Logically Characterizing Adaptive Educational Hypermedia Systems

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Abstract

Currently, adaptive educational hypermedia systems (AEHS) are described with nonuniform methods, depending on the specific view on the system, the application, or other parameters. There is no common language for expressing functionality of AEHS, hence these systems are difficult to compare and analyze. In this paper we investigate how a logical description can be employed to characterize adaptive educational hypermedia. We propose a definition of AEHS based on first-order logic, characterize some AEHS due to this formalism, and discuss the applicability of this approach.

1. Motivation

This paper aims at developing a logical characterization of adaptive educational hypermedia and web-based systems (AEHS). AEHS have been developed and tested in various disciplines and have proven their usefulness for improved and goal-oriented learning and teaching. However, these systems normally come along as stand-alone systems - proprietary solutions have been investigated, tested and improved to fulfill specific, often domain-dependent requirements. So far, there has been no attempt to define a common language for describing AEHS. We claim that such a shared language will support the analysis and comparison of AEHS, and, in addition, a comprehensible description of AEHS will encourage an extended use of adaptive functionalities in e-Learning. This is especially important with respect to the Semantic Web [13], and, associated, the Adaptive Web [4] which knows like a personal agent the specific requirements of a user, takes goals, preferences or the actual context into account in order to optimize the access to electronic information.

Bringing personalization to the Web requires an analysis of existing adaptive systems, and of course this holds for the special case of e-learning and education. In this paper, we propose a component-based definition of adaptive educational hypermedia systems. A functionality-oriented definition of adaptive hypermedia has been given by Brusilovsky, 1996 [1].:

Definition 1 (Adaptive hypermedia system) "By adaptive hypermedia systems we mean all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user."

The component-based definition proposed in this paper is motivated by Reiter`s theory of diagnosis [10] which settles on characterizing systems, observations, and diagnosis in first-order logic (FOL). We decompose adaptive educational hypermedia systems into basic components, according to their different roles in the system: Each adaptive (educational) hypermedia system is obviously a hypermedia system, therefor it makes assumptions about documents and their relations in a *document space*. It uses a *user model* to model various characteristics of individual users or user groups. During runtime, it collects *observations* about the user's interactions. Based on the organization of the underlying document space, the information from user model and from the system's observation, *adaptive functionality* is provided.

This paper is organized as follows: In the next section we give a first description of the components of an AEHS and explain their roles and functionality with examples. We then give a definition of AEHS based on FOL. Due to this formalization, an artificial AEHS with few adaptive functionalities is described in section 3, and four examples of existing AEHS. Due to space constraints, we can not present the complete descriptions in this paper but will only exemplary show the applicability of our definition. The detailed descriptions can be found in a Technical Report [6]. A synopsis of the results is given in section 4. We conclude with a discussion about the results of our logic-based characterization of AEHS.

2. Towards a Logic-Based Definition of AEHS

In this section we will first give a description of the components in AEHS and their roles. Afterwards we will give a formal definition of adaptive educational hypermedia systems based on first-order logic. We claim that an Adaptive Educational Hypermedia System (AEHS) is a Quadruple

(DOCS, UM, OBS, AC)

with

DOCS:

Document **S**pace belonging to the hypermedia system in question as well as information associated to this document space. This associated information might be *annotations* (e.g. metadata attributes, usage attributes, etc.), *domain graphs* that model the document structure (e.g. a part-of structure between documents, comparable to a chapter - section - subsection - hierarchy), or *knowledge graphs* that describe the knowledge contained in the document collections (e.g. domain ontologies).

UM:

User **M**odel: stores, describes and infers information, knowledge, preferences etc. about an individual user (might share some models with DOCS). The observations OBS are used for updating the user model UM. Examples of user models are overlay models where the user's state of knowledge is described as a subset of an expert's knowledge of the domain. Student's lack of knowledge is derived by comparing it to the expert's knowledge. A stereotype user modeling approach classifies users into stereotypes: Users belonging to a certain class are assumed to have the same characteristics.

OBS:

Observations about user interactions with the AEHS. Here, everything about the runtime behavior of the system concerning user interactions is contained. Examples are observations whether a user has visited a document, or visited document for some amount of time, etc. Other examples are rules for compiling e.g. quizzes for testing a user's knowledge on some subject, etc.

AC:

Adaptation **C**omponent: rules for *adaptive functionality* (e.g. whether to suggest a document for learning, or for generating reasonable learning paths, etc.), rules for *adaptive treatment* (e.g. sorting the links leading to further documents according to their usefulness for a particular user, etc.), etc.

To formalize this above definition let's gain a deeper insight into these components:

2.1 DOCS: The Document Space

The objects of discourse in the document space are the *documents*, and, if applicable, the knowledge *topics*. Their equivalent in the logical description are the atoms: the *document identifier (doc_id)* or *topic identifier (topic_id)* respectively.

Domain graphs (or knowledge graphs) are expressed as predicates that state the relations between the documents (or topics). For formalizing the part-of domain graph mentioned as an example in the previous section, we define predicates like

part_of(doc_id_1, doc_id_2) .

Another example is the *prerequisite* relation between documents stating which documents need to be learned before a certain document can be studied:

preq(doc_id_1, doc_id_2).

Some AEHS use a separate knowledge graph to express relations about knowledge topics. These topics normally do not correspond one-to-one to the documents. If a separate knowledge graph exists, this graph will be expressed by several predicates as well. E.g., a taxonomy on topics will be expressed by predicates like

is_a($topic\_id_1$, $topic\_id_2$) .

A further example are learning dependencies modeled on topics:

is_dependent($topic\_id_1$, $topic\_id_2$) .

2.2 UM: The User Model

The user model expresses, derives and draws conclusions about the characteristics of users. This might be done by modeling each individual user or by modeling typical groups that represent users with similar behavior, requirements, etc. (so called *stereotypes*). Objects of discourse in the user model are the *user* which are logically expressed by atoms, the *user identifier (user_id)*, and the various *characteristics* which can be assigned to this user in this AEHS. The characteristics of a user are expressed by predicates:

has_property(user_id, characteristic_x) or
has_property(user_id, characteristic_x, value), etc.

A prominent characteristic in AEHS is the knowledge a user has on documents (or knowledge topics). The first of the following examples uses a binary value for the knowledge, the second example allows different grades of knowledge:

has_property(doc_id, user_id, know) or
has_property(doc_id, user_id, know, value), etc.

The characteristic "knowledge" is very prominent for educational adaptive hypermedia systems, so we can abbreviate the above predicates by:

knows(doc_id, user_id) or
knows(doc_id, user_id, value), etc.

2.3 OBS: The Observations

Observations are the result of monitoring a user's interactions with the AEHS at runtime. Therefor, the objects for modeling observations are the users (as in the case of the UM) and the observations.

Typical observations in AEHS are whether a user has studied some document. The corresponding predicate is

obs(doc_id, user_id, visited) or
obs(doc_id, user_id, visited, value), etc.

If the document is a test and the user has worked on this test by answering the corresponding questions, predicates like

obs(doc_id, user_id, worked_on) or
obs(doc_id, user_id, worked_on, value), etc.,

are used.

2.4 AC: The Adaptation Component

Finally, the adaptation component contains rules for describing the *adaptive functionality* of the system. An example for adaptive functionality is to decide whether a user has sufficient knowledge to study a document (recommended for learning). This functionality belongs to the group of functionalities which determine the "learning state" of a document. A simple rule might be to recommend a document for learning if all documents that are "prerequisites", e.g. that need to be studied before this document can be learned, have been visited:

$$\forall \text{user\_id}\ \forall \text{doc\_id}_1$$
$$(\ \forall \text{doc\_id}_2\ \text{preq}(\text{doc\_id}_1, \text{doc\_id}_2) \Longrightarrow \text{obs}(\text{doc\_id}_2, \text{user\_id}, \text{visited})\ )$$
$$\Longrightarrow \text{learning\_state}(\text{doc\_id}_1, \text{user\_id}, \text{recommended\_for\_reading}).$$

The *adaptive treatment* is a set of rules describing the runtime behavior of the system. An often used adaptive treatment is the traffic light metaphor [1] to annotate links: Icons with different colors are used to show whether a document corresponding to a link is recommended for reading (green color), might be too difficult to study (yellow color), or is not recommended for reading (red color). The rule defining this adaptive treatment "document annotation" is:

$\forall$doc_id $\forall$user_id
learning_state(doc_id, user_id, recommended_for_learning)
$\Longrightarrow$ document_annotation(doc_id, user_id, green_icon).

2.5 Definition of Adaptive Educational Hypermedia Systems

In this section, we will give a logic-based definition for AEHS. We have chosen first order logic (FOL) as it allows us to provide an abstract, generalized formalization. The notation chosen in this paper refers to [11]. The aim of this logic-based definition is to accentuate the main characteristics and aspects of adaptive educational hypermedia.

Definition 2 (Adaptive Educational Hypermedia System (AEHS)) An Adaptive Educational Hypermedia System (AEHS) is a Quadruple

(DOCS, UM, OBS, AC)

with

DOCS:
Document **S**pace: A finite set of first order logic (FOL) sentences with atoms for describing documents (and knowledge topics), and predicates for defining relations between these atoms.

UM:
User **M**odel: A finite set of FOL sentences with atoms for describing individual users (user groups), and user characteristics, as well as predicates and rules for expressing whether a characteristic applies to a user.

OBS:
Observations: A finite set of FOL sentences with atoms for describing observations and predicates for relating users, documents / topics, and observations.

AC:
Adaptation **C**omponent: A finite set of FOL sentences with rules for describing adaptive functionality.

The components "document space" and "observations" describe basic data (DOCS) and run-time data (OBS). User model and adaptation component process this data, e.g. for estimating a user's preferences (UM), or for deciding about beneficial adaptive treatments for a user (AC).

3. Examples

This section provides two examples: The first example is a prototypical (artificial) AEHS whose purpose is to illustrate the applicability of the above proposed framework. The second example shows excerpts of the logical description of an existing AEHS: the NetCoach system [14]. Due to space constraints, we can not provide the full description of NetCoach in this paper. We have characterized three further AEHS, the Interbook system [3], the ELM-ART II system [15], and the KBS hyperbook system [7]. The complete logic-based description of these systems can be found in a technical report [6]. In this paper, we only summarize the results of the descriptions (section 4).

3.1 A very simple AEHS

We describe a simple AEHS, called *Simple* with the following functionality: Simple can annotate hypertext-links to documents by using the traffic light metaphor with two colors: red for non recommended, green for recommended pages.

3.1.1 Simple: Document Space

A set of n atoms (n corresponds to the number of documents in the document space) which name the documents:

$D_1, D_2, \ldots, D_n$.

Plus a finite set of predicates stating the documents that need to be studied before a document can be learned, e.g. D_j is a prerequisite for D_i:

preq(D_i, D_j) for certain $D_i \neq D_j$.

(N.B.: This AEHS does not employ an additional knowledge model).

3.1.2 Simple: User Model

A set of m axioms, one for each individual user:

$U_1, U_2, \ldots, U_m$.

3.1.3 Simple: Observations

One atom for the observation whether a document has been visited:

Visited.

And a set of predicates

obs(D_i, U_j, Visited) for certain D_i, U_j.

3.1.4 Simple: Adaptation Component

One atom for describing the values of the adaptive functionality "learning_state":

Recommended_for_reading,

and two atoms representing values of the adaptive treatment:

Green_Icon, Red_Icon.

Rules for describing the learning state of a document

$\forall U_i \forall D_j$

$(\ \forall D_k\, preq(D_j, D_k) \Longrightarrow obs(D_k, U_i, Visited)\ )$

$\Longrightarrow$ learning_state(D_j, U_i, Recommended_for_reading).

And rules for describing the adaptive link annotation with traffic lights:

$\forall U_i \forall D_j$

learning_state(D_j, U_i, Recommended_for_reading)

$\Longrightarrow$ document_annotation(D_j, U_i, Green_Icon),

$\forall U_i \forall D_j$

$\neg$ learning_state(D_j, U_i, Recommended_for_reading)

$\Longrightarrow$ document_annotation(D_j, U_i, Red_Icon).

3.2 NetCoach

NetCoach [14] is the successor of ELM-ART II and provides a framework for building adaptive educational hypermedia systems. NetCoach uses a knowledge base which consists of concepts. Due to space constraints, we can only describe a part of NetCoach, the complete description can be seen in a technical report ([6]).

3.2.1 NetCoach: Document Space

The document space consists of documents, test-groups and test-items.

$D_1, \ldots, D_n, TG_1, \ldots, TG_n, TI_1, \ldots, TI_n.$

Relation between documents are e.g.:

preq(D_i, D_j) for certain $D_i \neq D_j$.

infer(D_i, D_j) for certain $D_i \neq D_j$.

part_of(D_i, D_j) for certain $D_i \neq D_j$.

succ(D_i, D_j) for certain D_i and one $D_j \neq D_i$.

Further, NetCoach assigns certain test-items or test-groups to a document (see [6]).

3.2.2 NetCoach: Observations

NetCoach takes the following observations about the interactions of a user U_i with the system into account:

$obs(D_j, U_i, Visited)$ for certain D_j, U_i

$obs(TI_k, U_i, Worked\_testitem)$ for certain TI_k, U_i,

$obs(TI_k, U_i, Solved\_testitem)$ for certain TI_k, U_i, and

$obs(D_j, U_i, Marked)$ for certain D_j, U_i.

3.2.3 NetCoach: User Model

Among others, NetCoach derives whether a document D_j has been learned by a user U_i. A document has been learned, if it is either tested, inferred from other learned documents, or marked by the user. If there are no test items assigned to the document D_j or the tests are treated as voluntary exercises (i.e. criterion(D_j, Value) for Value=0), then D_j is assumed to be learned if it has been visited, or it can be inferred from other learned concepts, or marked by the user (for details, e.g. how rules like p_obs(D_j, U_i, Tested) are derived, compare [6]):

$$\forall D_j \; \forall U_i$$

$$p\_obs(D_j, U_i, Tested)$$

$$\vee \; (criterion(D_j, 0) \wedge (obs(D_j, U_i, Visited) \vee p\_obs(D_j, U_i, Inferred\_Known) \vee obs(D_j, U_i, Marked))$$

$$\Longrightarrow p\_obs(D_j, U_i, Learned).$$

3.2.4 NetCoach: Adaptation Component

NetCoach provides adaptive link annotation. E.g a link to a document D_j is marked with a green ball (a sign that this document is recommended for reading) for a user U_i, if all prerequisites of this page haven been learned by this user:

$$\forall D_j \; \forall U_i$$

$$(\forall D_k \, preq(D_j, D_k) \Longrightarrow p\_obs(D_k, U_i, Learned))$$

$$\Longrightarrow document\_annotation(D_j, U_i, Green\_Ball)$$

It supports learning goals (which are defined as a set of documents) and provides learning sequences to reach these learning goals (see [6]).

4. Synopsis of some logically characterized AEHS

This chapter provides synoptical tables of the logic-based characterization of the adaptive educational hypermedia systems NetCoach [14], Interbook [3], ELM-ART II [15], and KBS hyperbook [7] (the complete characterizations can be found in [6]). The atoms used in the four systems in the components DOCS, UM, OBS, and AC are summarized in table 1. Table 2 shows the used predicates. An overview on the rules is given in table 3.

Table 1: Atoms used in NetCoach, ELM-ART II, Interbook and KBS Hyperbook.

System	DOCS	UM	OBS
NetCoach	D_1, ..., D_n,	U_1, ..., U_m, Learned,	Visited,
	TG_1, ..., TG_k,	Inferred_Known, Tested.	Solved_Testitem,
	TI_1, ..., TI_ℓ.		Marked.
ELM-ART II	D_1, ..., D_n,	U_1, ..., U_m, Tested,	Visited,
	TI_1, ..., TI_ℓ.	Inferred_known.	Solved_Testitem.
InterBook	D_1, ..., D_n,	U_1, ..., U_m, Learned,	Visited,
	TI_1, ..., TI_ℓ,	Beginner, Intermediate,	Solved.
	C_1, ..., C_s.	Expert, No_knowledge.	
KBS Hyperbook	D_1, ...D_n,	U_1, ..., U_m, Learned,	Marked,
	C_1, ..., C_s.	Known, Well_known,	Expert,
		Excellently_known, Partly_known,	Advanced,
		Not_known, Child_known,	Beginner,
		Parent_known.	Novice.

System	AC-Adaptive Link Annotation	AC - Others
NetCoach	Green_Ball, Red_Ball, Yellow_Ball, Orange_Ball.	-
ELM-Art II	Green_Ball, Red_Ball, Yellow_Ball, Orange_Ball.	-
Interbook	Small_Checkmark, Normal_Checkmark, Big_Checkmark,	-
	Green_Ball, White_Ball, Red_Ball.	-
KBS Hyperbook	Green_Ball, White_Ball, Red_Ball.	-

Table 2: Predicates used in NetCoach, ELM-ART II, Interbook and KBS Hyperbook.

System	DOCS
NetCoach	preq(D_i, D_j) (prerequisite knowledge)
	infer(D_i, D_j) (documents inferred to be learned by studying D_i)
	succ(D_i, D_j) (reading order)
	part_of(D_i, D_j) (chapter structure)
	terminal_flag(D_i) (whether a document has no further sub-documents)
	criterion(D_i, Value) (defines number of testitems
	necessary for mastering D_i)
	test_assignment(D_i, X), X $\in$ {Testgroup, Testitem},
	(relates documents with testgroups and testitems)
ELM-ART II	preq(D_i,D_j) (prerequisite knowledge)
	out(D_i, D_j) (documents inferred to be learned by studying D_i)
	related(D_i, D_j) (author-defined relation between documents)
	successor(D_i, D_j) (reading order)
	part_of(D_i, D_j) (chapter structure)
	terminal_flag(D_i) (whether a document has no further sub-documents)
	test_assignment(D_i, X), X $\in$ {Testslot, Testitem}
	(relates documents with testslots and testitems)
InterBook	preq(D_i, C_j) (prerequisite knowledge)
	out(D_i, C_j) (concepts inferred to be learned by studying D_i)
	succ(D_i, D_j) (reading order)
	terminal_flag(D_i) (whether a document has no further sub-documents)
	part_of(D_i, D_j) (chapter structure)

KBS Hyperbook	keyword(D_i, C_j) assigns some concepts each document
	depends(C_i, C_j) learning dependencies between concepts
	role(D_i, X), X $\in$ {Course, Goal, Lecture, Example, etc.}
	role of the document D_i
	role(C_i, X), X $\in$ {Introduction, Concept}
	role of the concept C_i

System	UM	OBS	AC
NetCoach	-	obs(D_i, U_j, X), X $\in$ {Visited, Solved_Testitem, Marked}	
ELM-ART II	-	obs(D_i, U_j, X), X $\in$ {Visited, Solved_Testitem}	-
InterBook	-	obs(D_i, U_j, X), X $\in$ {Visited, Solved}	-
KBS Hyperbook	-	obs(C_i, U_j, Marked, Value),	-
		Value $\in$ {Expert, Advanced, Beginner, Novice}	

Table 3: Rules used in NetCoach, ELM-ART II, Interbook and KBS Hyperbook.

System	DOCS	UM	OBS
NetCoach	-	Rules to infer p_obs(D_i, U_j, X), X $\in$	-
		{Inferred_Known, Learned, Tested}	
ELM-ART II	-	Rules to infer p_obs(D_i, U_j, X), X $\in$	-
		{Inferred_Known, Tested}	
InterBook	-	Rules to infer p_obs(C_i, U_j, Learned, X), X $\in$	-
		{Expert, Intermediate, Beginner, No_knowledge}.	
KBS Hyperbook	-	Rules to infer p_obs(C_i, U_j, Learned, X), X $\in$	-
		{Known, Well_known, Excellently_known, Partly_known,	
		Not_known, Child_known, Parent_known}.	

System	AC - Adaptive Link Annotation
NetCoach	Rules to infer document_annotation(D_i, U_j, X),
	X $\in$ {Green_Ball, Red_Ball, Yellow_Ball, Orange_Ball}.
ELM-ART II	Rules to infer document_annotation(D_i, U_j, X),
	X $\in$ {Green_Ball, Red_Ball, Yellow_Ball, Orange_Ball}.
InterBook	Rules to infer document_annotation(D_i, U_j, X),
	X $\in$ {Green_Ball, White_Ball, Red_Ball,
	Small_Checkmark, Normal_Checkmark, Big_Checkmark}.
KBS Hyperbook	Rules to infer document_annotation(D_i, U_j, X),
	X $\in$ {Green_Ball, White_Ball, Red_Ball}.

System	AC-Adaptive Link Generation
NetCoach	Rules to infer next_best_page(D_i, U_j), learning_goal(X),
	curriculum_sequencing(D_1, $\ldots$, D_ℓ)
ELM-ART II	Rules to infer next_best_page(D_i, U_j) (+ a tutoring component
	for the lisp domain)
InterBook	Rules to infer prerequisite_based_help(D_i, U_j), learning_goal(D_i),
	reading_sequence(D_i, U_j), teach_me(D_i).
KBS Hyperbook	Rules to infer learning_sequence([C_1 $\ldots$, C_n], U_j), glossary(D_i)
	learning_goal([C_1 $\ldots$, C_n]), next_reasonable_goal(U_j)
	information_index([C_1 $\ldots$, C_n])

5. Discussion

In this paper, we have proposed a component-based definition of adaptive educational hypermedia systems that uses first-order logic to characterize AEHS. With this approach

- we can easily compare the adaptive functionality of the AEHS: we can e.g. derive that the above characterized systems are very similar in their way of employing adaptive functionality (all make adaptive navigation support, no adaptive presentation support (with respect to Brusilovsky's taxonomy of adaptive hypermedia technologies [2]));
- we hide a lot of functionality behind the rules, e.g. KBS Hyperbook uses a Baysian Network to calculate the Inferred_known characteristic. This is technically very different to calculating this characteristic by compiling the transitive closure of prerequisites. But, logically, it has the same functionality: to estimate the user's current knowledge state based on some input parameters (the observations);
- we can describe the taxonomy of concepts used by the systems in document spaces, the user models, the observations, and the adaptation component. E.g. in case of the document space, we can derive that Interbook uses documents, testitems and knowledge concepts, ELM-ART II uses documents and testitems, etc.;
- the rules in the adaptation component show which data is processed by the system for making decisions about particular adaptive treatment; decisions;
- thus we can encapsulate adaptive functionality in order to support transfer of functionality between AEHS,
- and to support the more wide-spread use of adaptation in web-based educational systems, e.g. by employing Web-services that provide adaptive features.

During the application of the proposed characterization of AEHS, it turned out that the documents and their relations play a decisive role for the way how adaptation components draw conclusions. We have seen, that, in contrary to our intentions motivated by the transfer of Reiter's approach [10] to educational hypermedia, we were not able to generalize the diversity of rules for adaptation for a meta-description of adaptation. However, we claim that a logical characterization of adaptive educational hypermedia is a way to find solutions of current open questions in this area. E.g. currently, there is no catalogue of "metadata for adaptation" which could be used in LOM [9], SCORM [12] or other catalogues of metadata for education. The main objection is that adaptive educational hypermedia systems are "too different" to generalize for a meta-data driven description. From the above characterizations we can derive which meta-data is needed by the characterized AEHS: We can derive which sources for input data are used in the different systems from DOCS and OBS. These sources can now be used as a candidate set for meta-data for adaptation.

Further, our approach contributes to solutions for the open document space problem [8,2]: If we consider adaptive functionality as a query in open environments (as it has been done e.g. in [5]) it turns out that a decisive task is to determine the characteristics of adaptive functionality in order to define useful queries.

6. Conclusion

This paper proposes a component-based definition of adaptive educational hypermedia based on first-order logic. We have shown the applicability of such a formal description language for adaptive educational hypermedia in various examples. We claim that this logical characterization of adaptive educational hypermedia enables comparison of adaptive functionality in a well-grounded way, promotes the transfer of adaptive functionality to other educational hypermedia and web-based systems, defines rule-based descriptions of adaptivity, and supports the understanding of the role of metadata for adaptation.

Acknowledgment

We would like to thank Peter Brusilovsky and Gerhard Weber for the discussions on their adaptive educational hypermedia systems.

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