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DYNAMIC KNOWLEDGE ROUTE SELECTION FOR PERSONALISED LEARNING ENVIRONMENTS USING MULTIPLE CRITERIA

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ABSTRACT

In this paper we deal with the problem of dynamically selecting a knowledge route suitable to individual learner's needs and profile, through a set of learning resources. We engage parameters of the learner's cognitive style and create a multi-criteria utility model that evaluates available didactic methods, using initial evaluations upon a set of basic cognitive categories. The proposed methodology is studied within the context of the European KOD project, where intelligent agents providing educational e-content brokerage services to the learners, require methods and tools to dynamically assess the suitability of the available educational resources.

KEY WORDS: Personalised e-Learning, Web-based Education

1. INTRODUCTION

The rapid evolution of Information and Communication Technologies (ICT) creates numerous opportunities for providing new standards of quality in educational services. It is generally agreed however, that education has not yet realized the full potential of the employment of ICT. This is mainly due to the fact that the traditional mode of instruction (one-to-many lecturing, or one-to-one tutoring), which is adopted in conventional educational technology, cannot fully accommodate the different learning and studying styles, strategies and preferences of diverse learners. In this context, the concept of personalized learning (PL) has emerged, which advocates that learning should not be restricted by time, place or any

other barriers, and should be tailored to the continuously modified individual learner's requirements, abilities, preferences, background knowledge, interests, skills etc [1].

The European IST Project Knowledge-On-Demand (KOD) aims to address needs for the effective and efficient distribution of electronically published learning material, and the provision of personalized learning services in order to favor life-long learning and knowledge transfer experiences through the Web [1]. The idea behind the KOD system is the generation of personal learning paths (referred to as "knowledge routes") on the published educational material, generated and updated according to the learners' characteristics (background, interests, skills, etc), which are constantly monitored and profiled.

There is a number of R&D efforts worldwide tackling with the engagement of learner's profile in order to create personalized learning paths. An increasing number of such applications are based on intelligent agents, either strictly concerned with user monitoring and guidance (Steve [2], Turvy [3], Mondrian [4], I-ATCL [5]) or as a technical basis for the organizational structure of the whole system (ALIVE [6], ABITS [7], GIA [8]). The basic difference between these systems and KOD is that, in order to provide personalized services, they depend on the intelligence of the "front-end" agents. On the contrary, KOD introduces the concept of embedding intelligence into the learning packages, so that even "dummy" presentation agents can be able to provide advanced personalization services.

Throughout this paper we will refer to the knowledge route as the recommended sequence of educational material and activities, tailored to individual learners' needs and profile according to a certain instructional design methodology. The knowledge routes are specified upon a package of learning assets built by a human tutor, who matches each knowledge route with a specific category of learners. The tactic usually followed is to select the knowledge route corresponding to the category that *closest* fits the learner's cognitive style. Two matters

rise here though: (a) the possibility to create multi-attribute models of the learners that will be able to include multiple parameters of the cognitive style, and (b) the creation of a utility model for each learner, so that each proposed knowledge route can be assessed.

In the remainder of this paper, we will describe a multi-criteria decision making methodology for creating utility models that can evaluate each knowledge route according

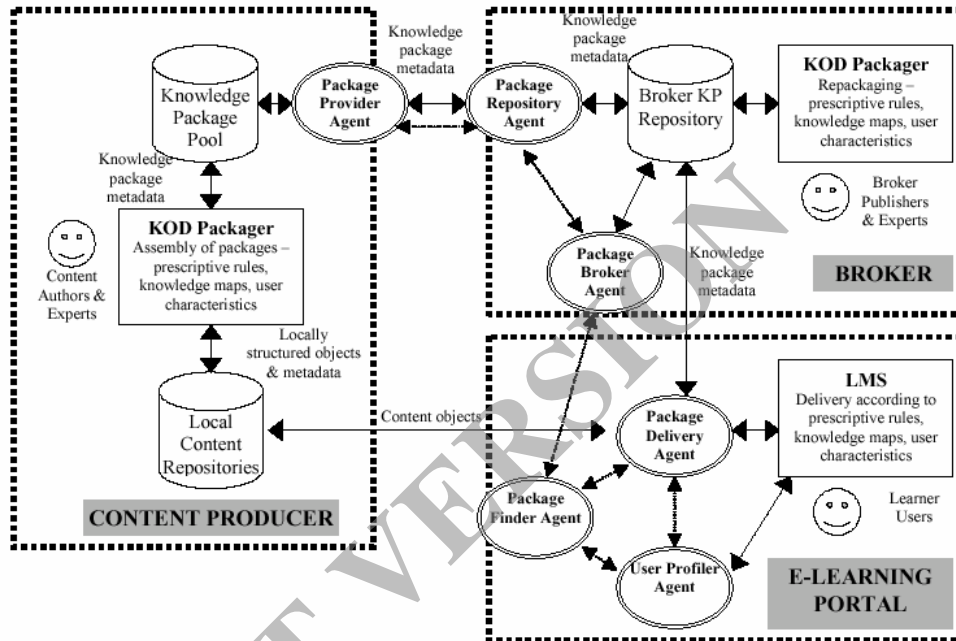


Figure 1: KOD architectural overview

to the parameters of the learner's model. The models are embedded into the decision modules of the brokerage services agents of the KOD system, providing enhanced personalized services, with minimum requirements for the front-end e-learning application

2. OVERVIEW AND ARCHITECTURE

The architecture of the KOD system [9] aims to provide the tools and methods for regulating services among the different categories of users envisioned in the KOD business model [10]. Three distinct roles (corresponding to distinct sub-architectures) represent the KOD system layout (Figure 1):

1. The **Publishing Service (role A)**, represented by content providers willing to publish educational e-content in an easy, reusable and interchangeable format. Apart from keeping raw and built-up assets in their internal data models and architectures, the Publishing Service actors (i.e. content owners, authors, publishers) provide evident formats describing their assets in a publicly accessible and monitorable space named

Knowledge Publishing Pool (KPP). The KPP hosts a collection of Packaged Interchanged Files (PIF) able to describe content in terms of building raw assets, their organization and availability.

2. The **Brokerage Service (role B)**, represented by an application service provider (Knowledge Brokerage Service Provider – KBS) providing the Publishing Services with (i) a Knowledge Packaging Toolkit (KPT) enabling them to package their content in the agreed PIF format, and (ii) a set of twin agents (the KPP agent resident at the Educational Publishing Service side, and the KBR agent resident at the broker side) able to shake hands and monitor publication of new PIFs in the KPP area, updating an internal repository at the Brokerage Service site, in order to keep track of all courses/assets available at remote KPP sites. The brokerage service is also equipped with an internal agents configuration environment (Agency Configuration Toolkit – ACT) and an internal version of the Knowledge Packaging Toolkit, enabling human operators of the brokerage service to eventually reconfigure and repackage materials.

3. The **e-learning Service (role C)**, represented by e-learning portals operators using existing commercial

LMSs as the underlying enabling technology. The assumption is that target LMSs will be IMS Content Packaging [11] compliant (also covering the foreseen extensions of this specification). In order to achieve such compliance (e.g. the ability to import KOD PIF files) a KP importer/adaptor module is developed for different market platforms. The e-learning service also provides access to user profiling capabilities provided by the Broker Service able to profile users and return relevant KOD PIFs to the e-learning service.

For the time being, “intelligence” regarding the personalization of the learning resources is included into the content packages, by the definitions of different knowledge routes for each category of learners. The KOD brokerage agents identify the learner’s needs, locate the educational material and retrieve learning resources matching the profile of the learner. In this paper we investigate methods for further enhancement of the intelligence of the agents participating in this process, by enriching their decision modules with a multi-criteria evaluation model of the didactic method followed in the creation of a knowledge route. This enhancement can not only offer on-the-fly assessment of the suitability of a knowledge package, but also even aid in evaluating different knowledge routes on the same learning assets consisting a package.

3. COGNITIVE STYLE

Tennant [12] defined cognitive style as “an individuals characteristic and consistent approach to organizing and processing information”. In order to demonstrate how a cognitive style model can be used in order to create the multi-criteria selection model, we will engage the classic Honey and Mumford model [13]. The Honey and Mumford model is a cognitive style model, developed for use in commerce, management and training situations. It categorizes learners according to the following dimensions of a person’s learning style: Theorist, Activist, Reflector, and Pragmatist. In order to classify learners in one of the categories, the model uses the answers in a specially designed Learning Styles Questionnaire (LSQ) of 80 questions, with binary answers of “Correct” and “False”.

From a practical point of view, it is important that a learner’s model describes not only how learners are categorised, but also how should the instruction method be adapted for each learner category [14]; that it, apart from the *descriptive* information (e.g. how learners are categorised into “active” and “reflective”), the model should provide *prescriptive* guidelines, which can lead to specific rules for designing instruction and adaptation (e.g. what types of educational content should be selected for active and reflective learners). The real complexity for the designers of e-learning systems arises when they try to

match subject matter with learner characteristics and appropriate instructional methods [15].

Intelligent tutoring systems developed that use classification of learners according to the Honey & Mumford LSQ, present educational material to the user according to the specific category (i.e. the INSPIRE system [16]). We argue that not only the parameters of the learner model can be used in a whole, creating thus a multi-attribute model, but they can also be processed as criteria upon which the candidate didactic methods for the specific learner should be evaluated.

Current international standardization efforts regarding syntax and semantics of a learner model that characterize a learner and his or her knowledge/abilities (i.e. IMS LIP [17], IEEE LTSC PAPI [18]) do not explicitly define information about the cognitive style of the learner. However, the IEEE PAPI Learner preference/performance data types provide data elements that allow cognitive style related information to be stored in an appropriate form. This data types could be used in order to represent a multi-attribute representation of the cognitive style model of the learner.

4. METHODOLOGY

According to Roy [19] the general methodology of decision making problems includes four general steps. The first step includes definition of the decision variables in a form of a consideration set A . This set includes all the available didactic methods, which will be evaluated by the decision maker (in our case, the brokering agent) and the decision problematic is the selection of one. That is the selection of one action from the consideration set of the form:

$$A = [\alpha_1, \alpha_2, \dots, \alpha_n]$$

The next step is modeling a consistent family of criteria, assuming that these criteria are non-decreasing value functions, exhaustive and non-redundant. Each criterion is defined on A as it follows:

$$g_i : A \rightarrow [g_{i*}, g_i^*] \subset \mathfrak{R} / a \rightarrow g(a) \in \mathfrak{R}$$

where $[g_{i*}, g_i^*]$ is the criterion evaluation scale, with g_{i*} the worst level of the i th criterion, g_i^* the best level of the i th criterion, $g_i(a)$ the evaluation or performance of action a on the i th criterion and $\underline{g}(a)$ the vector of performances of action a on the n criteria [20]. As criteria we use a 5-scaled climax of qualitative evaluations [“Not suitable at all”, “Not very suitable”, “Moderately suitable”, “Very suitable”, “Perfectly suitable”] showing the evaluation of each method upon each categories of the Honey and Mumford Learning Styles model (Figure 2).

This knowledge is initially given by an expert (e.g. the expert content creator) upon the basic four categories that consist the cognitive model of a learner.

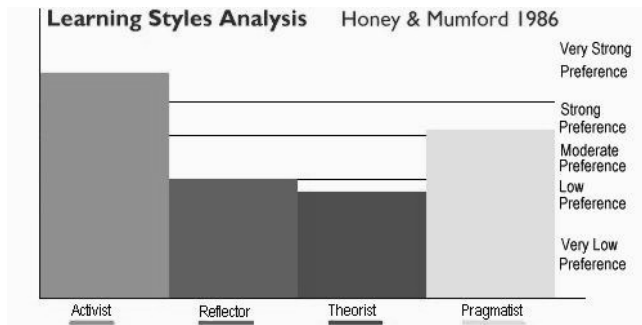


Figure 2: An example learner’s model (source: PSI-Press [21])

There are several methods for multi-criteria preference modelling that can be applied according to the nature of the decision problem [19]. In the following step, we use one of the most traditional approaches that leads to a functional representation g that can be formed directly from the criteria g_1, \dots, g_n that constitute A . Thus, the comprehensive preference model is characterized by a unique synthesizing criterion $g: g(a) = V[g_1(a), \dots, g_n(a)]$, where V is an aggregation function. The function will be in the form:

$$V(a) = \sum p_i g_i(a)$$

where $g_i(a)$ are the evaluations of each didactic method a regarding the suitability for each category of learners. The student model (dealt as a preference model in our context) consists of the weights provided by the Honey and Mumford LSQ, that is the weights p_i . The final value of V is the total utility of each method for the learner under study.

The final step corresponds to the integration of the methodology into the decision modules of the KOD brokerage agents. We will demonstrate how this can be achieved in the following section.

5. USAGE SCENARIO

A typical scenario of provisioning educational services via a KOD Knowledge Publishing Pool, follows these steps:

- 1) Content authors and experts assemble educational content assets into new knowledge packages. These packages typically include a number of knowledge objects, together with one or more navigational approaches including simple sequenced lists, knowledge maps and sets of prescriptive rules. These navigational approaches (the knowledge routes) are created from the content expert (e.g. tutor), and constitute different available didactic methods.
- 2) The new packages are published to a KPP. The Package Provider Agent detects the new packages in the KPP, and informs the Package Repository Agents. The

Package Provider Agent can also respond to requests from Package Repository Agents from this type of content.

- 3) Once a learner’s need has been established, the User Profiler assesses the need and sends a request to the Package Finder Agent.
- 4) The Package Finder Agent may determine that appropriate material is already available in the LMS or else requests it from one or more Package Broker Agents.
- 5) If a Package Broker Agent believes it can meet the need, it proposes a suitable package. If appropriate material is not available, the Package Broker Agent may request from human experts to provide an appropriate package and/or from Package Repository Agent to scan for potential material from content producers.
- 6) The Package Delivery Agent obtains the proposed knowledge package and determines how it should be loaded into the LMS for the users. This might mean selecting particular navigational paths for particular users of other forms of dynamic repackaging.
- 7) Once the complete package is available, the Package Delivery Agent directly informs the user (learner or tutor).

All stages of the above-described scenario require continuous evaluation of the knowledge routes, by several mediating agents. The decision on whether the package is suitable for the learner serviced or not, depends on the parameters of the learner profile. Enhancing the learner profile with a multi-attribute model depicting the cognitive style, and moreover providing this model to the brokering agents as a tool for evaluating the didactic methods implemented as knowledge routes in the content packages, can be proven valuable in dynamic educational content brokerage environments as the KOD KPP.

Let us demonstrate how the methodology is applied in the case of the Honey and Mumford LSQ. Following the steps described above, an expert content author selects a number of learning objects, in order to construct educational an e-learning course. The author wishes to add different knowledge routes, depending on the cognitive styles category the learner belongs to. We assume that a different didactic method is followed when a knowledge route is specified, so an evaluation of this route (and didactic method) for each route is included upon the basic four categories of cognitive styles. The author creates five different knowledge packages, with different knowledge routes upon the same knowledge objects (Table 1).

	KP1	KP2	KP3	KP4	KP5
Activist	3	2	5	3	5
Reflector	1	3	1	2	2
Theorist	4	5	2	1	1
Pragmatist	3	2	1	5	2

Table 1: The author provides an evaluation of each knowledge package (KP) on a scale from ‘1’ to ‘5’, upon each one of the cognitive categories.

If the traditional approach for selecting the educational material is followed:

- a) The User Profiler Agent provides the classification of the user in one of the four categories (for example, classifies the user as an Activist) and provides this characterization to the brokering agents.
- b) When a brokering agent (for example a Package Broker Agent) locates the five knowledge package, it examines the prescriptive rules defined in each package (for example: “IF the style=Activist, THEN Suitability=30%).
- c) The Package Broker agent selects the most appropriate knowledge package to be presented to the user.

This method has an important drawback: by classifying the learners into a specific category, it loses all information included into the parameters given by the Honey and Mumford model. For example, why a learner who scored a 90% in the ‘Activist’ category and 10% in the ‘Pragmatist’ category, should be treated as having the same cognitive style with a learner scoring 90% in the ‘Activist’ category and 85% in the ‘Pragmatist’ category?

Introducing the multi-criteria methodology presented in the previous section would alter the described scenario as it follows:

- a) The User Profiler Agent created a multi-attribute cognitive model of the user, according to the results of the Honey and Mumford model (Table 2).
- b) When the Package Broker Agent locates the five knowledge packages, it calculates the total utility (that is suitability) of each package, using the methodology described in the previous section.
- c) The Package Broker agent selects the most appropriate knowledge package to be presented to the user (Table 3).

It is interesting to note in this example the difference between the application of a simple rule-based selection of the method (in this case the agent would classify the learner as ‘Activist’ and would propose the knowledge package KP3) and the proposed methodology. Using the multi-attribute cognitive model and the multi-criteria evaluation model, we observe that the most appropriate knowledge packages seems to be KP4, being the only knowledge package suitable for the combination of categories that characterize the learner’s cognitive style.

	LSQ Scores	Normalized
Activist	90%	0,35
Reflector	55%	0,22
Theorist	25%	0,10
Pragmatist	85%	0,33

Table 2: The cognitive styles preference model, as derived from the Honey and Mumford Learning Styles Questionnaire.

	Utility
KP1	2,67
KP2	2,51
KP3	2,51
KP4	3,25
KP5	2,96

Table 3: The total utility evaluations of the available knowledge packages (KPs).

Similar scenarios can be demonstrated when a single knowledge package contains several different knowledge routes, or when different knowledge packages are available, containing knowledge routes created with totally different didactic methods.

6. CONCLUSION

The proposed enhancement to the decision making modules of the brokering agents in the KOD Knowledge Publishing Pools reformulates the problem of simply locating a suitable knowledge package into a decision problem concerning whether the knowledge routes included in the package are best fitting the learner’s cognitive style. This evaluation is not based on static, pre-defined instructional rules (“IF the learner belongs to this category, THEN this didactic method is suitable”), but it introduces dynamic evaluation of each available method upon multiple criteria. Engaging such a multi-criteria modelling methodology provides the following feasibilities in this decision problem:

- Efficient structuring of the selection problem;
- Introducing both quantitative and qualitative criteria in the evaluation process;
- Acquiring transparency in evaluation of the alternatives, allowing good argumentation in decisions;
- Applying a sophisticated theoretical method in a field of practical interest.

Initial testing experiments have been carried out in a Java based, multi-agent environment and have produced encouraging results. In order though for the methodology to be properly validated, it has to be fully integrated into a large scale system as the one being currently developed within the KOD project, and be tested during all phases and types of interactions, as described in the previous steps. Such validation experiments should include embedding the method into the Learner Profiling procedures, into the Package Creation procedures and the Package Finding and Brokering processes. This would also require valid transformation of the ontology and language used by the KOD intelligent agents, in order for the multi-criteria description to be understood and its results to be communicated.

In this paper, the decision problem was modeled using the Honey and Mumford LSQ parameters as input variables,

but we believe that the proposed methodology can be similarly applied in the case of other cognitive style models too. Future research will be focused on applying of several other models, either separately or combined, and studying methods to resolve conflicts that might arise in the latter case. Moreover, an issue to be also studied is the application of more complex multi-criteria decision making methodologies for modeling the user preferences.

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