accustomed. Although it may cause problems of comprehension and cognitive overload in inexperienced readers, it is appropriate for those with a high level of knowledge who know exactly the information they need and want to access it directly, without any restriction that delays them. Obviously, the advantage over the usual web navigation is that, in this case, the structure of navigation is chosen in a personalized way, taking into account the knowledge subdomain the reader is interested in and his experience level.

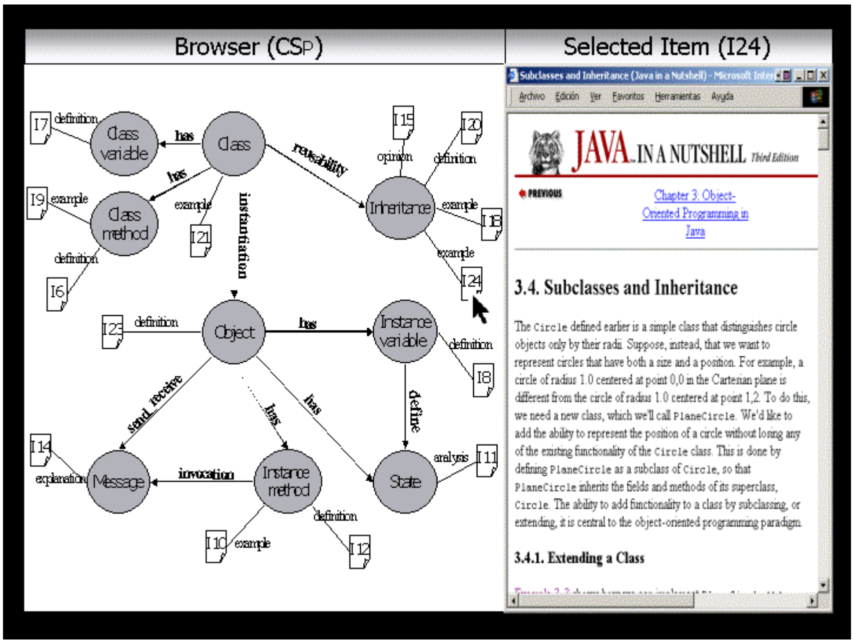

Figure 3. Traditional navigation

As shown in figure 3, the interaction with the system is done through an interface composed by two panels: the first shows the navigation structure (the chosen CS_P), and the second provides the contents of the selected item (I24). By looking at the first panel, the reader knows the currently selected item, the concept to which it is associated, which other items are linked to the same concept, and which concepts are connected to the current concept.

While the readers visit items, the system studies their behaviour to discover the navigation strategies used by the group of readers that navigate freely, that is, without having to follow the paths predefined directly or indirectly by the author. From this analysis, performed using transition matrices, the system extracts the navigation patterns common to most readers, and based on them, it proposes to the author some changes to the CS. The suggested changes will allow the tutor to adapt his representation of the conceptual and informational domain to the mental models the readers of the system have. We call this type of adaptation "adaptation by feedback", given that the structure of the HS is redefined in function of the navigation of it performed by a significant number of free readers. Among other things, this method allows to discover conceptual associations accepted by most readers that have not been considered by the tutor, or to determine concepts, items and conceptual associations that are rarely contemplated. For example, if most readers visit the item I6 in Figure 1 after visiting I19 or I12 it is because they accept a conceptual relation between "Instance method" to "Class method", which is not reflected in the author's CS.

4.2 Navigation by Concept Summary

In section 2 it was stated that, with the double objective of reducing the disorientation problems and of focusing the navigation to specific subdomains, the systems offers as navigation structure a partial presentation of the CS. Nevertheless, some readers will be interested in visualizing the whole CS in order to learn from a global perspective the semantic of its concepts and the relations between them. In these cases, SEM-HP allows the reader to browse a structure that only shows the concepts and the conceptual relations. Since the informational domain (items and functional associations) is not explicit, the size of the navigation structure is considerably reduced, and it is possible to clearly visualize the whole conceptual domain.

In this type of navigation, the reader selects concepts instead of items, so, when clicking a concept he obtains a summary with information about it. This summary is dynamically generated by the composition of the items linked to the concept, and the information is organized in the summary according to a compositional structure initially specified by the tutor. The order that an item will have in the summary is determined by its role. Hence, the tutor establishes the structure of the summaries ordering the roles and specifying which are compulsory and which are optional. Finally, in the summary of a concept there will be a section for each role. For the compulsory roles, the section will contain the information of all the items associated to the concept through that role, while optional sections are contracted and only show the name of the role.

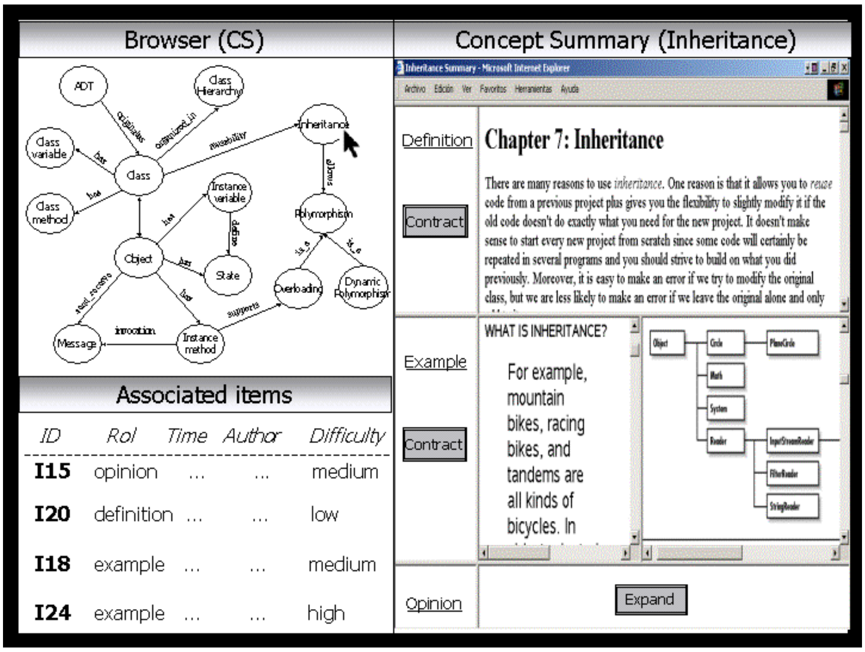

Figure 4. Navigation by concepts

Figure 4 shows an user interface for this mode of navigation: in the upper left the conceptual navigation structure is shown, bellow it we can see the information about the items associated to the selected concept ("Inheritance" in the example), in he right the generated summary is displayed. This summary shows firstly the section "definition", showing the contents of the item I20, then the section "example", which contains two items, I18 and I24, and finally the section "opinion", which was defined to be optional and is therefore contracted.

When the reader studies a summary he can expand the optional sections (making them compulsory), or contract the compulsory sections (turning them into optional), and even reorder the different sections at will. The changes performed by the reader will change the compositional structure used to generate further summaries for him. In this way, the structure of the summaries is adapted to his preferences.

4.3 Navigation by Conceptual Relation

In this type of navigation, the reader browses the information in an order that is consistent with the semantic relations among concepts. For this, the tutor restricts the possible paths through the navigation structure by means of two elements: navigability of the conceptual relations and order rules.

The navigability of a conceptual relation is the direction in which it can be followed. By default, it is the direction of the relation, that is, from the origin concept to the destination concept. However, the tutor can increase its navigability, so the relation can also be followed in the other direction. For example, if the conceptual relation "instantiation" in Figure 3 is extended it may be followed from "Class" to "Object" and from "Object" to "Class". Once the navigability has been determined, the conceptual relations can be seen as navigation links.

The order rules associated to the item i_j, $Ro(i_j)=\{Ro^1(i_j), ..., Ro^n(i_j)\}$ partially define the different paths the reader can follow in order to reach it. By default, for each item there is an order rule for each navigation link that has as destination the concept to which the item is associated. The rule's body, in addition to following the mentioned link, requires the immediately previous visit to any of the items connected to the concept that is origin of the link. Table 2 shows the order rules for the item I14 associated to the concept "Message" in the CS_P in Figure 3. These rules establish that for accessing the explanation about "Message" the reader must arrive (following the corresponding relation), after having studied any item connected to the concept "Instance method" (Ro^1) or to the concept "Object" (Ro^2).

Table 2. Default order rules for I14

Ro^1(I14)	previous(I10) or previous(I12) and follow("invocation") → Visitable(I14)
Ro^2(I14)	previous(I23) and follow("send_receive") → Visitable(I14)

If the tutor desires, he can add new restrictions to an order rule, for example, requiring (*before*) or forbidding (*not before*) a previous visit, in two or more navigational steps, to other items in the structure. These modifications are analysed by the system and are only allowed if they keep the HS consistent. In table 3 we can see the rule Ro^2(I14) after a modification that requires that, in order to visit I14 the reader must have previously read the analysis, performed in the item I11, about the notion "State".

Table 3. Ro^2(I14) modified by the tutor

Ro^2(I14)	**before(I11) and** previous(I23) and follow("send_receive") → Visitable(I14)

Since this type of navigation depends on the visits previously performed, the system annotates, beside each item, the number of times it has been visited. This information will allow the reader to be more aware of his navigation history and, based on the order rules, he will be able to know which other items he must visit in order to access the ones he is interested in. To assure that the reader only accesses the allowed items, non-accessible items are hidden and disabled in the navigation structure. Summarizing, in a navigational step there a three kinds of accessible items:

a) Items associated to the current concept. These provide new information about the concept connected to the last visited item.

b) Items connected to a concept that is destination of a navigation link that starts in the current concept, which also satisfy at least one of their order rules. These items contain information about a concept semantically related to the previous one.
c) In addition, there is a set of items that can be always visited. These items, called starting points, are linked to concepts that are not destination of any link. These items are related to basic concepts, and are the beginning of any navigational path.

4.4 Navigation Restricted by Knowledge

As described in section 3, in every navigation mode the accessibility restrictions in knowledge rules are evaluated, with the aim of determining if the knowledge acquisition proposed by the tutor in the update rule of the visited item must be performed. In navigation restricted by knowledge, knowledge rules are also used to guide the navigation in function of the pedagogic prerequisites expressed by the author.

This type of navigation is the most suitable for inexpert readers that want to learn a knowledge subdomain in an exhaustive and proper way. Besides, it is the closest to the usual educational model, in which the tutor directs the students' learning, presenting the information in a didactic order, oriented to their specific knowledge level [Martín-Puente et al., 2003].

For example, let's assume that, in the CS_P in figure 3, the teacher considers that for understanding the example of "Class method" included in I9 it is necessary: 1) Having a high knowledge about "Instance method" (definition in I12 and example in I10), and having a reasonably good idea about the definition of "Object" (I23), or: 2) Having deeply studied an example of "Class" (I21), and superficially knowing the definition of "Class method" (I6). These knowledge requisites are expressed in the knowledge rules Rk(I9), as shown in table 4. Hence, a student can only see I9 if his knowledge state satisfies the conditions imposed in Rk^1(I9) and/or Rk^2(I9).

Table 4. Knowledge rules for I9

Rk^1(I9)	K(I12)≥"high" and K(I10)≥"high" and K(I23)≥"medium"→ Accesible (I9)
Rk^2(I9)	K(I21)="total" and K(I6) ≥"low" → Accesible (I9)

Knowledge rules also allow the tutor to express restrictions such as the one shown in table 5, which expresses the following situation: If a student has gained a high knowledge about the item I18 (which shows a complex example of inheritance), it is not necessary for him to visit I24 (which has a simplified version of that example). In the same knowledge rule there can be both accessibility and idoneity restrictions. When the author changes the update and knowledge rules the system checks several properties, disallowing changes that would lead to an unsatisfactory HS. For example, knowledge and update rules that would make any item unreachable are not allowed.

Table 5. Knowledge rule for I24

Rk^1(I24)	K(I18)≤"high" → Idoneus (I24)

In addition, in this mode of navigation, the system applies several adaptive techniques that increase the productivity in the navigation process and improve the student's learning process quantitatively and qualitatively. For example, the system annotates the student knowledge state on the navigation structure he uses. Hence, by showing the knowledge degree in each item, the system makes the student more aware of his learning process. In addition, forbidden items (those with accessibility restrictions not satisfied by the student) are hidden and disabled. At the same time, relevant items (those witch accessibility and idoneity restrictions satisfied by the student) are marked in a special way. Additionally, some techniques are applied in order to guide the student to fulfil his learning objectives. Among them, we can cite the generation of personalized guided routes [Medina-Medina et al., 2003]. A route is a list of items, which, when visited in the specified order, allows the student to reach the desired knowledge state. It can be specified by the tutor or by the student, and both the items in the route and its length will be adapted to the student's preferences. In this way, for two students with the same knowledge goals the route can be different, depending on their preferences and their current knowledge state.

5. CONCLUSIONS AND FURTHER WORK

The proposal in SEM-HP of a semantic navigation structure represented by a semantic network of concepts and items benefits both the tutor and the readers of the HS. It helps the tutor to build and structure his conceptual and information domain, while for the reader it is an orientation support that considerably reduces the situations in which the feel lost during the navigation process. In addition, the different modes in which the CS can be browsed (summarized in table 1) favours the user's individuality and permits more flexibility.

In SEM-HP the learning process of the readers is a major element. To support this learning process it maintains knowledge and update rules, which are defined by the tutor and allow the system to model how the students learn. These rules are also used to personalize the navigation structure to the knowledge of the person viewing it, as part of a set of different user adaptation techniques. Those adaptation techniques aim to ease the learning process by reducing the confusion and disorientation in the reader, showing only information that suits his knowledge, aptitudes, preferences and goals.

In order to model adaptive hypermedia systems, SEM-HP distinguishes four interrelated subsystems: memorization (storage, structuring and maintenance of the knowledge offered by the system), presentation (selection of subsets of CS that capture knowledge subdomains), navigation (definition of navigational links and order rules), and learning (management of the update and knowledge rules, and the learning process of the users). In addition, it defines a set of evolutionary actions that allow the tutor to create HS in a consistent way. These actions have a set of defined pre and post-conditions that guarantee the integrity of HS [Medina-Medina et al. 2002a].

Our further work is focused in experimentally verifying up to which extent the diversity of modes of navigation allowed in SEM-HP, and the adaptation methods applied in each mode contribute to improve the interaction of the reader with the HS, and his learning process. With this aim, we are implementing a prototype JSEM-HP [Molina-Ortiz, 2003] that permits the development and validation of AHS using SEM-HP model.

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