An Ontological Cognitive User Model For Adapting Generic Web Structures

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Abstract

Adaptation and Personalization systems can benefit with the incorporation of ontological knowledge, especially when it comes to modeling users. In this paper we present a cognitive approach to Web Personalization based on an ontology that contains users' cognitive factors. Accordingly, a human factors' ontology has been designed and developed using RDFa, and could be used in any Web-based application for returning an optimized adaptive result to the user. A commercial Website was filtered through an adaptive mechanism based on that ontology. This mechanism is described by a proposed set of RDFa objects for the imminent dynamic transformation and enhancement of the Web-based content. Consequently this describes the adaptation of user interfaces to the individualistic preferences and needs of users. The expected impact of the content reconstruction lies in the increase of users' satisfaction and efficiency of information processing, while users navigating in the personalized condition rather than the original one.

1. Introduction

The Web creates new challenges for personalized information presentation. The amount of information of the Web as well as the number of new users is growing rapidly. Because of the phenomenal growth of the Web, navigating through information consumes more time and it becomes a daunting task. There comes the need of personalization and adaptation mechanisms that aim to alleviate users' navigational difficulties and instead, satisfy the heterogeneous needs of the user population.

Today's most popular Websites (http://www.alexa.com/site/ds/top_500) like Google, Microsoft Live, Yahoo, Amazon, eBay, BBC news etc. primarily use customization techniques where users have direct control and explicitly select between certain options. In the same line, personalization is driven by the system which tries to serve up individualized pages to users according their profiles and needs. Although, personalization is used by many of these popular Websites (especially Google), the techniques they maintain are lying under the predetermined customization of services or products and not to the actual personalization and dynamic reconstruction of content based on user preferences. User preferences might be extended beyond the traditional characterizations of the user that might include intrinsic cognitive values that could be considered as the control factors for an efficient adaptation process.

Effective personalization improves content presentation and navigation by considering users' interests and preferences. Semantic profiles on the other hand attempt to augment and improve traditional adaptation mechanisms by using semantic information from resources like ontology.

This paper focuses towards modeling users' unique cognitive factors with an Ontological Cognitive User Model (OCUM) and a content ontology for the adaptation of an existing eCommerce Website based on OCUM.

In the remainder of the paper an adaptation paradigm of an existing commercial Website is presented. The Website's content was filtered through an adaptive mechanism based on OCUM. This mechanism is described by a proposed set of custom RDFa objects for the imminent dynamic transformation and enhancement of the Web-based content. An evaluation of the expected impact of the content reconstruction concludes the paper.

2. Theoretical Framework

Since the WWW is by definition a huge resource of information, it would make much sense that individuals' information processing characteristics should be taken into consideration. To that direction, our efforts are focused on improving the effectiveness of Websites by employing methods of personalization. As part of our previous research, it has been demonstrated that the incorporation of human information processing factors in eLearning environments leads to better comprehension on behalf of the users [8, 11].

The information processing parameters that we have used in the case of an eLearning environment, which had an actual effect on performance, comprise a comprehensive user model that includes the following three dimensions: Cognitive Style, Cognitive Processing Efficiency and Emotional Processing. The first dimension is unitary, whereas Cognitive Processing Efficiency is comprised of (a) Working Memory Span (WMS) [1] (b) speed and control of information processing and (c) visual attention [7]. The emotional aspect of the model focuses on different aspects of anxiety [3, 4, 9] and self-regulation.

Based on this experimental evaluation, our next step was to apply such individual differences theories in a context other than educational, namely the Web in general and the imminent hypertext/hypermedia content that is composed. From such a wide perspective that emphasizes on information processing and not strictly learning, the constructs of Cognitive Style and Working Memory Span were opted for as personalization parameters, considering that their effect in the case of our eLearning experiments was highly significant. Moreover, these factors address the issue of processing in a wider than the educational area, while the corresponding implications are viable for implementation on the Web.

Cognitive Style has been defined by Messick as consistent individual differences in preferred ways of organizing and processing information and experience, a construct that is different than learning style [13]. Cognitive styles represent an individual's typical or habitual mode of problem solving, thinking, perceiving or remembering, and "are considered to be trait-like, relatively stable characteristics of individuals, whereas learning strategies are more state-driven…" [12].

Riding and Cheema's Cognitive Style Analysis (CSA) has been used as a very representative theory of cognitive (not learning) style; additionally, the two independent scales of the CSA (Verbal/Imager and Wholist/Analyst) correspond ideally to the structure of hypertext environments. A personalized environment that is supported by an automated mechanism can be altered mainly at the levels of content selection and hypermedia structure; the content is essentially either visual or verbal (or auditory), while the manipulation of links can lead to a more analytic and segmented structure, or to a more holistic and cohesive environment. These are actually the differences in the preferences of individuals that belong to each dimension of the CSA scales [14].

The concept of Working Memory Span [2] also fits very well into our rationale of personalizing Websites on the basis of users' cognitive abilities and preferences. "The term working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" [1]; Baddeley also refers to individual differences in the working memory (digit) span of the population, thus providing a very good argument for using this concept as a personalization factor.

3. Ontological Cognitive Model

The proposed Ontological Cognitive User Model (OCUM) is based on the theoretical conceptualization of a comprehensive model in the field of Web personalization and adaptation, which integrates cognitive parameters and attempts to apply them on a Web-based environment. The particular cognitive concepts have already been proposed by the authors and positively evaluated in the information space [8].

Table 1. RDFa Instance of a User's OCUM

```
<div xmlns:v="http://www4.cs.ucy.ac.cy/
adaptiveWeb/rdf/#" typeof="v:Person">
  <div><span property="v:name">John
Smith</span>
      <span property="v:title">Managing
Director.</span>
      <span property="v:affiliation">AWeb
Solutions</span>
  </div>
  <div>Cognitive Style
      <span rel="v:imagerverbal">
Imager</span><br />
      <span
rel="v:wholistanalyst">Analyst</span>
  </div>
  <div>Working Memory
      <span rel="v:workingmemory">Low</span>
  </div></div>
```

An RDFa vocabulary has been designed based on the theoretical framework and can be found online (www4.cs.ucy.ac.cy/adaptiveWeb/rdf.xml).

This vocabulary (User Model) consists of a number of classes and properties which describe a user's profile. The main class of this vocabulary is Person that represents a living or fictional person. The Person class has the following basic properties: i) "name" property; the Person's name, ii) "title" property; the Person's title (i.e. Prof. or Managing Director), iii) "affiliation" property; the Person's affiliation. A Person class has also the following properties with regards its Cognitive Style parameters: i) “imagerverbal” property; the level of cognition of the Person regarding imager and verbal, ii) “wholistanalyst” property; the level of cognition of the Person regarding wholistic or analyst, and iii) “workingmemory” property; the Person’s working memory capacity.

In this respect, the Person class, for example, in the RDFa instance (Table 1) is the main entity. Specializations of the Person entity are the Cognitive Styles and the Working Memory entities.

Furthermore, there are three implicitly defined entities: the person's cognitive style, working memory capacity and his personal details.

4. Ontology Usage

In order to evaluate the framework’s performance as well as the impact of our model’s dimensions into the information space, we have designed and authored an experimental environment in the application field of eCommerce. The eCommerce (Web) environment that has been developed used the design and information (hypermedia) content of an existing commercial Website of Sony Style (www.sonystyle.com).

Table 2. RDFa Instance of a Content Object

```
<div xmlns:v="http://www4.cs.ucy.ac.cy/
adaptiveWeb/rdf/#" typeof="v:SmartObject">
  <span property="v:name">Sony</span>
  <span property="v:category">13'
Laptop</span>
  <span property="v:summary">2.5GHz CPU
Intel Core 2 Duo, 4GB RAM, 250GB HD</span>
  <div about="/sonyvaio/sz/memory">
    <span property="v:title">Memory
Information</span>
    <span property="v:content">4GB Memory
RAM, 250GB Hard Disk</span>
  </div>
  <div about="/sonyvaio/sz/cpu">
    <span property="v:title">CPU
Information</span>
    <span property="v:content">2.5GHz CPU
Intel Core 2 Duo</span>
  </div></div>
```

This Website provides products’ specifications of the Sony Company, and in general is very representative of the sites that we inspected in our high level analysis since it stands in between a serious layout and an aesthetically rich form of presentation. We have developed an exact replica of the Sony Vaio Notebooks section in sonystyle.com. Another RDFa vocabulary (www4.cs.ucy.ac.cy/adaptiveWeb/rdf.xml) has been designed that enables standard annotations in any XHTML Web-page, thus making structured data available for our framework’s adaptation process, but also for any service or tool that supports the same standard. Table 2 shows an instance of the RDFa content model.

This vocabulary (Content Model) vocabulary consists of a number of classes and properties which describe an adaptive object based on users’ cognitive styles. The main class of this vocabulary is SmartObject that represents an adaptive web object. This class has the following properties: i) “name” property; the concept’s name, ii) “category” property; the concept’s category, iii) “summary” property; the summary description of the concept, iv) “title” property; the title of the concept’s sub-element, and v) “content” property; the concept’s sub-element content. The “about” property (Table 2) is used by RDFa to distinguish different sub-elements of the concept.

Furthermore, a Web Browser (Mozilla Firefox) Extension has been developed in order for the browser to recognize and implement the extended content objects (SmartObject), and map them with the user’s OCUM instance (Table 1).

4.1 Mapping Process for Content Adaptation

Our main goal in this section is to show in a more detail how a Web browser should interpret the SmartObject of the RDFa schema and adapt the containing information based on the user’s OCUM and consequently the abovementioned cognitive factors. Based on Tables 1 and 2, the Web browser combines the user’s OCUM with the containing information of the SmartObject entity, adapting the content. The adaptation process involves the transformation and/or enhancement of a given raw Web-based hypertext content (provider’s original content) based on the impact the specific human factors have on the information space [8] (i.e., show a more diagrammatical representation of the content in case of an Imager user, as well as provide the user with extra navigation support tools). Figure 1 shows the possible Web-based hypertext content transformations / enhancements based on the mapping process that take place during adaptation process based on the influence of the human factors and the theory of individual differences.

Based on figure 1, the meta-characteristics of a user profile are deterministic (at most 3); Imager or Verbalizer, Analyst or Wholist and Working Memory level (considered only when low).

For a better understanding, a user that happens to be an Imager gets a diagrammatical representation of the containing information of the SmartObject entity. The "about" attribute is used by the Web browser to distinguish the logical meaning of a sentence when creating the diagrammatical representation. In other words, the "about" attribute is used for sub-elements of a SmartObject. As we will see furthermore, the "about" attribute is interpreted differently by the browser when the user types change. On the other hand, when a user is a Verbalizer (prefers text instead of diagrammatical representations), no changes are made to the containing content of SmartObject. Furthermore, if a user is an Analyst, the information will be enriched with a tabbed menu to be easier accessible. The menu will consist of the SmartObject's sub-elements. Each sub-element along with the "title" property (Table 2) is used in this case to create the tabbed menu with the title of each sub-element comprising an item of the menu.

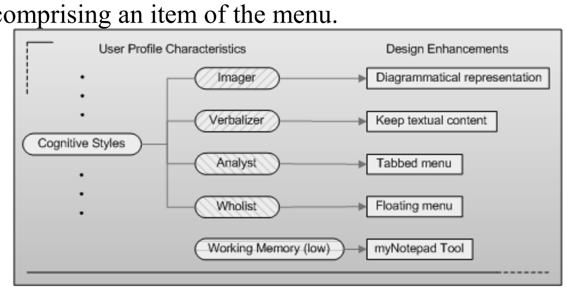

Figure 1. Hypertext Content Transformations

Each sub-element is added to the tabbed menu and is used as a dynamic link to the containing information of the particular entity. The same logic of transformation is used when mapping the SmartObject with a Wholist user. In this case, a dynamic floating menu with anchors is created so to guide the users on specific parts into the hypertext content while interacting. Again, the sub-elements comprise the menu's items.

Finally, when users happen to have a low working memory level, the browser will provide them with the "myNotepad" tool (temporary memory buffer) for storing a section (sub-element's content) of the page and keep active information that is interested in until the completion of a cognitive task at hand.

5. Evaluation

The following section describes the experimental design and the results that support the notion of personalization in generic Web-based hypertext environments.

5.1 Methodology

For the purposes of our research a within participants experiment was conducted, seeking out to explore if the personalized condition serves users better at finding information more accurately and fast. A pilot study that involved a between participants design demonstrated inconsistent effects, suggesting that a within subjects approach would yield more robust results.

The number of participants was 89; they all were students from the Universities of Cyprus and Athens and their age varied from 18 to 21, with a mean age of 19. They accessed the Web-based hypertext environments using personal computers located at the laboratories of both universities, divided in groups of approximately 12 participants. Each session lasted about 40 minutes; 20 minutes were required for the user-profiling process (real-time psychometric tests), while the remaining time was devoted to navigating in both hypertext environments, which were presented sequentially (as soon as they were done with the first environment, the second one was presented).

The hypertext content was about a series of Sony laptop computers: general description, technical specifications and additional information were available for each model. As stated in the introductory section, we considered that the original (raw) version of the environment was designed without any consideration towards cognitive style preferences, and the amount of information was so high and randomly allocated that could increase the possibility of cognitive overload. The personalized condition addressed these issues by introducing as personalization factors both cognitive style and working memory span.

The psychometric materials that were used are the following:

Cognitive Style: Riding's Cognitive Style Analysis, standardized in Greek and implemented in the .NET platform. The test is separated in three parts: the first part assesses the Imager/Verbalizer dimension by calculating the time required for participants to construct mental representations of 24 given sentences. In the following two phases, the time that users devote to integrate or disambiguate two sets of figures indicates their position on the Analyst/Wholist axis.

Working Memory Span: Visuospatial working memory test [5, 6, 7], firstly developed at the E-prime platform, afterwards implemented in the .NET platform. This visual memory test examines participants' ability to temporarily store visual figures. Each figure that has to be remembered is shown for two seconds, and afterwards a set of five figures is presented, including the one that had to be stored. Users are asked to identify the figure that was shown before. Complexity and resemblance of the stimuli increases gradually.

In each condition, users were asked to fulfill three tasks: they actually had to find the necessary information to answer three sequential multiple choice questions that were given to them while navigating. All six questions (three per condition) were about determining which laptop excelled with respect to the prerequisites that were set by each question. There was certainly only one correct answer that was possible to be found relatively easy, in the sense that users were not required to have hardware related knowledge or understanding.

As soon as users finished answering all questions in both conditions, they were presented with a comparative satisfaction questionnaire; users were asked to choose which hypertext environment was better (1-5 scale, where 1 means strong preference for environment A and 5 for environment B), regarding usability and user friendliness factors.

The dependent variables that were considered as indicators of differences between the two hypertext environments were: 1) Task accuracy (number of correct answers), 2) Task completion time, 3) User satisfaction

At this point a few clarifications about the methodology are necessary: a) Users did not know which the personalized condition was, nor were they encouraged to use any additional features, b) To avoid training effects, half of the users received the raw condition first (considered as environment A), whilst the other half started the procedure with the personalized (again considered as environment A), c) To avoid a possible effect of differences in difficulty of each set of three questions, they were alternated in both environments. Due to a design error, the division was not in half, but 53 participants received the first combination and 36 the alternated. However there was not observed any effect; all questions were proven of equal difficulty- to the extent that this is possible of course.

The within participants design, finally, allowed the control of differences and confiding variables amongst users.

5.2 Design Implications

In this Web-based (hypermedia) setting, there are some considerations in the way our selected cognitive factors were implemented in the eCommerce environment, which have to be discussed.

Users with low WMS received a “myNotepad” tool that allowed them to make entries of goal-related information; this tool was meant to serve as an additional buffer for participants with low memory span, alleviating disorientation and cognitive load caused by the high amount of information included in the original hypertext environment. Users were able to add in this notepad the link and a general description of the section they are visiting, allowing them to code large amounts of information. This approach has of course to be further evaluated with working memory-specific experiments, since there is much depth in the role of working memory and corresponding strategies.

5.3 Results

The most robust and interesting finding was the fact that users in the personalized condition were more accurate in providing the correct answer for each task. The same user in the raw condition had a mean of 1 correct answer, while in the personalized condition the mean rose to 1.9.

Since the distribution was not normal and the paired samples t-test assumptions were not met, Wilcoxon Signed Ranks Test was performed, showing that this difference is statistically significant at zero level of confidence ($Z= -4.755$, $p=0.000$). This is probably a very encouraging finding, implying that personalization on the basis of these factors (cognitive style and WMS) benefits users within an eCommerce environment, as long as there are some cognitive functions involved of course (such as information seeking).

Equally interesting is the fact that users in the personalized condition were significantly faster at task completion. The mean aggregated time of answering all three questions was 541 seconds in the raw condition, and 412 in the personalized. A paired samples t-test was performed ($t(88)=4.668$, $p=0.000$) demonstrating significance at zero level of confidence. Again, this second dependent variable (time) shows that the personalized hypertext environment is more efficient.

As it concerns the satisfaction questionnaire, 23 users leaned towards the personalized environment, 17 had no preference while 13 preferred the raw. This descriptive statistic is merely indicative of whether participants would consciously observe any positive or negative effects of the personalized condition.

A considerable percentage leaned towards that condition (or at least users did not seem somehow annoyed by such a restructuring), but overall it cannot be supported that they were fully aware of their increase in performance, as shown by the abovementioned findings.

In sum, the specific experiment shows in a rather clear way that users performed better within the personalized environment, and these findings are statistically very robust. It could be argued of course that there is no way to be fully aware if information processing was more efficient at a deeper level, or users simply found the personalized condition more of their (perhaps unconscious) liking, thus devoting more conscious cognitive effort.

Nevertheless, such an increase in performance, which is consistent to the findings of previously conducted experiments in the field of eLearning, provides support for the further development and application of our theoretical model in different Web-based hypertext / hypermedia environments.

6. Conclusions

The basic objective of this research paper was to introduce a cognitive approach to Web Personalization based on an ontology that contains users' cognitive factors. Accordingly, a human factors' ontology has been designed and developed using RDFa, and could be used in any Web-based application for returning an optimized adaptive result to the user. Their specific influence and the Web design enhancements and hypertext content transformations have been described and positively evaluated in the eCommerce domain.

It was clearly demonstrated that users' information finding was more accurate and efficient, both in terms of providing correct answers to the task questions and in task completion time. These findings reveal that our approach turned out to be initially successful, with a significant impact of human factors in the personalization and adaptation procedure of Web-based hypertext and hypermedia environments.

Even though the evaluation of the OCUM concept in the eCommerce domain is really encouraging for the validity and integrity of the relation within and between these cognitive dimensions and their effective impact in the information space, this ontology can only be considered as a proposal. Main goal is to initiate and drive this research to a concrete human factors ontology that can be used in any hypertext computer-mediated system enhancing one-to-one services delivery based on an efficient user-centric dynamic content reconstruction (adaptation).

Finally, even if the Sony site is quite a representative Website of how information is distributed in the Web, further testing on various types of Websites is required in order to establish a rigid connection between human factors and information processing in Web-based hypertext / hypermedia environments.

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