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A SEMANTIC-ORIENTED ARCHITECTURE OF A FUNCTIONAL MODULE FOR PERSONALIZED AND ADAPTIVE ACCESS TO THE KNOWLEDGE IN A MULTIMEDIA DIGITAL LIBRARY*

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Abstract. This paper presents dissertation work on semantic-oriented architectures and models for personalized and adaptive access to the knowledge in a multimedia digital library. The work was presented on October 27, 2008 before the Specialized Academic Council in Informatics and Mathematical Modelling at the Higher Attestation Commission. As a result of the work there appeared a functional module providing customized user access to the library content flow. The module used an IEEE PAPI and IMS LIP-oriented ontological user model. The main services provide customized user access, browsing, searching, and grouping of digitised objects and collections, user profile management, tracking the user's behaviour, etc. The services require and trace out data about the preliminary level of the users' knowledge in

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† This article presents the principal results of the doctoral thesis "Semantic-oriented Architecture and Models for Personalized and Adaptive Access to the Knowledge in Multimedia Digital Library" by Desislava Ivanova Paneva-Marinova (Institute of Mathematics and Informatics), successfully defended before the Specialised Academic Council for Informatics and Mathematical Modelling on 27 October, 2008.

the domain covered by the digital library, their object observation style, cognitive goals and interests, preferences about the objects/collections presentation and grouping, physical limitations, used knowledge delivery channels (Web, mobile phone), etc. Then they transform the available digitised objects into a new personalized form, and finally deliver them to the user. The module uses special usage scenarios/instructions defining a wide range of service actions dependent on the user's background, events, informal learning situations, knowledge delivery channels, etc.

Introduction. The implementation of the idea of access to information and knowledge for anyone, regardless of time and location, through the effective use of information and communication technologies in multimedia digital libraries (MDLs) has led to a new type of services, related to personalizing and adapting the information and resources provided to the users. Personalization means "the ways in which information and services can be adapted according to the specific needs of an individual or a community" [16]. In general it includes such activities as:

– selection and recommendation of information resources according to the personal characteristics of the user (demographic status, goals, tasks, skills, motivation, achievements, interests, preferences, *etc.*) on one hand and according to the user's behaviour in the environment on the other;
– adapting the user interface, the means of navigation, the display format and the ways of providing information resources.

On this basis, there are three types of personalization:

– content personalization, based on the user preferences, preliminary knowledge and experience, goals, needs, behaviour, *etc.*;
– personalization of the ways of delivering and formatting the content;
– complete personalization, combining the previous two approaches.

On the other hand, adaptivity allows activities for providing different variation options for the information content. Adaptivity concerns the development of templates for generating different variations of information units [11].

Personalization in current MDLs tends to be concerned with remembering which digital object/collection the users have visited last, how they would like it to be presented, and different levels of completeness of the object's content and versions. In most cases users are able to edit their own personal profile, maintain their personal page which keeps track of their event transaction, and browse collections and objects in long ordered/unordered lists. However, users often get frustrated while searching because of the substantial personal effort needed to locate information of their interest and needs. Observing the cognitive process in a digital multimedia library as a whole, users are very rarely allowed to get access to objects and collections which are conditioned on a wide range of personal data and preferences that are built to provide customized browse and search results. Such behaviour is absent in database systems, which always provide the same response to everyone. The personalizing and adaptive techniques in present MDLs are based on relatively simple models. This is the way to limit the working area and to avoid many serious problems which require deep study. The existing systems are about to ask themselves such questions as: what is the difference between temporary and permanent user characteristics and requirements, how to determine the personalization type, when to use temporary and permanent personalization and adaptivity, *etc.* Improving the existing algorithms is a partial solution to such problems, but there is a need for complete new strategies and algorithms which surpass the current solutions, considering factors such as trust, reputation, truthfulness, validity, usefulness of the provided resources as well as using richer descriptive user models. There is another direction for improvement which is the development of the mechanisms for "meeting" the individual needs, preferences, level of user's competence with the existing information content in the environment, taking into account the factors which affect the resources and the person (for example, changeability, time, increasing or decreasing the interest, validity, *etc.*). There is a need to develop semantics-based architectures and models for personalized and adaptive access to the information resources. The fixed user roles must be replaced with a more flexible approach, which allows the integration of human and automatic reasoning. The social effect is also important—communication, social integration, environment for sharing resources, ideas, knowledge, *etc.* Having these factors in mind and looking for other factors, which would help creating more personalized and adaptive frameworks is a subject to many current and future researches [11].

This paper presents semantic-oriented architecture of a functional module for personalized and adaptive access to the knowledge[1] in a multimedia digital library. It presents the developed basic scheme, models, algorithms, rules, infrastructure and architectural components. The module aims to modify the MDL content flow according to the users' individual preferences, cognitive goals and needs, object observation style, interests, previous knowledge, motivation, achievements, current circumstances, *etc.*, determined in a special ontology-based user profile. The architecture of the presented functional module is based on a

[1]By *knowledge* we mean information resources created by specialists according to the domain context.

special scheme for the implementation of personalized and adaptive logic[2] for access to the knowledge in the MDL (see Section 2). Section 3 describes the main sub-modules of the functional module. In section 4 there are rules defined for generation of customized information flows in the MDL. The ontological model describing the knowledge about the user of a particular multimedia digital library "Virtual Encyclopaedia of the Bulgarian Iconography" is presented in section 5. For the ontology development the IEEE PAPI and IMS LIP[3] standards are used on a conceptual level. In section 6 the main algorithms of some sub-modules of the described functional module are described. Their software implementation is tested in the multimedia digital library "Virtual Encyclopaedia of the Bulgarian Iconography". Section 7 presents the achieved results and directions for future development in the studies.

2. Basic scheme for the implementation of a personalized and adaptive logic for access to the knowledge in a multimedia digital library. The personalized and adaptive access to the knowledge in a MDL is based on a special scheme for the implementation of personalized and adaptive logic for access to the knowledge. This scheme has to trace all the activities realizable by the users and the respective replies of the system [8].

According to this scheme the users enter data about themselves—goals and interests, knowledge level in the thematic domain, covered by the library, preferences about the system interface, the given content, knowledge delivery channels, *etc.* Using these data the system creates a user profile. It is based on a special ontological model of the knowledge about the user and his/her behaviour in the MDL environment, also called user ontology. The profile represents a structured set of ontological metadata, partly entered by the users and partly generated automatically by the environment during a tracking process [6, 7]. The profiles are stored in a repository of user profiles.

Another important component of the scheme is the user query aiming at composing a personalized and adaptive information flow[4]. Forming the query activates a special functional sub-module defining rules for composition of the flow. It takes knowledge from the user profile and follows special instructions/scenarios for creation of personalized and adaptive information flow that could satisfy the

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[2]In this case *logic* means the procedures and algorithms on which the software application will work, the information flows, the events that occur, *etc.*

[3]IEEE PAPI – Personal and Private Information (IEEE PAPI) and IMS Learner Information Package (IMS LIP) – are standards defining the semantic and syntax of the information about the learners in the eLearning environment.

[4]Information objects, which are accessible for the user within a session.

user's wishes and needs. Thus, the user gets the desired knowledge. The next step is the presentation of the resulted personalized and adaptive information flow. Figure 1 schematically depicts the described basic scheme for the implementation of a personalized and adaptive logic in the MDL.

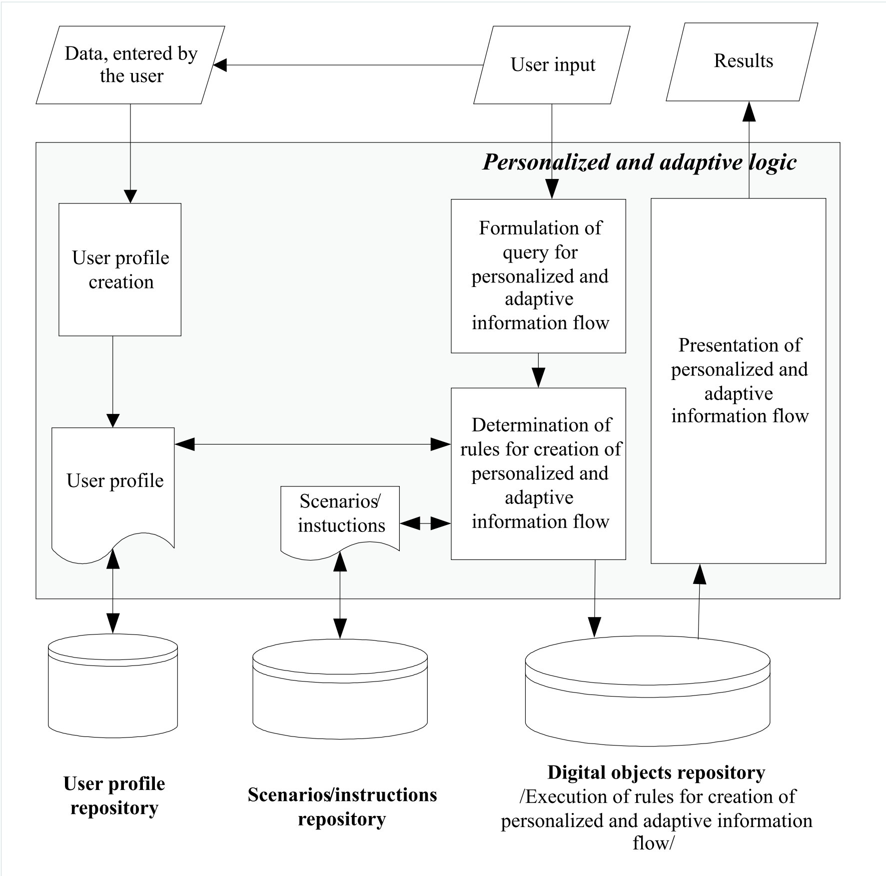

Fig. 1. Basic scheme for the implementation of personalized and adaptive logic in a multimedia digital library

Before the development of the scheme begins, the requirements that it must satisfy are analysed. This will guarantee that the functional module providing personalized and adaptive access to the knowledge in the multimedia digital library will work properly.

3. Functional module for personalized and adaptive access to the knowledge in a multimedia digital library.

Main objects and repositories managed by the functional module The functional module for personalized and adaptive access to the knowledge in a multimedia digital library manages the following types of objects [8]:

- *digital objects* (also called library objects): These are media objects (text, images, video, *etc.*), segmented, indexed and annotated with appropriate metadata. A part of them expresses the semantic content of the objects using a domain-specific ontology and another, the administrative/technical information about the objects and its ingredients. To this end appropriate models and language for description of the semantics and administrative information through metadata are used.
- *information objects*: These are digital objects with their descriptions.
- *user profiles*, developed on the basis of ontology, capturing user knowledge – demographic status, data for cognitive goals, interests, preferences, motivation, preliminary user's knowledge level in the domain, covered by the multimedia digital library, behaviour in the MDL environment. This set is used as input data for the functional modules, constructing the personalized information flow in the architecture, which is subject of description.
- *rules* for the implementation of personalized and adaptive access to the digital and/or information objects in the library. These are instructions defining a wide range of activities for every functional submodule of the architecture.

Digital objects and user profiles are respectively stored in a *digital object repository* and a *user profile repository*. The instructions are directly implemented in the corresponding architectural functional modules. The access and management of the repositories, different types of objects and their descriptive metadata are provided by a set of sub-modules of the described functional module.

Main components of the architecture of the functional module providing services for personalization and adaptive access in a multimedia digital library

The functional module is based on the basic scheme for the implementation of personalized and adaptive logic described in previous section. It includes the following set of main functional modules and sub-modules [8]:

- Module for managing the activities with the user profiles.
- Module for the creation of personalized and adaptive information flow according to the user profile and pre-formulated rules for creation of personal-

ized and adaptive information flow using digital objects stored in the MDL. It contains:

- ◦ Functional sub-module for personalized display of the information objects according to the preliminary knowledge level of the user in the domain, covered by the multimedia digital library.
- ◦ Functional sub-module for personalized display of the information objects according to the object observation style defined by every user.
- ◦ Functional sub-module for dynamic generation and visualization of collections of information objects grouped by one grouping criterion chosen by the user.
- ◦ Functional sub-module for displaying the information objects grouped by several criteria, which are chosen by the user during a search process.
- ◦ Functional sub-module for tracking the rubrics: interests and cognitive goals of the user profile and deliver on-demand recommended by the system information objects and knowledge for observation from the thematic areas that are required by the user.
- ◦ Functional sub-module notifying the user when new objects and content, covering their interests and cognitive goals are included.
- ◦ Functional sub-module for searching, extracting, and displaying user preferred objects conformable to user's physical limitations, for example, sounds for visually impaired people, *etc.*
- ◦ Functional sub-module for displaying personalized content in language preferred by the user.
- ◦ Functional sub-module for choosing and displaying the most suitable versions/formats of the digital objects according to the used MDL content delivery channels (Web, mobile phone, and *etc.*).

– Functional module for tracing the user's behaviour in the MDL environment
- ◦ Functional sub-module tracking and saving the objects and collections chosen by the user, the object observation path, and time in order to recommend objects of user's needs and interests.
- ◦ Functional sub-module, tracking and saving the competence level in the thematic areas of the multimedia digital library in order to recommend more detailed or simpler objects for observation.

The functional module managing the activities with the user profiles covers the following functionalities: development of user ontology capturing knowledge about users and their behaviour in the MDL environment; creation of personal profiles by annotating and indexing the knowledge about the users through an user ontology; cataloguing the users' personal profiles; ontological metadata management, *etc.* This module is a main component of the architecture. It provides the formal explicit knowledge about the user, using the MDL through the user ontology. This ontological model of the user knowledge is conceptually based on the IEEE PAPI and IMS LIP standards, developed in the eLearning area for user modelling. Section 5 describes this user ontology in detail.

Annotation and semantic indexing of the user knowledge constructs personal profiles that can be catalogued. The collected metadata will be used by the other module for creation of personalized and adaptive information flows. These metadata are dynamically changeable according to the subsequent activities of the user in the environment and any changes of his/her profile.

The next group of modules concerns the adaptation and personalization of the content flow using different characteristics of the user profile. These functionalities are accomplished by displaying different level of detail description and presentation of the digital objects—the main tasks of the functional module that displays a personalized content (*i.e.*, information objects) according to the preliminary knowledge level of the user in the domain covered by the library. The users determine this level themselves by entering it in the profile. They can subsequently change the value of their preliminary knowledge or they can use the functional module, displaying personalized content/objects according to defined user object observation styles. The style defines the way of displaying specific criteria which describe digital objects. These two modules assist the object observation by generating new objects containing parts of the originals for every user. This activity can be determined as a process of development or modification of the information materials according to individual requirements, preferences and knowledge level.

The next module in the architecture dynamically provides generation and visualization of collections of information objects according to a main grouping criterion chosen by the user. This grouping provides easy object observation. The selected criterion can be changed with another one later, which enables new grouping. The extension of this functionality is realized through another functional module that in a real search process shows a collection of grouped objects in addition to the returned results. The grouping criteria are chosen during the user profile development or in the search form.

User cognitive goals and interests are categories that give information to the system on why the user chooses it and what he/she wants to find out (learn). The architecture provides a special functional sub-module tracking these rubrics in the profile and delivering on-demand objects and knowledge for observation. These rubrics can have a fixed or dynamically generated value. If the user does not select a value the system does not provide objects on-demand. Another possibility is that the system delivers objects necessary for users with low knowledge level in the domain covered by the MDL.

The digital libraries are environments that constantly change by including new objects and knowledge or replacing those created before. Therefore, in the architecture we include a functional sub-module notifying the user that new objects are included. The input data used by this module are the values of cognitive goals and interests.

A special module for searching, extracting and displaying of objects conformable to users' physical limitations is considered in order to provide access to the library for the disabled people.

In a multilingual digital library it is necessary to provide object grouping according to the user's preferred language. The last module of this section – functional module for choosing and displaying the most suitable versions/formats of the digital objects according to the used MDL content delivery channels – is suitable if we expect that the knowledge in our MDL will be accessed not only through the Internet, but also through mobile phone and other devices. The development of such a sub-module is imposed by the last year's tendency for the implementation of ubiquitous delivery of information—anywhere and anytime with various devices.

The last service concerns the user behaviour in the MDL environment and recommends objects for observation. Its first module tracks out and saves the objects and collections chosen by the user, the object observation path, and time in order to recommend objects of the user's needs and interests. The information from these actions is necessary in cases when the system makes inferences for the users' difficulties and the library objects and collections that are interesting to the users.

Following good practices of the eLearning systems, the architecture can be extended including functional module that tracks the competence level in the thematic areas of the library in order to recommend more detailed or simpler objects for observation. The implementation requires the development of quizzes and questions as well as testing the users during the process of object observation. The users decide whether to use this atypical option for a multimedia digital library.

According to the basic scheme for personalized and adaptive access logic, it is necessary to develop abstract scenarios/instructions for the creation of personalized and adaptive information flow. They include possible ways of exploring the objects/collections or their parts depending on the options that users set in their profiles. Besides, the scenarios/instructions contain specific concepts used for describing the objects and collections in the library. These concepts come from the ontology, capturing the knowledge of the MDL's domain. These specifics of the scenarios/instructions determine their use in describing the rules for dynamic generation of personalized and adaptive information flows [10, 11].

4. Personalized and adaptive logic for creation of customized information flow in a multimedia digital library.

Rules for creating a personalized information flow

Let

$X_1 = \{x_{11}, x_{12}, \dots, x_{1p_1}\}$ be the set of all demographic characteristics (personal data) of the user model,

$X_2 = \{x_{21}, x_{22}, \dots, x_{2p_2}\}$ be the set of all user's preferences of the user model,

$X_3 = \{x_{31}, x_{32}, \dots, x_{3p_3}\}$ be the set of all characteristics, related to the education and experience of the user model

...

$X_k = \{x_{k1}, x_{k2}, \dots, x_{kp_k}\}$ be the set k of characteristics of the user model or user's actions in the MDL environment, $k = 1..n$

Then

$\forall x_{ij} \in X_i, \quad i = 1..k, j = 1..p_k \quad \exists q_i, \quad q_i \in Q : x_{ij} \rightarrow q_i,$

where Q is the set of all results—objects of the MDL knowledge domain that are most suitable for observation by the user for its characteristics and actions on the MDL environment.

Let

$X = \bigcup\limits_{i=1}^{k} X_i$ be the taxonomy of the user model (demographic characteristics, cognitive skills, preferences, interests, *etc.*);

$Y = \bigcup\limits_{i=1}^{n} Y_i$ be the taxonomy of the objects in the MDL knowledge domain (in this case the set of iconographic objects—icons, mural paintings, *etc.*, the set of included iconographic techniques, the set of iconographic schools, the set of artists, *etc.*) presented at [15, 9];

$Z = \bigcup\limits_{i=1}^{m} Z_i$ be the taxonomy of the user's actions in the MDL environment (selection, browsing, etc.).

Then

$\forall j, r, l \forall x_{ij} \in X_j, y_{ir} \in Y_r, z_{il} \in Z_l \quad \exists q_i, q_i \in Q : x_{ij} \cup y_{ir} \cup z_{il} \rightarrow q_i$

and

$\forall j, r \forall x_{ij} \in X_j, y_{ir} \in Y_r \quad \exists q'_i, q'_i \in Q' : x_{ij} \cup y_{ir} \rightarrow q'_i$

i.e. for the intersection of X, Y and Z the following axiom may be used:

IF $(X_1 = x_{1j}, X_2 = x_{2j}, \ldots, X_i = x_{ij}, \ldots)$
  AND $(Y_1 = y_{1r}, Y_2 = y_{2r}, \ldots, Y_i = y_{ir}, \ldots)$
  AND $(Z_1 = z_{1l}, Z_2 = z_{2l}, \ldots, Z_i = z_{il}, \ldots)$
THEN $(Q = q_1, q_2, \ldots, q_n)$

where Q is the set of all results—objects of the MDL knowledge domain ($Q \supseteq Y$), that are most suitable for observation by the user for its characteristics and actions on the MDL environment.

In the more limited case – the intersection of X and Y:

IF $(X_1 = x_{1j}, X_2 = x_{2j}, \ldots, X_i = x_{ij}, \ldots)$
  AND $(Y_1 = y_{1r}, Y_2 = y_{2r}, \ldots, Y_i = y_{ir}, \ldots)$
THEN $(Q' = q'_1, q'_2, \ldots, q'_n)$

where Q' is the set of all results—objects of the MDL knowledge domain ($Q' \supseteq Q, Q' \supseteq Y$), that are most suitable for observation by the user for definite characteristics [8].

For example:

IF (X_1 = Knowledge level in the MDL domain: beginner, X_2 = Interest: Iconography)
  AND (Y_1 = Iconographical objects: icons, Y_2 = Iconographic school: Bansko-Razlog iconographic school)
  AND (Z_1 = User actions: object browsing)
THEN (Q = Iconographical objects: beginner level, Iconographic school: beginner level)

Rules for creation of adaptive information flow

Let

$A = \bigcup_{i=1}^{l} A_i$ be the taxonomy of the adaptive aims (content adaptation, interface adaptation, *etc.*), where $l$is the overall number of adaptive aims;

$B = \bigcup_{i=1}^{s} B_i$ be the taxonomy of the adaptive methods (additional explanations (objects), selected parts of the objects, objects grouping, *etc.*), where s is the overall number of adaptive methods;

$X = \bigcup_{i=1}^{n} X_i$ be the taxonomy of user model characteristics (demographic characteristics, cognitive skills, preferences, interests, *etc.*), where n is the overall number of user model characteristics [6, 7];

$Y = \bigcup_{i=1}^{k} Y_i$ be the taxonomy of the objects in the MDL knowledge domain (in this case the set of iconographical objects – icons, mural paintings, *etc.*, the set of included iconographic techniques, the set of iconographic schools, the set of artists, *etc.*), where k is the overall number of the objects in the MDL knowledge domain [15];

$Z = \bigcup_{i=1}^{m} Z_i$ be the taxonomy of the user's actions in the MDL environment (selection, browsing, *etc.*), where m is the overall number of the user's actions in the MDL environment;

$D = \bigcup_{i=1}^{p} D_i$ be the taxonomy of the devices used by the user to access the MDL environment (PDA, PC, smart phone, iTV, *etc.*), where p is the overall number of the devices used by the user to access the MDL environment.

Then:
$\forall p, k, j, r, l, m \forall a_{ip} \in A_p, b_{ik} \in B_k, x_{ij} \in X_j, y_{ir} \in Y_r, z_{il} \in Z_l, d_{im} \in D_m \quad \exists g_i, g_i \in G : a_{ip} \cup b_{ik} \cup x_{ij} \cup y_{ir} \cup z_{il} \cup d_{im} \rightarrow g_i$
and
$\forall p, k, j, r, m \forall a_{ip} \in A_p, b_{ik} \in B_k, x_{ij} \in X_j, y_{ir} \in Y_r, d_{im} \in D_m \quad \exists g'_i, g'_i \in G' : a_{ip} \cup b_{ik} \cup x_{ij} \cup y_{ir} \cup d_{im} \rightarrow g'_i$

i.e. the intersection of A, B, X, Y, Z and D the following axiom may be used:

IF $(A_1 = a_{1p}, A_2 = a_{2p}, \ldots, A_i = a_{ip}, \ldots)$
AND $(B_1 = b_{1k}, B_2 = b_{2k}, \ldots, B_i = b_{ik}, \ldots)$
AND $(X_1 = x_{1j}, X_2 = x_{2j}, \ldots, X_i = x_{ij}, \ldots)$
AND $(Y_1 = y_{1r}, Y_2 = y_{2r}, \ldots, Y_i = y_{ir}, \ldots)$
AND $(Z_1 = z_{1l}, Z_2 = z_{2l}, \ldots, Z_i = z_{il}, \ldots)$
AND $(D_1 = d_{1m}, D_2 = d_{2m}, \ldots, D_i = d_{im}, \ldots)$
THEN $(G = g_1, g_2, \ldots, g_n)$

where G is the adaptive technique for selection of sets of objects from the knowledge domain of the MDL and/or part of them ($G \supseteq Y$) that are adapted according to adaptive aims and methods and are consistent with the user model, the user's actions in the MDL environment, used access devices and the available library objects.

In the more limited case—the intersection of A, B, X, Y and D:

IF $(A_1 = a_{1p}, A_2 = a_{2p}, \ldots, A_i = a_{ip}, \ldots)$
AND $(B_1 = b_{1k}, B_2 = b_{2k}, \ldots, B_i = b_{ik}, \ldots)$
AND $(X_1 = x_{1j}, X_2 = x_{2j}, \ldots, X_i = x_{ij}, \ldots)$
AND $(Y_1 = y_{1r}, Y_2 = y_{2r}, \ldots, Y_i = y_{ir}, \ldots)$
AND $(D_1 = d_{1m}, D_2 = d_{2m}, \ldots, D_i = d_{im}, \ldots)$
THEN $(G' = g'_1, g'_2, \ldots, g'_n)$

where G' is the adaptive technique for selection of sets of objects from the knowledge domain of the MDL and/or part of them ($G' \supseteq G, G' \supseteq Y,$) that are adapted according to the adaptive aims and methods and are consistent with the user model, used access devices and the available library objects.

For example:

IF (A_1= Adaptive aim: content adaptation)
AND (B_1= Adaptive method: display of definite descriptive characteristics of the MDL objects, descriptive characteristics: $h_1, h_2, \ldots, h_n$)
AND (X_1 = Knowledge level in the MDL domain: beginner X_2 = Interest: Iconography)
AND (Y_1 = Iconographic objects: icons, Y_2= Iconographic school: Bansko-Razlog iconographic school)
AND (Z_1 = User actions: objects browsing)
AND (D_1 = Used device: PC)
THEN (G = Icons with descriptive characteristics – $h_1, h_2, \ldots, h_n$: beginner level, Iconographic school: beginner level)

5. Ontological model of the knowledge about the MDL user. Building a user model for a multimedia digital library involves defining: the "who", or the degree of specialization in defining who is modelled, and what the user history is; the "what", or the cognitive goals, plans, attitudes, capabilities, knowledge, and beliefs of the user; the "how" the model is to be acquired and maintained; and the "why", including whether to elicit information from the user, give assistance to the user, provide feedback, or interpret the user's behaviour. On the other hand, the interpretation of the user model does not have to be considered apart from the developed standards and specifications in student area (in particular, our MDL user can be considered a learner or a user who looks for special knowledge), because we aim to maximize its reusability and portability.

The IEEE Personal and Private Information (PAPI) [2] and IMS Learner Information Package [3] are two of the most important and well-developed standards for student modelling. Both standards deal with several categories for information about a learner. These standards have been developed from different points of view [1]. The PAPI standard reflects ideas from intelligent tutoring systems where the performance information is considered as the most important information about a learner. The PAPI standard also stresses on the importance of inter-personal relationships. On the other hand the LIP standard is based on the classical notion of a CV and inter-personal relationships are not considered at all.

After we found these specifics of the standards, we decided to take them into consideration, to combine some of their parts and to add some specific extensions, too [6, 7].

To develop the user model we also trace the already created learner ontologies in several eLearning systems and projects and some MDL user ontologies in order to capture the good practices and experience, because we consider that our MDL user has mainly learning and cognitive goals and uses the given digital objects for intellectual and knowledge enhancement. Part of this analysis is presented in [6].

From our point of view the user model needs to cover a certain amount of information that can be divided into two main groups [6]:

- *general user information,* such as actual and historic data (personal information), goals, interests, wishes, cognitive aptitudes, object observation styles, measures for motivation state, preferences regarding the object presentation method, *etc.*,
- *information about user's behaviour* in the multimedia digital library such as chosen paths for object observation, chosen objects and collections, overall competence level, difficulties during the understanding of the information, *etc.*

User ontology. The main scope of the described ontology is to formally present the user's characteristics (background) and his/her behaviour (actions) in the multimedia digital library in order to provide personalized and adaptive access to the MDL knowledge.

In terms of the general structure of our user model for the ontology we determine the following list of basis concepts:

Concepts in the user ontology

- User
- Personal data—name, surname, id, age, postal address, email, telephone
- Education and experience (educational background)—preliminary knowledge level, speciality, qualification degree, validation period, year of graduation, institution/university/school, course name, course description, course

duration

- Preference—object grouping style, object observation style, preferred object according to physical limitation, preferred language
- Motivation—interest, knowledge level in the MDL domain
- Cognitive goal
- Behaviour in the MDL
    - Object observation time
    - Chosen object
    - Chosen collection

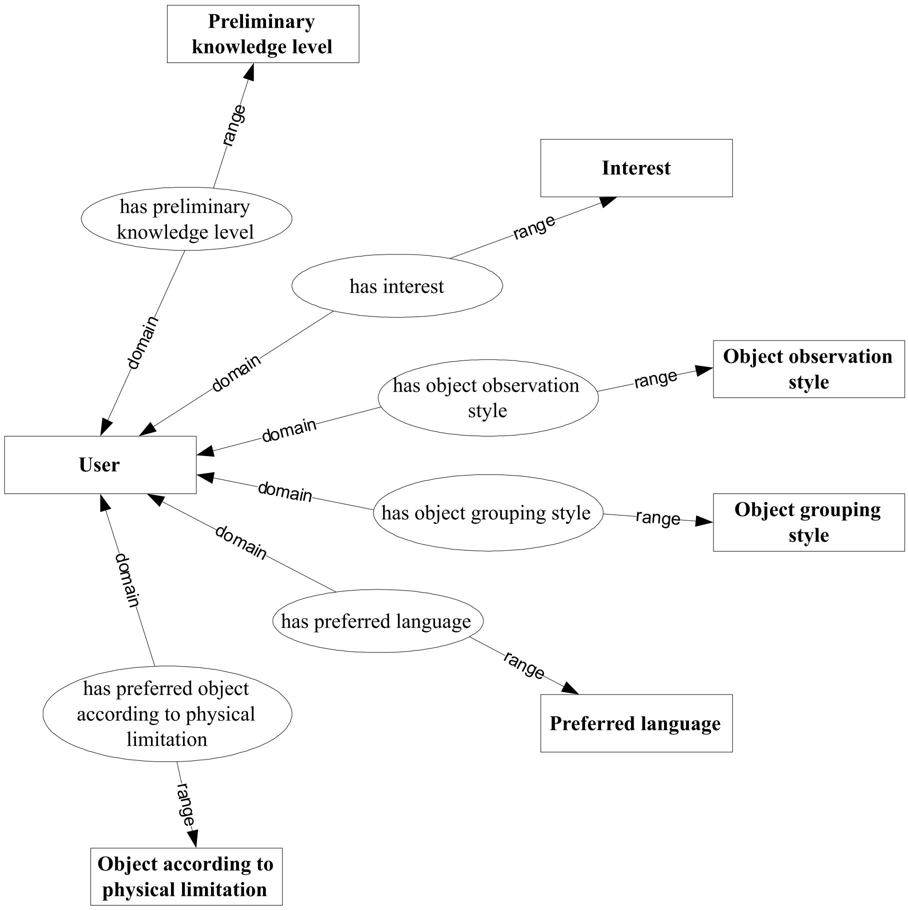

Fig. 2. Main classes and properties relating the class 'User' with the classes 'Motivation' and 'Preference' in the user ontology

- Object observation path
- Competence level in the MDL domain

Main properties such as *has object grouping style, is knowledge level in the MDL domain, has preferred language, etc.,* provide the relations between the individuals of class concepts. The basic restrictions for all the relations are defined in the model's ontological description: *There is a class for every relation.* Many facts were found while working with the ontology. For example, *Level of preliminary knowledge in the MDL domain—A1*: at first it is related to *Style of exploring the digital objects—B1*: All the digital objects have *author, school and period* characteristics. Relating instances of a class with a set of instances from another class with a choice option is defined by more complex facts that one can use. For example, *Level of preliminary knowledge in the MDL domain—A1*: is related to *Style of exploring the digital objects B1, B2, etc.*, which are predefined and the user chooses what is best for them. The instances of the classes are set according to the application of the ontological model in the multimedia digital library "Virtual Encyclopaedia of the Bulgarian Iconography" [5, 12, 13].

Figure 2 depicts the main classes and properties relating the class 'User' with the classes 'Motivation' and 'Preference' in the user ontology.

A more detailed description of the conceptualization level of the user model is presented in [10].

The language used for the formalization of the ontology is Web Ontology Language [4] because of its functionality, tool support (in particular the Protégé 3.0 development tool), and status as an official W3C recommendation.

6. Implementation of sub-modules of the functional module for personalized and adaptive access to the knowledge in a MDL. For tests and assessment of the functionality, in the multimedia digital library "Virtual Encyclopaedia of the Bulgarian Iconography" we developed and implemented three main sub-modules of the described functional module:

- Functional sub-module for personalized display of the information objects according to the preliminary knowledge level of the user in the domain, covered by the target MDL (Module 1).
- Functional sub-module for personalized display of the information objects according to the object observation style defined by every user (Module 2).
- Functional sub-module for searching, extracting and delivery of information objects grouped according to several criteria, which are chosen by the user during a search process (Module 3).

The development follows the iterative method. During the design phase of Module 1 the principles of work, the characteristics and the base idea defined the main algorithm: For the work of the module there are two main procedures developed: the procedure for entering or changing the preliminary knowledge level in the profile of the MDL user and the procedure for getting data about the preliminary knowledge level from the user profile and for personalized adaptation of the MDL objects visualization according to this characteristic and the object observation style [10, 11].

Procedure for entering or changing the preliminary knowledge level in the profile of the MDL user. Let **$level** be the new preliminary knowledge level in the profile of the user **$X.** The procedure works according to the following algorithm:

Step 1: Load the ontology
$ontology = new ontology();
Step 2: Load data about the user **$X**
$ontology−>setCurrentUser($ontology−>getUserByNickname($X));
Step 3: Load the new preliminary knowledge level **$level** for the user **$X.**
$ontology−>setUserChar('has_preliminary_knowledge_level', $level);
Step 4: Save of the ontology change
$ontology−>saveOntology();
Step 5: End.

Procedure for getting data about the preliminary knowledge level from the user profile and for personalized adaptation of the MDL objects visualization according to this characteristic and the object observation style. Let **$level** be the new preliminary knowledge level in the profile of the user **$X.** The procedure works according to the following algorithm:

Step 1: Load the ontology
$ontology = new ontology('depl');
Step 2: Load data about the user **$X**
$ontology−>setCurrentUser($ontology−>getUserByNickname($X));
Step 3: Select the value of the variable **$level**—preliminary knowledge level for the user **$X**
$level = $ontology−>getUserChar('has_preliminary_knowledge_level', $datatype);
Step 4: If the preliminary knowledge level is fixed, go to Step 5, else go to Step 6.
Step 5: Determine the object observation style according to the preliminary knowledge level **$level**:
Let **$level** = p_i, then the object observation style is **$style** = S_i, where S_i is some subset of the characteristics S, describing a MDL object.

Step 6: Get the data for the object observation style for user **$X** from the ontology:
$style = $ontology−> getUserChar('has_object_observation_style', $datatype);
$style e a subset of the set, describing the MDL object S.
Step 7: If $style is an empty set, go to Step 8, else go to Step 9.
Step 8: Set a default value for the preliminary knowledge level $level = $\mathrm{p_k}$ $ontology−> setUserChar('has_preliminary_knowledge_level', $level); and the corresponding value $style = $\mathrm{S_k}$. Save the ontology: $ontology−>saveOntology();
Step 9: Deliver the new information flow that shows the digital objects described with characteristics selected according to the preliminary knowledge level in the MDL domain of the user.
Step 10: End.

Figure 3 gives a graphical description of the procedure for getting data about the preliminary knowledge level from the user profile and for personalized adaptation of the MDL objects visualization according to this characteristic and the object observation style.

During the design phase of Module 3 the following main algorithms are defined:

Let $U = \{u_1, u_2, \ldots, u_h\}$ be the set of all MDL digital objects and $C = \{c_1, c_2, \ldots, c_n\}$ be the set of all characteristics describing one object from U.

Let $V = \{v_{11}, v_{12}, \ldots, v_{1j_1}, v_{21}, v_{22}, \ldots, v_{2j_2} \ldots, v_{n1}, v_{n2}, \ldots, v_{nj_n}\}$ be the set of all values for the characteristics of the object from U, where $\{v_{i1}, v_{i2}, \ldots, v_{ij_i}\}$ is the set of the values for the characteristic c_i.

The function chr is defined in the following way: $\mathrm{chr} : U \times C \to V$, $\mathrm{chr}(u, c) = v$, where $u \in U$, $c \in C$, $v \in V$, *i.e.* the characteristic c of the object u has value v. Moreover, if $\mathrm{chr}(u, c) = v_1$ and $\mathrm{chr}(u, c) = v_2$, where $v_1, v_2 \in V \Rightarrow v_1 = v_2$, *i.e.* the characteristic of one object may have only one value.

Step 1: Select the main characteristic c_i for the digital objects and their value. Activate the search filter in the following way:
Let $X = \{x \in U | \mathrm{chr}(x, c_i) = v_{ij}\}$ for a fixed i, *i.e.* X is the set of all objects of U, that have values $v_{ij} \in V$ for the characteristic $c_i \in C$.

Step 2: Grouping the results—Select $Y \subset C$, where Y is the set of all grouping characteristics, describing a digital object and $c_i \notin Y (c_i$ is from Step 1). For $\forall k \in Y$ the families $F_k = \{G_1, G_2, \ldots, G_p\}$ are created, where $G_j = \{g \in X | \mathrm{chr}(x, k) = v_j\}$, $j = 1, 2 \ldots, p$.

In the example depicted in Figure 4 U is the set of all digital objects and $X \subset U$ is the set of all objects from U which have the value Tryavna for the main

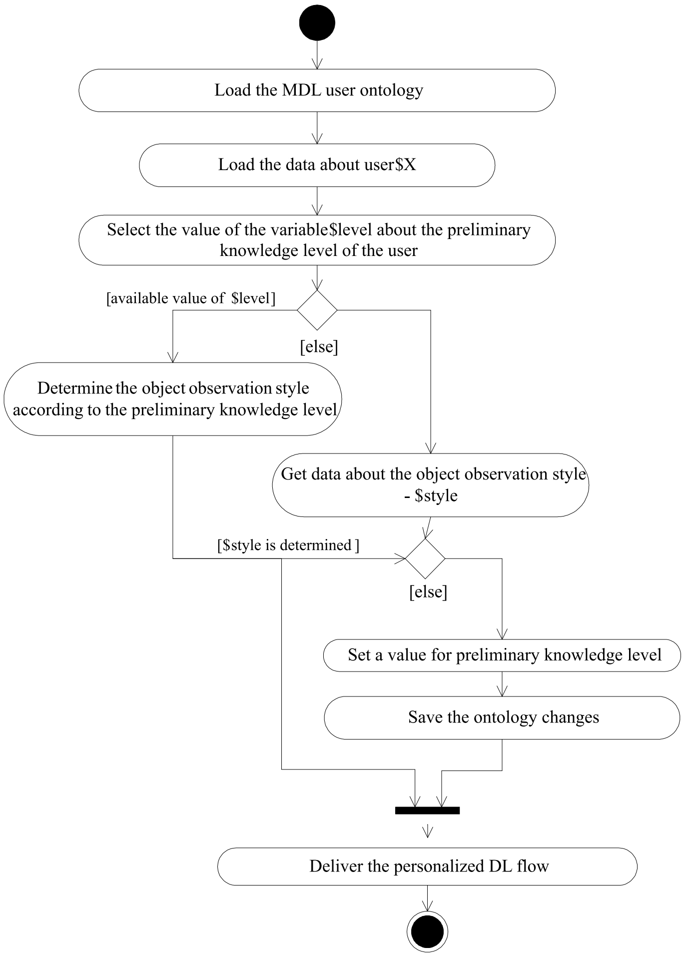

Fig. 3. Algorithm for getting data about the preliminary knowledge level from the user profile and for personalized adaptation of the MDL objects visualization according to this characteristic and the object observation style

search characteristic—Region, *i.e.* $X = \{x \in U | \mathrm{chr}(x, \mathrm{Region}) = \mathrm{Tryavna}\}$. The result of this search is three digital objects.

The family F_p is created by grouping the result digital objects according to the Author characteristic:

$F_1 = \{G_1, G_2\}$, where $G_1 = \{g \in X | \mathrm{chr}(g, \mathrm{author}) = \mathrm{Papa\ Vitan\ Koyuv}\}$ and $G_2 = \{g \in X | \mathrm{chr}(g, \mathrm{author}) = \mathrm{unknown}\}$

The number of the set elements are respectively $|G_1| = 2$ and $|G_2| = 1$.

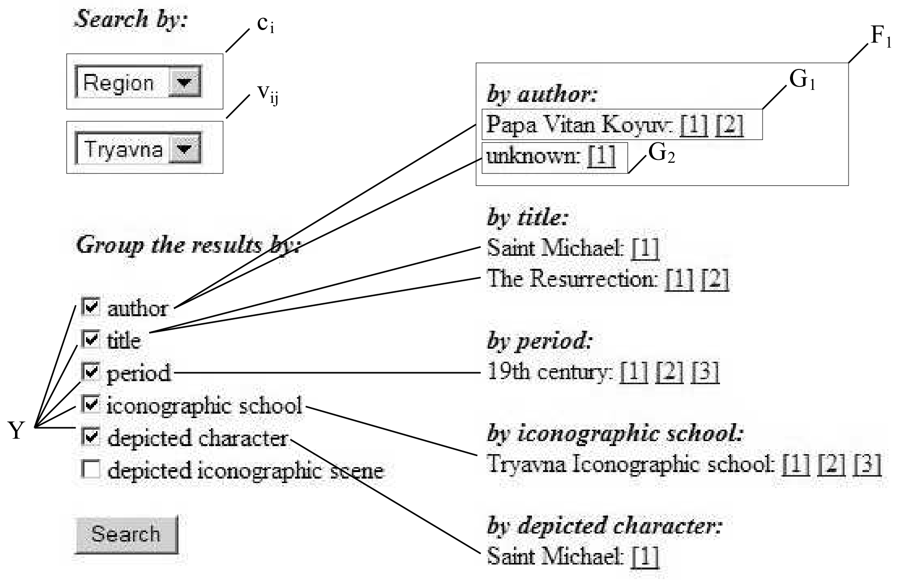

Fig. 4. Context-based search of information objects by a main criterion with grouping of the results according to four selected criteria from the set Y

The objects in F_1 have the same number as in the set X. The figure also shows grouping of the search results according to the characteristics: *title, period, iconographic school* and *depicted character*. This algorithm is valid for arbitrary grouping of the results from context-based search according to one main characteristic.

7. Conclusions. A tendency from the last few years points towards the use of digital libraries as a source of digital knowledge and environment for its delivery. This tendency determines the development of new methods and techniques for personalization, content adaptation, and changeability of the interface according to the user's individual characteristics, preferences and behaviour in the MDL environment. In this article we presented a semantic-oriented architecture of functional module providing personalized and adaptive access to the MDL knowledge with a special user ontology. The module covers a wide range of personalized and adaptive activities in the MDL environment satisfying the user's needs and wishes. The main characteristics of the user model are described and several functional modules use them for semantic reasoning and generation of personalized information flow.

REFERENCES

[1] Dolog P., W. Nejdl. Challenges and Benefits of the Semantic Web for User Modelling, In the Proceedings of AH2003 workshop at 12th World Wide Web Conference, 2003, Budapest, Hungary, Available Online: `http://www.l3s.de/~dolog/pub/semanticwebandum.pdf` (accessed on June 15, 2007).

[2] IEEE Personal and Private Information. Draft 8 Specification, Available online: `http://edutool.com/papi/` (accessed on June 15, 2007).

[3] IMS Learner Information Package Specification V1.0.1. Available online: `http://www.imsglobal.org/profiles/` (accessed on June 15, 2007).

[4] OWL Web Ontology Language Overview. W3C Recommendation 10 February, Available Online: `http://www.w3.org/TR/owl-features/` (accessed on June 15, 2007).

[5] Paneva D., L. Pavlova-Draganova, L. Draganov. Digital Libraries for Presentation and Preservation of East-Christian Heritage. In: Proceedings of the Open Workshop "Generic Issues of Knowledge Technologies", 14 September, 2005, Budapest, Hungary, 75–83.

[6] Paneva D. Ontology-based Student Modeling. In: Proceedings of the Open Workshop, "Ubiquitous Learning challenges: Design, Experiments and Context Aware Ubiquitous Learning", 20–21 September, 2006, Turin, Italy, 17–21.

[7] Paneva D. Use of Ontology-based Student model in Semantic-oriented Access to the Knowledge in Digital Libraries. In: Proceedings of the Open Workshop "Semantic Web and Knowledge Technologies Applications", 12 September, 2006, Varna, Bulgaria, 31–41.

[8] Paneva D. Service-based Architecture for Personalized and Adaptive Access to the Knowledge in Digital Library. In: Proceedings of the International Conference on Mathematical and Computational Linguistics, 6 July, 2007, Sofia, Bulgaria, 93–106.

[9] Paneva D., L. Pavlova-Draganova, L. Draganov. Towards Content-sensitive Access to the Artfacts of the Bulgarian Iconography. In: Proceedings of the Fifth International Conference "Information Research and Applications" – i.Tech 2007 (ITA 2007 – Xth Joint International Scientific Events on Informatics), 26 June–01 July, 2007, Varna, Bulgaria, Vol. **1**, 33–38.

[10] Paneva-Marinova D. Disertation work on: Senatic-oriented architecture and models for personalized and adaptive access to to knowledge in a multimedia digital library. Sofia, Bulgaria, 2008, 1–182.

[11] Paneva-Marinova D. Authoreferat of a disertation work on: Senatic-oriented architecture and models for personalized and adaptive access to to knowledge in a multimedia digital library. Sofia, Bulgaria, 2008, 1–51.

[12] Paneva D., L. Pavlova-Draganova, L. Draganov. Towards Content-sensitive Access to the Artfacts of the Bulgarian Iconography. *International Journal Information Technologies and Knowledge*, **2**, No 4 (2008), 313–318.

[13] Pavlov R., L. Pavlova-Draganova, L. Draganov, D. Paneva. e-Presentation of East-Christian Icon Art. In: Proceedings of the Open Workshop "Semantic Web and Knowledge Technologies Applications", September, 2006, Varna, Bulgaria, 42–48.

[14] Pavlov R., D. Paneva, N. Moumoutzis, P. Arapi, E. Ovcin, G. Morrone, Z. Markus. Analysis of Innovative Learning Services in Web. Interactive TV and Mobile Applications for Non-formal Settings (Analytical study, LdV project CHIRON), 2006, 1–120 (to be published).

[15] Pavlova-Draganova L., D. Paneva, L. Draganov. Knowledge Technologies for Description of the Semantics of the Bulgarian Iconographical Artefacts. In: Proceedings of the Open Workshop "Knowledge Technologies and Applications", 31 May–1 June, Kosice, Slovakia, 41–46.

[16] Smeaton A., J. Callan. Personalisation and Recommender System in Digital Libraries. *International Journal Digital Libraries*, **5** (2005), 288–308.

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