Rules for Learner Modeling and Adaptation Provisioning in an Educational Hypermedia System∗

Elvira Popescu, Costin Bădică
Software Engineering Department
University of Craiova
Bvd.Decebal 107, Craiova, 200440, Romania
{popescu_elvira, badica_costin}@software.ucv.ro

Philippe Trigano
Heudiasyc, UMR CNRS 6599
Université de Technologie de Compiègne
60200 Compiègne, France
ptrigano@hds.utc.fr

Abstract

This note presents our initial proposal for capturing knowledge required for learner modeling and adaptation provisioning in an educational hypermedia system using a rule-based approach. Rules have been categorized as i) modeling rules – necessary for the identification of the learner style based on observed learning preferences and ii) adaptation rules – necessary for content adaptation based on learning style and/or learning preferences.

1. Introduction

Adaptation is an important requirement that has been set for the next generation e-learning systems. In particular, adaptation to the learning style has been described as an important step towards individualized instruction.

Learning style has been intensely studied by educational psychology and related areas during the last two decades. These efforts have produced a great amount of knowledge regarding categorization and description of learning styles along many dimensions.

The work presented in this paper proposes the explicit capturing and application of learning style knowledge into an adaptive educational hypermedia system. The paper is organized as follows. We start with a discussion of the context of our work including the general structure of the system and an outline of our approach. We follow with a precise description of modeling rules for identification of learning styles and adaptation rules based on learning styles and/or learning preferences. In order to make the presentation independent of a particular rule representation formalism, we have chosen to express our rules in an informal pseudo-code notation.

In our opinion the main achievements of our work are threefold: i) separation of knowledge about learning styles as modularized sets of rules; ii) explicit representation of the rules, encouraging their understandability, maintainability and reusability; iii) facilitation of appropriate implementation of the rules in an adaptive educational hypermedia system.

2. Context of use

This research takes place in the framework of a learning-style based adaptive educational system (LSAES), i.e. an educational system that adapts the learning content and navigation to the particular learning style of each student. Learning style can be defined as a combination of cognitive, affective and other psychological characteristics that serve as relatively stable indicators of the way a learner perceives, interacts with and responds to the learning environment [13]. In order to accomplish this goal, the first task is to have a model of the student with regard to learning style, therefore a learner modeling component is necessary. Our LSAES thus offers the following functionalities:

- an authoring tool for the teachers, allowing them to create courses conforming to the LSAES format;
- a course player for the students, enhanced with two special capabilities: i) learner tracking functionality (monitoring the student interaction with the system); ii) adaptation component (supplying the student with educational content that best matches her/his learning style);
- a modeling component that analyzes the behavior of the student and identifies the corresponding learning styles.

The general structure of the application is presented in figure 1.

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Usually, LSAESs are based on a single particular learning style model [16]. The most popular learning style models are: Felder-Silverman [10] (used in [2], [4], [5]), Honey and Mumford [12] (used in [14]) and Witkin [20] (used in [18]). We take a different approach by characterizing the student by a set of learning preferences, which we included in a unified learning style model (ULSM) [15], rather than directly by a particular learning style. ULSM integrates learning preferences related to: perception modality (visual vs. verbal), field dependence/field independence, processing information (abstract concepts and generalizations vs. concrete, practical examples; serial vs. holistic; active experimentation vs. reflective observation, careful vs. not careful with details), reasoning (deductive vs. inductive), organizing information (synthesis vs. analysis), motivation (intrinsic vs. extrinsic; deep vs. surface vs. strategic vs. resistant approach), persistence (high vs. low), pacing (concentrate on one task at a time vs. alternate tasks and subjects), social aspects (individual work vs. teamwork; introversion vs. extraversion; competitive vs. collaborative), study organization (formal vs. informal), coordinating instance (affectivity vs. thinking). This set of learning preferences has the advantage of being independent of any particular learning style model. In addition, most learning styles introduced in the literature can be characterized by a subset of these learning preferences. The correspondence between the learning preferences and a particular learning style model is captured within the “Modeling rules” component (see fig. 1), as it will be described in section 3.

The characteristic-based modeling of the student also allows for a finer granularity of adaptation actions. The specific adaptation actions that must be applied for each learning preference are specified by means of the “Adaptation rules” component, as illustrated in section 4.

According to [8], the existence of a static description of the learning content (metadata) is a necessary condition for introducing an adaptation model (dynamic description). Our choice for organizing and annotating the educational material has been detailed in [17]. Basically, we have conceptualized the learning material using a hierarchical organization: each course consists of several chapters, and each chapter can contain several sections and subsections. The lowest level subsection contains the actual educational resources. Each such elementary learning object corresponds to a physical file and has an associated metadata file. These metadata were created by enhancing core parts of Dublin Core [9] and Ullrich’s instructional ontology [19] with some specific extensions to cover the requirements of a LSAES. Specifically, these metadata describe the learning object from the point of view of instructional role(LoTtype), media type(dc: type), level of abstractness and formality (hasAbstractness, hasFormalness), type of competence (hasCompetency) etc. The use of these metadata facilitates both the learner modeling and the adaptivity provisioning. Thus, by analyzing the interaction between the student and the learning objects described by the metadata (time spent on each learning object, order of access, frequency of accesses), the system can infer a particular learning preference of the student. Furthermore, the teacher has to supply only annotated learning content while the adaptation logic is provided by the system, in the form of adaptation rules, as we will see in section 4.

3. Rules for identifying learning styles

Currently more than 70 learning style models were proposed in the literature [7]. Each such model contains, apart from its rationale and the psychological theory behind it, a description of the typical behavior of the learner belonging to each learning style dimension. Based on this natural language description and starting from the set of identified learning preferences presented in section 2, we can extract a set of rules for inferring learning styles (the “Modeling rules”, as they appear in figure 1).

More formally, let \( L \) be a learner and let \( \text{Pref}(L) \) be the set of learning preferences identified for learner \( L \) by analyzing her/his behavioral indicators. Obviously, \( \text{Pref}(L) \subseteq \text{Pref/ULSM} \), where \( \text{Pref/ULSM} \) is the set of learning preferences included in our ULSM [15]. Specifically, \( \text{Pref/ULSM} = \{ p_{\text{visual}}, p_{\text{verbal}}, p_{\text{fieldDependence}}, p_{\text{fieldIndependence}}, p_{\text{abstract}}, p_{\text{concrete}}, p_{\text{serial}}, p_{\text{holistic}}, p_{\text{activeExperimentation}}, p_{\text{reflectiveObservation}}, p_{\text{carefulDetails}}, p_{\text{notCarefulDetails}}, p_{\text{deductive}}, p_{\text{inductive}}, p_{\text{synthesis}}, p_{\text{analysis}}, p_{\text{intrinsic}}, p_{\text{extrinsic}}, p_{\text{deep}}, p_{\text{strategic}}, p_{\text{surface}}, p_{\text{resistant}}, p_{\text{highPersistence}}, p_{\text{lowPersistence}}, p_{\text{oneTask}}, p_{\text{alternateTasks}}, p_{\text{individual}}, p_{\text{team}}, p_{\text{extraversion}}, p_{\text{introversion}}, p_{\text{competitive}}, p_{\text{collaborative}}, p_{\text{formal}}, p_{\text{informal}}, p_{\text{facticity}}, p_{\text{thinking}} \} \) (meaning of each preference obviously results from its name).

We are now interested in categorizing the student according to a particular learning style model. Let \( L_{\text{LSM}}(L) \) be the learning style of learner \( L \) with regard to learning style model \( M \). It should be noted that some learning style models include the learner into only one learning style, while others offer several dimensions, each with two opposite axes. In the first case, \( L_{\text{LSM}}(L) \) has exactly one element, while in the second case, \( L_{\text{LSM}}(L) \) is an \( n \)-tuple, where \( n \) is the number of dimensions defined in the learning style model.

Let us take for example Ned Herrmann’s Whole Brain Model [11]. According to this model, the brain can be divided into four quadrants, each area having an associated model of thinking and learning:
- left cerebral – "theorists". They like facts, details, critical thinking, precise definitions, unambiguous instructions.
- left limbic – "organizers". They like step-by-step instructions, outlines, check-lists, timelines, problem solving with clear steps and procedures.
- right limbic – "humanitarians". They prefer cooperative learning, group discussion, role-playing, personal approaches and examples.
- right cerebral – "innovators". They prefer brainstorming, metaphors, illustrations, pictures, synthesis, holistic approaches, alert rhythm.

Therefore for this model we have: \( Herrmann\_model\_set = \{"Theorist", "Organizer", "Humanitarian", "Innovator"\} \). This means that for all learners \( L \), we have \( LS_{Herrmann\_model}(L) \in Herrmann\_model\_set \). For example, for a particular learner \( L \) we might have \( LS_{Herrmann\_model}(L) = "Humanitarian" \).

The following set of four rules can be extracted from the characteristics of the four learning styles, as they are defined by Herrmann [11]:

**THEORIST**

\[
\begin{align*}
\text{IF} & \quad p_{\text{carefulDetails}} \in \text{Pref}(L) \land p_{\text{abstract}} \in \text{Pref}(L) \land p_{\text{deductive}} \in \text{Pref}(L) \land p_{\text{analysis}} \in \text{Pref}(L) \land p_{\text{highPersistence}} \in \text{Pref}(L) \\
\text{THEN} & \quad LS_{Herrmann\_model}(L) = "Theorist"
\end{align*}
\]

**ORGANIZER**

\[
\begin{align*}
\text{IF} & \quad p_{\text{concrete}} \in \text{Pref}(L) \land p_{\text{deductive}} \in \text{Pref}(L) \land p_{\text{analysis}} \in \text{Pref}(L) \land p_{\text{oneTask}} \in \text{Pref}(L) \\
\text{THEN} & \quad LS_{Herrmann\_model}(L) = "Organizer"
\end{align*}
\]

**HUMANITARIAN**

\[
\begin{align*}
\text{IF} & \quad p_{\text{concrete}} \in \text{Pref}(L) \land p_{\text{team}} \in \text{Pref}(L) \land p_{\text{extraversion}} \in \text{Pref}(L) \land p_{\text{inductive}} \in \text{Pref}(L) \\
\text{THEN} & \quad LS_{Herrmann\_model}(L) = "Humanitarian"
\end{align*}
\]
For example, the intended interpretation of the ORGANIZER rule is: if a learner has preference of processing concrete information (rather than abstract or general information), has preference for deductive (rather than inductive) reasoning, has preference for an analytic (rather than synthetic) way of organizing information and usually concentrates on a single task at a time (rather than on multiple tasks) then it can be inferred as belonging to the "Organizer" learning style model according to Ned Herrmann’s model.

Let us now take another example, the Felder-Silverman learning style model [10]. According to this model learners are characterized by their preferences in four dimensions:

• active versus reflective learners
• sensing versus intuitive learners
• visual versus verbal learners
• sequential versus global learners.

Active learners learn by trying things out and enjoy collaborative working, while reflective learners like to think about the material first and prefer working alone. Sensing learners have a preference towards facts and details and they tend to be practical and careful, whereas intuitive learners prefer abstract material, they like to innovate, to discover possibilities and relationships. Visual learners remember best what they see (pictures, diagrams, schemas etc) while verbal learners get more out of words, either spoken or written. Sequential learners tend to gain understanding in linear steps, while global learners learn in large leaps, being fuzzy about the details of the subject but being able to make rapid connections between subjects.

Therefore for this model we have: $FelderSilverman_{model} = \{(A_1, A_2, A_3, A_4)\}
A_1 \in \{"Active", "Reflective"\}, A_2 \in \{"Sensing", "Intuitive"\}, A_3 \in \{"Visual", "Verbal"\}, A_4 \in \{"Sequential", "Global"\}$. This means that for all learners $L$, we have: $LS_{FelderSilverman_{model}}(L) \in FelderSilverman_{model_{set}}$. For example, for a particular learner $L$ we might have $LS_{FelderSilverman_{model}}(L) = ("Active", "Sensing", "Visual", "Global")$.

The following set of rules can be extracted from the characteristics of the four learning styles, as they are defined in [10]:

**ACTIVE**

IF $p_{activeExperimentation} \in Pref(L)$ AND $p_{team} \in Pref(L)$ AND $p_{synthesis} \in Pref(L)$ AND $p_{inductive} \in Pref(L)$ AND $p_{holistic} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Active"

**REFLECTIVE**

IF $p_{reflectiveObservation} \in Pref(L)$ AND $p_{individual} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Reflective"

**SENSING**

IF $p_{concrete} \in Pref(L)$ AND $p_{carefulDetails} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Sensing"

**INTUITIVE**

IF $p_{abstract} \in Pref(L)$ AND $p_{notCarefulDetails} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Intuitive"

**VISUAL**

IF $p_{visual} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Visual"

**VERBAL**

IF $p_{verbal} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Verbal"

**SEQUENTIAL**

IF $p_{serial} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Sequential"

**GLOBAL**

IF $p_{holistic} \in Pref(L)$
THEN $LS_{FelderSilverman_{model}}(L) \in "Global"

As we can see, in case of the "Visual"/"Verbal" and "Sequential"/"Global" dimensions, there is a one-to-one correspondence between the learning preference in $Pref(L)_{LSM}$ and the learning style axis in $LS_{FelderSilverman_{model}}(L)$.
4. Adaptation rules

Adaptation can be done based on the student learning style according to educational practices or directly based on the set of characteristics associated to the student preferences.

Apart from defining the characteristics of the learners belonging to each learning style, for most of these models there are proposed teaching practices that effectively address the educational needs of students with the identified styles. Starting from these teaching methods (which only include a traditional learning view) and enhancing them with e-learning specific aspects (technology related preferences), we can extract the adaptation rules for our LSAES (shown as “Adaptation rules” in figure 1).

We will first illustrate this approach with some simple rules for adapting an e-learning course to the needs of the students with different Felder-Silverman learning styles [10].

Adapt course for ACTIVE learner
IF
"Active" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Integrate interactive animations, simulations, small games
Include many exercises
Provide communication facilities (forum/chat)

Adapt course for REFLECTIVE learner
IF
"Reflective" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include less exercises
Integrate questions that encourage reflection
Provide context-aware note-taking tool

Adapt course for SENSING learner
IF
"Sensing" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include more facts and practical content
Provide many examples
Include various multimedia objects

Adapt course for INTUITIVE learner
IF
"Intuitive" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Focus on abstract concepts and theories
Provide less examples

Adapt course for VISUAL learner
IF
"Visual" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include plenty of videos and images
Present content using graphics, schemas, flowcharts

Adapt course for VERBAL learner
IF
"Verbal" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include text and audio material
Provide communication opportunities (forum, chat)

Adapt course for SEQUENTIAL learner
IF
"Sequential" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include step-by-step presentation of the content
Place links to related subjects at the end of the course
Highlight Next and Previous buttons
Hide outlines
Present tests at shorter intervals

Adapt course for GLOBAL learner
IF
"Global" $\in$ LS_{FelderSilverman\_model}(L)
THEN
Include outlines and summaries
Integrate links to related topics in the content
Place exercises at the end of the chapter
Provide advanced organizers or mind maps

Alternatively, based on our characteristic-based modeling approach, we can associate adaptation rules for each of the identified learning preferences ($Pref(L)$).

According to [1] and [3], adaptation of educational hypermedia systems can be done with regard to three levels:

- **Navigation Level Adaptation** by means of direct guidance, link ranking, link hiding (hiding, disabling, removing), link annotation, link generation, adaptive maps;

- **Content Level Adaptation** by means of content hiding, additional explanations, specific media type filtering (e.g. no video or no audio), specific item filtering (e.g. no definitions, no examples, no outlines), different web page versions for different student learning styles;

- **Presentation Level Adaptation** by means of inserting/removing fragments, altering fragments, stretch-text, sorting fragments, dimming fragments.

The adaptation logic can be thus decomposed into elementary actions, such as inserting, eliminating, sorting or moving learning objects. In the case of our LSAES, an adaptation rule can be abstracted as follows:

General adaptation rule
IF
$X \in Pref(L)$
THEN
$Action\ Object\ \{\ Value\}$
Object can be either a metadata element of a learning object, carrying a specific Value (as described in section 2), or an interface element or a communication tool.

For example, in case of a specific perception modality preference, the recommended action would be to present the learner first with the preferred media type and then with the alternative representation types:

Adaptation actions for learners with "Visual" preference
IF
p_visual ∈ Pref(L)
THEN
Sort dc: type {image, video, animation, text, sound}

Adaptation actions for learners with "Verbal" preference
IF
p_verbal ∈ Pref(L)
THEN
Sort dc: type {sound, text, video, image, animation}

Similarly, in case of a preference towards concrete, practical examples, the course should be focused more on facts, practical aspects and examples. Each new concept will be first illustrated by an example and only then the theoretical aspects will be covered. More formally,

Adaptation actions for learners with "Concrete" preference
IF
p_concrete ∈ Pref(L)
THEN
Sort LoType {Example, Definition}
Sort hasAbstractness {concrete, neutral, abstract}

In case of a holistic preference, the interface elements for sequential navigation (in our case the buttons "Next" and "Previous") will be hidden, given the learner the possibility to freely jump through the courseware. At the same time, the exercises will be moved at the end of the chapter, in order to give the learners the opportunity to holistically understand the subject first. Furthermore, there will be added links to related or complex to help situate the learnt subject and contribute to create the big picture.

Adaptation actions for learners with "Holistic" preference
IF
p_holistic ∈ Pref(L)
THEN
Hide NextButton
Hide PrevButton
Move_endChapter LoType (Exercise)
Insert LoType (AdditionalInfo)

In case of an introvert learner, she/he will be presented with an asynchronous communication channel, such as a forum, while an extravert learner will benefit more from a synchronous communication channel, such as a chat.

Adaptation actions for learners with "Introvert" preference
IF
p_introversion ∈ Pref(L)
THEN
Highlight Forum

Adaptation actions for learners with "Extravert" preference
IF
p_extraversion ∈ Pref(L)
THEN
Highlight Chat

Note that a prototype LSAES providing functionalities discussed in section 2 is currently under implementation using Apache Cocoon framework [6]. Rules can be mapped to XSLT transformations and then they can be easily integrated into the Cocoon pipeline.

5. Conclusions

We have proposed an initial formalization of knowledge about learning styles and/or learning preferences and its application in an adaptive educational hypermedia system, as modularized sets of rules. The proposal is under implementation in a prototype system. We shall report on our progress in forthcoming papers.

References


