Ontology-Based User Modeling for Pedestrian Navigation Systems

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Abstract. Human-centered and user-adaptive systems are at the heart of the Design for All and Ambient Intelligence initiatives. Obviously, user models are necessary "ingredients" of such systems. We present a user model for navigation systems (mainly pedestrian), which is based on relevant human wayfinding and navigation theories. We represent this model through a Semantic Web ontology and show how it can be incorporated in an indoor navigation system called OntoNav, which enables personalized path selection.

1 INTRODUCTION

Gluck [1] defines wayfinding as "*the procedure that is used for the orientation and navigating, in order an individual to navigate from one place to another, especially in very huge and complex environments indoors or outdoors*". In general, it is a particularly demanding process, which requires the mobilization of a number of cognitive/mental processes, besides the kinetic ones. Such process is, naturally, executed unconsciously for the majority of people. However, for certain categories of individuals, with certain abilities/disabilities considering their cognitive and/or physical status, wayfinding and navigating may be an extremely cumbersome process. Hence, a "one-size-fits-all" approach does not apply to pedestrian navigation. Personalization of navigation is required and it necessitates the establishment of some appropriate user model that will be taken into consideration when a) computing possible navigation paths, b) selecting the "best" path and c) guiding the user through it by giving her appropriate instructions.

In this paper we present the main theories regarding navigation and their relevance to user models. We exploit such knowledge in order to build a User Navigation Ontology (UNO) that can be used in a navigation system for personalized path selection. Specifically, UNO is an ontology that was developed for modeling users based on their individual characteristics that influence a) navigational decisions (i.e., selection of the optimum path), and b) the form and the means that these navigational decisions are communicated/presented to them. In order to put the presented model in the context of a navigation system we briefly describe OntoNav, an indoor navigation system implemented with Semantic Web technologies.

The organization of the rest of the paper is as follows. In Section 2 we present some theoretical foundations on pedestrian wayfinding and navigation. Additionally, we outline the basic principles and concepts of a navigation-oriented user model. A more formal specification of these concepts is provided in Section 3, where the core of the UNO ontology is presented. In Section 4 we present the basic functionality of OntoNav, while in Section 5 we describe some related work that has partially influenced our work. The paper concludes with directions for future research.

2 MODELING USERS FOR NAVIGATIONAL PURPOSES

2.1 Human Navigation and Wayfinding Theories

Wayfinding is a fundamental human activity and an integral part of everyday life. Individuals are mainly using their knowledge and previous experience with geographic spaces in order to navigate from one location to another. As a result, a huge amount of research literature from the fields of cognitive science, psychology and artificial intelligence examines the mechanisms that enable humans to find their way in unknown and complex environments. In the following paragraphs we discuss the main theoretical approaches to human wayfinding and navigation that have influenced our work.

Wayfinding

Downs and Stea [2] suggested that wayfinding involves the following four steps:

1. Orientation: Finding out where someone is with respect to nearby landmarks and the navigation destination.
2. Route Selection: Selecting a route, under certain criteria, that will eventually lead the individual to the desired destination.
3. Routing Control: Constant control and confirmation that the individual follows the selected route.
4. Recognition of destination: The ability of an individual to realize that she has reached the destination or is located in a nearby area.

In general, the wayfinding ability of individuals is greatly influenced by a number of factors, based on findings from research in human neurophysiology [3]. The most important of these are:

1. Individual Characteristics (e.g., age, sex, cognitive development, perceptual capability, mental and physical condition).
2 Characteristics of the environment (e.g., size, luminosity, signage, utilization, structure, familiarization with it).
3. Learning Processes (e.g., learning strategies, learning conditions, learning abilities).

Furthermore, the wayfinding ability of individuals is mainly affected by the following four factors: spatial ability, fundamental information processing capabilities, prior knowledge of the environment and motor capabilities. S*patial ability* can be defined as the ability of every individual to perceive the surrounding environment with its sensing and cognitive mechanisms. This ability includes all cognitive procedures that are used whenever we are learning our environment and comprehend correlations among its elements. This leads to *spatial consciousness*, which describes the degree to which an individual understands/reacts with the environment using her spatial ability. Thus, wayfinding is a dynamic and demanding cognitive procedure, which involves many spatial and navigational abilities. Moreover, similarly to every other human activities, not every individual has the same navigational skills

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[4]. This fact calls for a classification of potential users of a navigation system so that it could provide its services in a way tailored to their specific cognitive and physical abilities/disabilities.

Navigational Awareness

Navigational awareness is defined as the wayfinding task which takes place when the individual who navigates in an area has complete knowledge of the navigation environment. There are two distinct types of navigating through an environment, with significant differences between them. The first navigation type is based on what is called *procedural* or *route knowledge*. The procedural knowledge is human centered (ego-referenced) and is mainly acquired through personal exploration of an unknown environment. The main characteristic of the procedural knowledge is that, while an individual can navigate from one landmark to another in a known route, she has no other knowledge about alternatives routes (fastest, quickest, etc.). The second type of navigation is based on the *survey knowledge*. Such knowledge is acquired through iterative multiple explorations of an area following different path each time. This type of survey knowledge is characterized by its ability to support distinctive places of the environment (landmarks) as reference points and, thus, is called world-referenced.

Research in this area has shown that acquiring complete knowledge of unknown, big and complex areas is a dynamic process, which involves four distinct steps [5]:

1. Recognition of landmarks: Objects may constitute landmarks for two reasons a) for their distinguishing characteristics, and b) due to their individual significance [6]. Objects can be distinguishable because of their architectural style, size, or color [7]. Moreover, objects can become significant landmarks whenever they provide navigational information (e.g., when they are positioned at a crossroad or junction, at big interior halls that connect different corridors, etc.).

2. Correlation of routes or connections with landmarks: Routes and connections are formed while navigating between two landmarks. Acquiring route knowledge is highly correlated with the process of recognizing landmarks, which can be recalled with the same cognitive mechanism that is used to recall a route at a future time. This step is the cognitive procedure of matching routes with landmarks.

3. Primary Survey Knowledge: This type of knowledge is acquired after a thorough survey and exploration of the navigation environment. When acquired, it provides the means to calculate different routes and to estimate the distance between landmarks.

4. Area–Route Segmentation: This step provides the mechanisms to decompose a huge area to smaller segments/regions. Such smaller regions are parts of bigger regions, which in turn form other bigger ones and so on. This "segmentation procedure" enables the individual to mentally focus on regions relevant to its navigation task, to discover relations between different spaces, and, thus, by minimizing the amount of information to be processed optimizes the navigating performance of an individual.

2.2 Navigation-oriented User Modeling

According to the previously presented theoretical findings, a navigation-oriented User Profile (UP) is based on attributes from the following categories/components (see Figure 1):

1. General User Demographics: This category captures all the basic user information such as name (required only for user identification and profile indexing, thus it can simply be a nickname), age, gender, as well as a series of optional information, e.g., communication details, etc. (if required by the application for billing, statistical or other reasons).

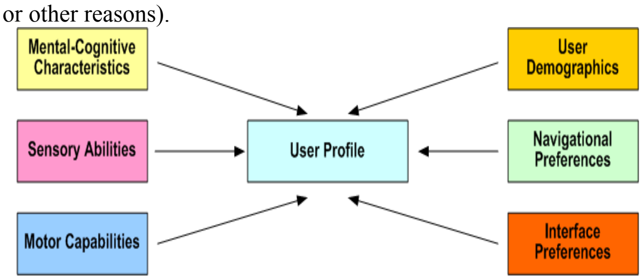

Figure 1. Components of a navigation-oriented User Profile

2. Mental/Cognitive Characteristics: this category captures all information considering user's mental/cognitive abilities as follows:

i. *Consciousness functions*: in this Boolean attribute the system captures the existence of possible malfunctions in the user consciousness abilities. Such abilities correspond to general mental functions which control user's state of awareness and alertness.

ii. *Orientation disability*: This Boolean attribute captures user's orientation ability, which corresponds to knowing and ascertaining her relation to oneself, to others, to time and to the surrounding environment. This ability describes the cognitive abilities that an individual must possess in order to be able to navigate in a geographical space. Hence, potential malfunctions in this ability significantly hinder the navigation procedure.

iii. *Mental disabilities*: This Boolean attribute holds true if the user has disabilities considering her mental functions (mental impairment, Alzheimer disease, etc.).

iv. *Mental functions considering user's behavior and personality*: In this subcategory the system captures behavioral and personality characteristics such as introversion–extroversion, social abilities, psychic and emotional stability. These characteristics differentiate one person from another and this knowledge is used for the personalization of the routing instructions. As discussed in [9], such information affects the way that an individual comprehends and follows routing instructions.

v. *Concentration to an objective*: The World Health Organization defines this mental function as "*the mental ability of an individual to remain focused on an external stimuli or an internal experience for a certain period of time*". Difficulty on this function is more often met in elderly people, teenagers and children.

vi. *High level cognitive functions*: this category considers difficulties in high level cognitive functions, such as decision making, planning and execution of actions and plans, degradation of memory functions, etc. Potential malfunction of any of these cognitive functions may lead to difficulties for the users to understand and execute complex instructions in a timely manner. Therefore, a navigation system should be able to correspond to such information by selecting proper paths and customizing the routing instructions in a way suitable for a user suffering from such impairments.

3. User's Sensory Abilities: Sensory impairments affect the way a user exploits her sensing abilities (especially viewing and hearing) during wayfinding. This category is further divided to two subcategories: visual and audile abilities. The visual abilities of users can be categorized using the following main criteria:

i. Visual Sharpness: A: perfect, -B: good, -C: medium, -D: bad.

ii. Visual Quality: Impairment in this ability affects the way an individual perceives light, color, texture, contrast and, in general, the quality of user's vision. Possible quality values are – A: perfect, -B: good, -C: medium, -D: bad.

The audile abilities of users are divided in four categories – A: perfect, -B: good, -C: medium, -D: bad, (where A means that the user has full hearing ability and D that she cannot hear at all).

4. User's Motor Abilities: This category captures a user's ability to move from one place to another with respect to the way she controls and coordinates her movement. Motor abilities refer to all kinetic abilities of users and not only to those associated to their mobility, although the latter are more important from the perspective of navigation. Users are categorized as having:

i. Autonomous mobility without assistive devices

ii. Mobility supported by an escort (with or without assistive devices).

iii. Autonomous mobility with wheelchair.

iv. Autonomous mobility with assistive devices (other than wheelchair)

Note that the user profile of a user supported by an escort should be the profile of the escort, since the latter is responsible for the navigation of the disabled user.

5. Navigational Preferences: This category captures user's navigational preferences. Typical preferences are:

i. No specific preferences.

ii. Selection of the shortest route first.

iii. Selection of the fastest route first.

iv. Preference in most "popular" path elements (e.g., main corridors and stairs).

v. Avoidance of stairs.

vi. Avoidance of crowded areas (e.g., for blind users).

vii. Selection of the most/less popular path among all users.

viii. Existence of landmarks in computed paths.

ix. Dynamic tracking during navigation and provision of routing corrections.

6. Interface Preferences: This category captures user's preferences considering the means and the media in which user will receive routing instructions:

i. Type of user's device (e.g., PDA, mobile/smart phone, mobile computer, information kiosk).

ii. Modality of instructions' presentation:

a. Only textual information

b. Both textual and visual information

c. Only visual information

d. Both textual and audio information

e. Both visual and audio information

f. Only audio information.

2.3 Discussion

As it is obvious from the above categorization, a UP is defined as the set of the characteristics chosen by the user. Every UP attribute takes either a value from a category of values or a Boolean value (Yes/No or True/False). Additionally, some attributes may assume values from a closed set (e.g., good, bad, etc.).

Apart from the aforementioned components that affect navigation-oriented user modeling, special emphasis should be given to the factors *age* and *gender*, since many of the abovementioned human navigational and wayfinding capabilities are dependent on them [8][9]. Moreover, gender and age affect the way that routing guidelines should be presented to users [10][11]. For example, for male users in the age range 16-65 the most suitable way of providing routing instructions is by using descriptions in metric and geographic notations (e.g., "follow this route to the north for one kilometer, then turn towards north-east and drive for about two more kilometers"). On the other hand, for female users, irrespective of their age, the most suitable way for providing navigational instructions is by using landmarks (e.g., "follow this road until you arrive to the next church, then turn right until you arrive at a square, then you may find your destination at the upper part of the square"). For children and elderly people the most suitable way of providing routing instructions is by segmenting the path in many easy-to-remember segments, i.e., having at least one clearly distinguishing landmark.

The aforementioned age and gender categorization is also applicable to the user interface modality used for presentation of the routing instructions. Therefore, for males the best choice is audio instructions. On the other hand, for females the most efficient modality is visual representations of landmarks with textual or auditory instructions. For elderly and young people the visual representation of landmarks is the most effective approach, in combination with maps with arrows pointing at the desired destination.

3 A USER NAVIGATION ONTOLOGY

The model described in the previous section has to be specified in a suitable form (possibly Web-based) in order to be used in modern applications. Hence, we have decided to represent it through a Semantic Web ontology. For that purpose we have used the Web Ontology Language (OWL) [12] for describing the user classes and their properties. Ontology-based systems are becoming more and more popular due to the inference and reasoning capabilities that ontological knowledge representation provides. Moreover, Semantic Web standards, and technologies in general, provide a solid basis for open and interoperable information systems.

For the development of the UNO ontology we followed the directives of ontology engineering that promote ontology reuse and alignment between existing ontologies. Specifically, during ontology development we have tried to extend some of the concepts specified in the GUMO ontology (see section "Related Work"). An extract of the UNO concept hierarchy is shown in Figure 2, while Figure 3 illustrates the basic UNO properties. Informal definitions of the top-level UNO concepts follow (the definitions of properties are regarded straightforward):

Ability: the super-class of the various abilities of a user with regard to the navigation procedure. A user may have many abilities. Disabilities may be defined through the use of the Quality class values (see below).

Demographics: value classes for user demographics (age, gender). Its subclasses are implemented as value partitions as dictated by the W3C Semantic Web Best Practices Group [18].

Quality: another class representing a value set for describing the degree/quality of the various abilities. Its values are {bad, medium, good, perfect}. A bad quality value for an ability denotes a disability.

User: an abstract class that subsumes the more specific defined user classes.

The main difference between UNO and GUMO, apart from their scope, is that UNO is used actively in inference procedures, while GUMO provides a core knowledge base (i.e., taxonomy and assertions of individuals) for basic classification of users and their characteristics. Hence, a key feature of UNO lies in the formal definition (through restrictions, and necessary and sufficient conditions) of user classes. In the current version of UNO we have included a minimal set with some possible classes. Each specific navigation application should extend this set appropriately. The use of the OWL-DL language enables very expressive user definitions. Indicative definitions (in mixed OWL and first-order-logic-like notation, for readers unfamiliar with Description Logics notation) of such *defined concepts* are:

YoungWheelchairedUser ↔
∃ hasAbility AutonomousWheelchairedMobility ∧
∃ hasAge LessThan18

VisuallyImpairedMaleAdultUser ↔
∃ hasAbility (AbilityToSee ∧ hasValue(hasQuality, bad)) ∧
∃ hasAge Between18and60 ∧ hasValue(hasGender, male)

(Note: *hasValue* is a reserved OWL term)

After performing reasoning on an ontology with such defined user classes, these will be classified under the generic User class and the various user instances will be classified accordingly.

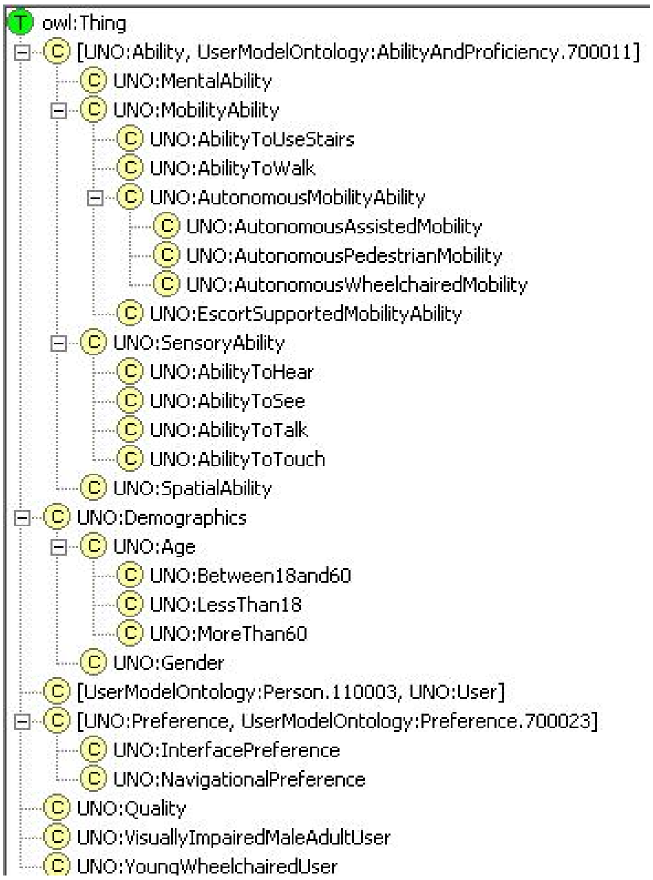

Figure 2. The basic UNO taxonomy (the prefix *UNO* denotes a UNO class, while *UserModelOntology* denotes a GUMO class)

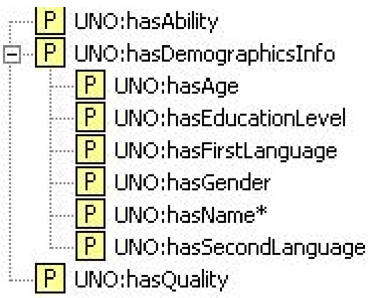

Figure 3. The basic UNO hierarchy of properties

Regarding alignment with GUMO, some UNO classes are declared as equivalent to GUMO classes (e.g., Preference). Moreover, some individuals of GUMO have been transformed to primitive classes in UNO (e.g., individual AbilityToTalk of GUMO class AbilityAndProficiency has been asserted as class AbilityToTalk in UNO). Regarding demographics information, we have modeled some relevant GUMO instances as binary properties, since otherwise we would have to create a different instance of such information for each separate user. The aforementioned transformations (instances to classes and instances to binary relations) have been performed in order to enable more complex concept expressions for describing user class. Finally, we should note that there are GUMO classes that have not incorporated/aligned to the current version of UNO, although they are relevant to the domain of navigation. For example, the class Motion could be used for supporting dynamic tracking and route corrections and the class PhysicalEnvironment could support the context-aware adaptation of navigation instructions (e.g., high noise level could trigger increase in the volume level of audio instructions).

4 OntoNav: A HUMAN-CENTERED INDOOR NAVIGATION SYSTEM

In this section we describe how the aforementioned UNO ontology is incorporated in an indoor navigation system called OntoNav. Note that in the description of OntoNav we focus on issues that assist the reader in understanding how UNO affects the navigation procedure. More details on OntoNav design and implementation can be found in [13][14].

OntoNav, is an integrated indoor navigation system, which is based on a hybrid modeling (i.e., both geometric and semantic) of such environments. OntoNav is purely user-centric in the sense that both the navigation paths and the guidelines that describe them are provided to the users according to their physical and perceptual capabilities as well as their particular routing preferences. For the description of path elements (e.g., corridors, junctions, stairways) an *Indoor Navigation Ontology* (INO) has been developed. The instances of such ontology are created by annotated GIS building blueprints. In order to compute the candidate paths for a specific user request, a dual graph representation of the ontology is also created (*topology graph*). The main OntoNav components along with the main workflow are shown in Figure 4.

The basic functionality of OntoNav can be summarized in the following steps:

1. Creation of a User Profile (if the user is unknown to the system, retrieval of a cached one else). In terms of ontological knowledge management, UP creation is the process of asserting UNO (concept and property) instances about the user, her abilities and demographics.
2. Invocation of the Navigation service where the desired destination is given as input to the system.
3. Creation of a user-compatible topology graph (i.e., that can be traversed by the user). This task is performed by applying production rules to the UP information (UNO instances) and the path elements semantics (INO instances).
4. Computation of the k-Shortest Paths between origin and destination locations in this graph.
5. Ranking of these paths according to additional UP information and selection of the "best" path for the specific user along with the most appropriate instructions for this path.

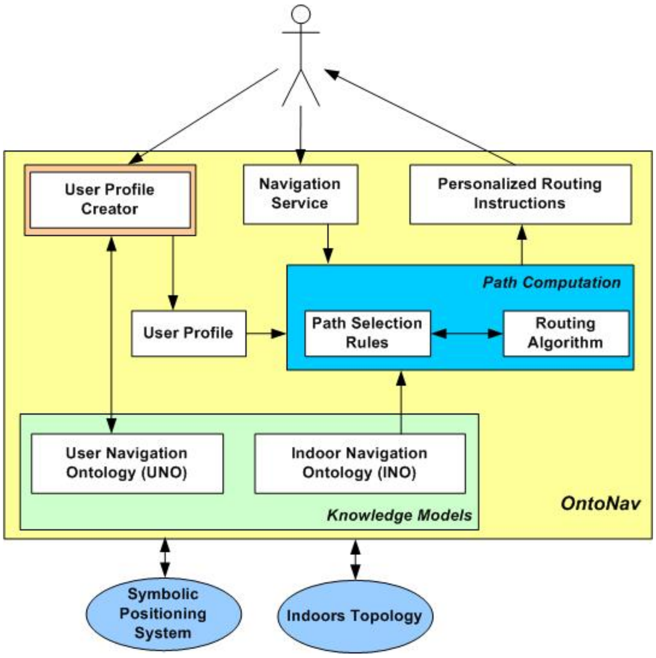

Figure 4. OntoNav architecture and basic workflow

The path-selection process (steps 3 and 5) is performed through sets of production rules. The definition of such rules involves both the spatial semantics (expressed through INO) and the user semantics (expressed through UNO). The rules are applied to the INO instances in order to infer and assert which paths are considered accessible and appropriate for each user request. Such path-selection rules are further analyzed to *physical navigation rules*, *perceptual navigation rules* and *navigation preferences*. The physical navigation rules are applied first (step 3), in order to discard any paths that are not physically accessible by the user. The perceptual navigation rules depend on the user's cognitive/mental status, demographics (e.g., age, education) as well as sensory abilities. Finally, paths that match the user preferences (e.g., paths containing elevators) are identified with the application of the navigation preference rules. The rules are described through the Semantic Web Rule Language-SWRL [15]. Some indicative rules are the following (the UNO user classes used in these rules are hypothetical and their definitions are analogous to those presented in Section 3):

Rule 1 (Physical Navigation Rule)

UNO:HandicappedUser(u) $\wedge$ INO:Stairway(s) $\rightarrow$
INO:isExcludedFor(s,u)

Rule 2 (Perceptual Navigation Rule).

UNO:BlindUser(u) $\wedge$ INO:hasDescription(pass,descr) $\wedge$
INO:Textual_Description(descr) $\rightarrow$
INO:hasPerceptualPenaltyFor(pass,u)

Rule 3 (Navigation Preference).

UNO:LazyUser $\wedge$ INO:Motor_Passage(p) $\rightarrow$
INO:hasPreferentialBonusFor(p, u)

As one can observe, some of these rules "mark" the path elements that should be excluded from the user-compatible topology graph (through the isExcludedFor property), while others reward/penalize some path elements (through the properties hasPreferentialBonusFor, hasPerceptualPenaltyFor, etc.). The final ranking of the

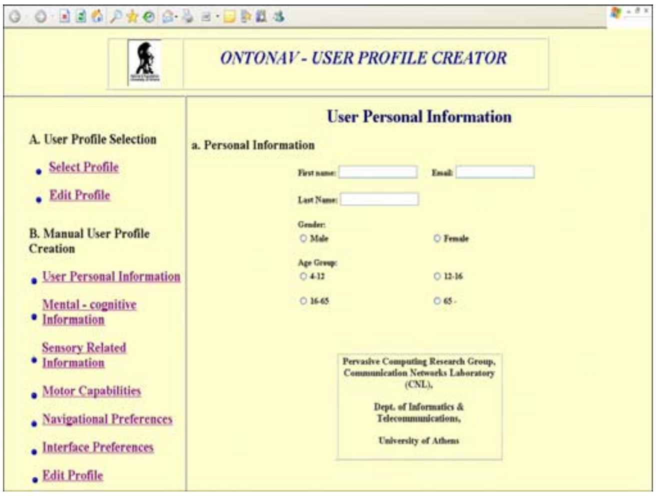

Figure 5. Screenshot of the User Profile Creator

traversable paths (step 5) is based on such bonus/penalty assertions and on the path length, which always remains a key selection criterion.

4.1 User Profile Management in OntoNav

A key component of the OntoNav architecture, with respect to user modeling, is the User Profile Creator (UPC). This component provides users with an interface that enables them to create their UP according to the UNO terminology (see Figure 5). The first time a user invokes the system's interface, she has the option to choose a profile from a set of predefined UPs. Currently there are four general types of UPs representing:

a. users without disabilities,
b. users with motor disabilities,
c. users with hearing disabilities, and
d. users with visual disabilities

The user can even choose a combination of the latter three UP types and subsequently customize such predefined profile accordingly. Alternatively, she may create a custom profile by providing all the indispensable information that can describe her physical and cognitive status, as well as her navigational and interface preferences. Moreover, the UP is completely dynamic; the user may view, alter, update, or delete part or all of her profile if necessary.

The OntoNav architecture also specifies a navigation supporting component called Navigation-Aiding Module (NAM) (see Figure 6 and refer to [13] for more details). Its primary task is to detect deviations from the initially planned path and help users return to it or find a new more suitable one. Since NAM continuously tracks the users' navigational behavior (in terms of spatiotemporal changes) it could be exploited as a means of inferring or "calibrating" (i.e., correcting) some UP elements. Inference of UP elements is a hot topic in UP creation since users are not always willing to explicitly describe their profile. Moreover, they are often reluctant to reveal any disabilities they may have. Hence, an unobtrusive monitoring systems, such as NAM, could facilitate seamless UP creation. Such functionality would involve sophisticated pattern matching algorithms (UP Inference and Calibration component in Figure 6) This component, currently under development, tries to infer user characteristics from the trajectories she follows during navigation and her navigation-relevant history (user movement statistics). However, such inference demands accurate indoor positioning systems which are not widely available and deployed yet.

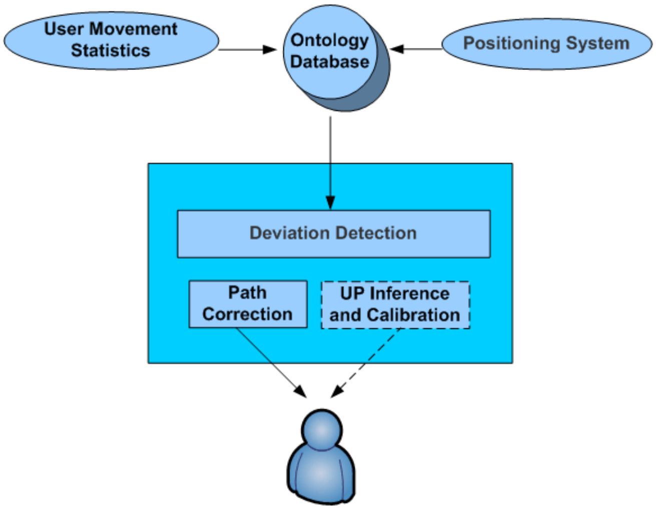

Figure 6. The Navigation Aiding Module

5 RELATED WORK

To our knowledge there is no other user model for describing user characteristics from the perspective of navigation. On the other hand, there are some generic, user modeling efforts that try to cover a wide range of application domains and to adopt open technologies for enabling interoperability between systems. The most relevant work of this category is the General User Model Ontology (GUMO) [16]. GUMO has means of representing several "user dimensions" such as user demographics, user abilities, user emotional and psychological status, etc. In addition, it supports the specification of some auxiliary information such as the preferences, interests, and knowledge of the users. The main advantage of GUMO is that it is implemented in OWL, which has become very popular in the Semantic Web [12] community. This language not only provides a well-defined syntax for user models but is also capable of describing the semantics that are implied by a model. As already mentioned, we have tried to align UNO with GUMO by reusing and extending all suitable concepts and attributes.

GUMO has been partially influenced by the UserML language [17]. UserML's objective was to provide a commonly accepted syntax, based on the XML standard, for representing user models in Web applications. UserML is quite generic and, thus, can be used as a syntax layer for any semantic user model.

6 CONCLUSION AND FUTURE WORK

In this paper we have presented some background knowledge on navigation theory from various disciplines (e.g., psychology, physiology), which directly affects any navigation-oriented user model. Furthermore, we have taken into consideration these theoretical implications in order to construct a user ontology. Finally, we have shown how such ontology is instantiated and actively involved in the navigation procedure of the OntoNav system through inference rules.

However, several issues remain open for further research in this area. One of the most interesting and important issues is the (semi-) automatic user model creation. Specification of rules that represent dependencies between model entities (derived from relevant theories) seem to be a promising solution, although hard to implement. For example, the ability of a user to concentrate on an objective may be automatically inferred by her age. Another challenging issue, and "common" with respect to user profiles, is privacy protection (since UNO describes also personal information such as health/physical/mental status). Finally, as UNO is still under development, we have not taken into consideration all the UP components identified in Section 2.2, since some of them are difficult to capture (e.g., mental/cognitive characteristics).

ACKNOWLEDGEMENT

This work was performed in the context of the "PENED" Programme, co-funded by the European Union and the Hellenic Ministry of Development, General Secretariat for Research and Technology (research grant 03ED173).

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