Supporting Adaptive Interactive Systems with Semantic Markups and Human Factors

Marios Belk, Panagiotis Germanakos, Efi Papatheocharous, Marios Constantinides, George Samaras
Department of Computer Science, University of Cyprus, Nicosia, Cyprus
{belk, pgerman, efi.papatheocharous, mconst02, cssamara}@cs.ucy.ac.cy

Abstract

This paper focuses on adapting Web environments based on cognitive factors of users. In particular, a semantic Web-based adaptation framework is proposed that enables authors to enrich Web content with semantic markups, which are further processed and reconstructed by an adaptation mechanism based on cognitive factors of users. With the aim to study the effect of cognitive factors on the adaptation of Web content, a user study has been conducted with 37 participants providing interesting insights with respect to the effect of adaptation in terms of user satisfaction while interacting with an adapted and a non-adapted version of the same Web environment.

1. Introduction

Adaptive interactive systems [1] have gained popularity since the mid-90s due to the exponential increase of content and users of the World Wide Web. Although researchers and practitioners of adaptive interactive systems come from different disciplines, like user modeling, information retrieval, Web-based education, and many more, they all share a common goal; to improve the usability of the system and provide a positive user experience by personalizing content and functionality according to the users' intrinsic characteristics and preferences.

Considering the main functionalities of adaptive interactive systems [1], effective personalization of Web content involves an important challenge; to model any hypermedia content in a way that would enable efficient and effective navigation and presentation as a result of the adaptation process. In a more technical view, the challenge is to study and design structures of meta-data (i.e., semantics) at the Web content author's side, aiming to construct a Web-based adaptation mechanism that will serve as an automatic filter, adapting the distributed Web content based on the user models. Semantic markup contributes to the whole adaptation process with machine-understandable representation of Web content. In this context, machine-understandable data can be incorporated into the design of Web environments to inform the adaptation mechanism of the intention of specific sections and accordingly adapt them based on the user models and adaptation rules.

The work presented in this paper lies on previous research [2] that proposed a human factor and Web content ontology, designed and developed with RDFa that was utilized in a Web environment for returning an optimized adaptive result to users. The proposed ontology was embedded in an adaptive interactive system by annotating Web content with semantic information that was further adapted based on the cognitive characteristics of users. The main outcome from the work conducted has shown that the adapted version of a Web environment based on the users' cognitive characteristics, and proposed ontology, has increased their satisfaction, task accuracy and performance.

Follow up work of the authors is to support the semantic content creation process with a Web authoring tool that is part of a complete adaptation framework, as well as increase our understanding in respect to the impact of human factors in the adaptation process of Web environments. While the work in [2] utilized predefined environments to provide the adaptation effects based on cognitive characteristics of users, main aim of this work is to assist the whole adaptation process with a dynamic adaptation mechanism that will support Web authors throughout the content creation, and dynamically reconstruct content based on the users' cognitive characteristics. Furthermore, as in [2], the overarching objective of both works is to study the effect of adapting content and functionality of Web environments based on cognitive factors of users.

The paper is organized as follows: In Section 2, we provide related work in semantic-based annotation approaches as well as content authoring tools in the context of adaptive interactive systems. Section 3 presents the proposed semantic-based adaptation framework which is further evaluated with a user study in Section 4. Consequently, we conclude the paper in Section 5 with a discussion on the results and future prospects of our work.

2. Related Work

Apart from studying various user modeling and adaptation mechanisms, in order to build an adaptive interactive system, it is also necessary to study and design the structure of semantics [3]. In this context, we suggest that we should investigate the incorporation of cognitive characteristics, with the aim to feed the adaptation mechanism with semantically enriched, machine-understandable information in order to adapt the Web content based on the user models.

The Semantic Web initiative [4] is focusing on the creation of technologies and languages, and use of rich ontologies that can capture a wide variety of relationship types that will facilitate machines to understand the meaning of information on the World Wide Web. These ontologies are modeled using ontology representation languages such as the Extensible Markup Language (XML), the Resource Description Framework (RDF), or the Web Ontology Language (OWL) [3].

Various ontology-based annotation approaches for producing semantic markups have been proposed in the literature. One such system is OntoSeek [5], which uses simple conceptual graphs to represent queries and resource descriptions for content-based information retrieval. Another popular system is SHOE [6] that uses a set of Simple HTML Ontology Extensions enabling Web content authors to annotate their Web-pages with semantics expressed in terms of ontologies. SemTag [7] is an application that performs automated semantic tagging of large corpora. Protégé-2000 [8] is a tool for ontology development and knowledge acquisition that can be adapted for editing models in different Semantic Web languages. Annotea [9] is a Web-based shared annotation system, based on a general-purpose open RDF infrastructure that provides a simple infrastructure for associating annotations with Web documents. Google's search engine also supports enhanced searching in Web-pages, by using RDFa embedded in XHTML [10] with the aim to improve the way specific search results are presented to users.

In this context, ontology-based annotations could assist the adaptation process by enabling Web content authors to semantically annotate Web content that will be further fed to an adaptation mechanism in order to understand and effectively communicate the semantic content in an adaptive format to the user interface. Furthermore, it is important to assist the Web content author, with novice level of knowledge regarding Web content creation, with an easy-to-use tool to create semantically enriched Web content that will be further transparently included in an adaptation mechanism.

Authoring tools in the context of adaptive interactive systems have been proposed in the past as part of adaptive educational systems. Chang et al. [11] proposed a learning content adaptation tool that assisted authors to adjust predefined Web templates for specific handheld devices of users. Another work [12] aimed to support educators throughout the authoring process of educationally meaningful content for personalized learning. Finally, a more recent example includes the Mobile E-learning Authoring Tool [13], an authoring tool that produces adaptive learning content and assessment material for mobile devices.

The work presented in this paper is different from the aforementioned authoring tools in that it is not focused on educational environments but addresses generic Web environments. In particular, the tool that is presented assists Web content authors to create semantic markups in Web-pages for supporting the adaptation process based on cognitive characteristics of users. To the best of the authors' knowledge this is among the first attempts to propose a complete semantic Web-based adaptation framework that assists both content providers with semantic content creation, as well as users by providing adapted content and functionality to their cognitive characteristics based on an effective adaptation mechanism.

3. Semantic Web Adaptation Framework

In this section we describe a semantic Web-based adaptation framework (Figure 1) with the aim to provide adapted content and functionality of Web environments based on user models which include cognitive factors. The framework consists of the following interconnected layers: i) *User Modeling*, for extracting the cognitive characteristics of users, ii) *Semantic Authoring Tool*, for the creation of semantically-enriched, machine-understandable content, iii) *Adaptation Mechanism*, that performs various adaptation rules obtained by experts and which are based on the user models and the semantically-enriched content, and iv) *Adaptive User Interface*, that presents the Web content in an adapted format and through adapted navigation controls based on the users' cognitive characteristics.

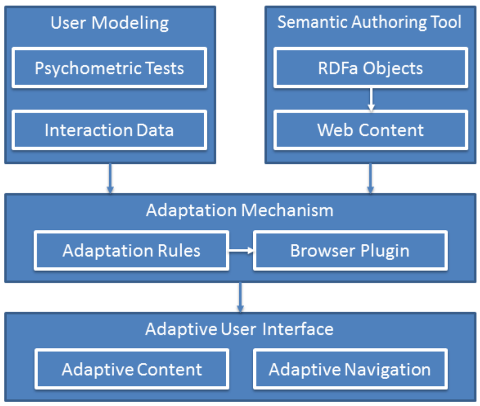

Figure 1. Semantic Web Adaptation Framework

3.1. User Modeling

For user modeling a series of psychometric tests are used to highlight differences in the cognitive characteristics of users, in combination with a specific clustering technique (*k*-means clustering) that analyzes the interaction data of users and groups users based on similar navigation behavior [14].

Among the popular theories of individual styles proposed [15][16][17], the current work utilizes Riding's Cognitive Style Analysis (CSA) [15] that classifies users based on how they process information (i.e., verbally or non-verbally), and how they organize information (i.e., holistically or analytically), and Baddeley's Working Memory Span (WMS) [17] that refers to a brain system that provides temporary storage and manipulation of information necessary during cognitive tasks.

3.2. Semantic Authoring Tool

The semantic authoring tool supports the creation process of adaptive Web content with semantic markups (Figure 2). The development has been based on Wordpress[1], which is a widely used Content Management System on the World Wide Web. In particular, a customized version of Wordpress has been developed and extended to enable the creation process of Web content with specific RDFa tags. The RDFa standard has been used in this work since it easily integrates machine-understandable information into the current Web-page paradigm and workflow [18].

[1] Wordpress Statistics, http://wordpress.com/stats

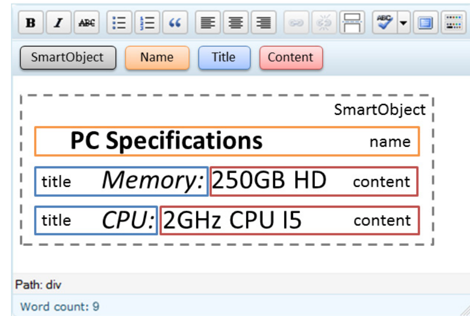

Figure 2. Semantic Web Authoring Tool

An RDFa schema[2] has been designed for that purpose to enable standard annotations in an XHTML Web-page, thus making structured data available for our framework's adaptation mechanism, but also for any service or tool that supports the same standard. Table 1 shows an instance of the RDFa content model.

Table 1. RDFa Instance of a Web Object

```
<div xmlns:v="http://adaptiveweb.cs.ucy.ac.cy/rdf/#"
typeof="v:SmartObject">
    <span property="v: name">PC Specifications</span>
    <div property="v:element">
        <span property="v:title">Memory</span>
        <span property="v:content">250GB HD</span>
    </div>
    <div property="v:element">
        <span property="v:title">CPU</span>
        <span property="v:content">2GHz CPU I5</span>
    </div>
</div>
```

The RDFa instance in Table 1 consists of a number of classes and properties which describe an adaptive Web object. The main class of the RDFa vocabulary is *SmartObject* representing an adaptive Web object. This class has the following properties: i) *name*, the concept's name, ii) *element*, the element of a concept, iii) *title*, the title of the concept's element, and iv) *content*, the content of the concept's element.

3.3. Adaptation Mechanism

The adaptation mechanism is responsible for adapting the RDFa objects that are generated by the semantic authoring tool based on the cognitive characteristics of the user models, which are obtained from the user modeling mechanism. A Web browser extension has been developed in order for the Web browser to recognize and process the RDFa objects. A fuzzy rule-based mechanism [19] is further utilized on

[2] smartag Schema, http://adaptiveweb.cs.ucy.ac.cy/resources/rdf.xml

the RDFa objects to provide the adaptation effects based on the users' cognitive characteristics. Main goal of this section is to show in more detail how the Web browser interprets the *SmartObject* of the RDFa schema and adapts its containing information.

The adaptation process involves the transformation and/or enhancement of a given Web-based content (Web author's original content) based on the impact specific human factors have on the information space [2] (i.e., present content in a diagrammatical representation in case of an Imager user, as well as provide the user with extra navigation support tools).

The personalization process consists of 3 main phases; a) the Web content author first creates Web objects with semantic markups utilizing the semantic authoring tool, b) the browser plugin parses the generated XHTML documents, extracts the semantic markups and further applies specific adaptation rules based on the user models, and c) accordingly communicates the adaptation effects on the users' interfaces, presented in the next section.

3.4. Adaptive User Interface

The instances of a user model are deterministic (at most 3); Imager or Verbalizer, Analyst or Wholist and Working Memory level (i.e., low, medium, high). Figure 3 illustrates two example adaptation effects based on the RDFa instance of Table 1.

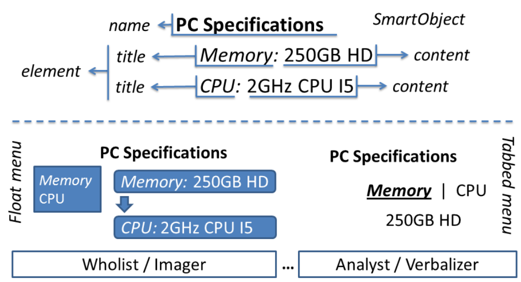

Figure 3. Adaptation Effects of the RDFa Instance

In particular, in the case a user belongs to the Imager class, a diagrammatical representation of the containing information of *SmartObject* is presented. The *element* property is used by the Web browser to distinguish the items (elements) of a *SmartObject* when creating a diagrammatical representation (e.g., Memory and CPU are two elements of the *SmartObject* instance in Table 1). On the other hand, when a user belongs to the Verbalizer class (prefers verbal representations), no changes are made to the elements of *SmartObject*. Furthermore, in case a user belongs to the Analyst class, the information will be enriched with a tabbed menu to arrange information in a manner that is closer to the analytic way of information organization. In particular, each item of the tabbed menu will consist of the *title* property of each *SmartObject* element. This way, each item of the menu is linked to the *content* property of a particular element. 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 of the Web content while interacting. Again, the *title* property of the elements comprise the menu's items, linked to the *content* property of each element.

Finally, in case users have low Working Memory level, the browser will provide them with a supportive tool for storing a section (element's *title* and *content* property) that the user is interested in until the completion of a cognitive task (i.e., "remember the specifications of a computer").

4. User Study

The aforementioned adaptation framework has been evaluated through a user study to investigate the effect of adaptation in Web environments.

4.1. Method

The study was carried out during the month of March 2012. The sample included 37 Computer Science students of age between 22 and 25 that voluntarily participated in the study. All users accessed a Web-site that was designed for the purpose of the study using personal computers located at the laboratories of the University. Each session lasted about 30 minutes; 15 minutes were required for the user modeling process, while the remaining time was devoted to navigate in a commercial Web-site and evaluate their experiences through a questionnaire.

During the user modeling process, students provided their demographic characteristics (i.e., name, age, education level, etc.) and performed a number of interactive tests utilizing cognitive processing psychometric tools in order to quantify their cognitive characteristics. Finally, the students were asked to freely navigate in two different versions of a commercial Web-site selling computer products that was developed for the purpose of the experiment (i.e., original -non-adapted- and personalized -adapted to their respective cognitive characteristics-). During the navigation, the participants received specific cognitive tasks (e.g., "Find the laptop that could be used by IT professionals") related to the content of the environment in order to assimilate task-based navigation behaviour.

As soon as the participants experienced navigation in both environment versions, they were presented with a comparative usability questionnaire, with the aim to measure their preference between the two environments. In particular, a modified version of the WAMMI questionnaire [20] has been employed in our study. The modified version is composed of 5 main constructs with 5 anchor scales (total 12 questions). Each question asked the participants to choose which environment they preferred (using a scale from 1-5, where 1 means strong preference for environment A -original- and 5 for environment B -adapted-).

The constructs of the questionnaire are: *Attractiveness*, degree to which users like the Web-site; *Control*, degree to which users feel "in charge" of the Web-site; *Efficiency*, degree to which users feel that the Web-site provides the information they are looking for within a reasonable timeframe; *Helpfulness*, degree to which users feel that the Web-site enables them to solve their problems with helpful tools or by finding helpful information; *Learnability*, degree to which users feel they can get to use the Web-site if they access it for the first time.

The following null hypothesis was formulated for the purpose of this research, H0: there is no general preference of users towards the original or personalized environments based on the adaptation effects, considering also other main effects with respect to the cognitive characteristics of users.

4.2. Results

In order to simplify the analysis we combined the response categories into two nominal categories (i.e., prefer original environment, prefer personalized environment) [21].

Overall objective of the study was to examine the preference of users towards the environment (i.e., original or personalized). Results revealed that 27 users (73%) preferred the personalized environment and 10 users (27%) preferred the original environment. A binomial statistical test was conducted (H0: p(original)=0.5 and p(personalized)=0.5) indicating that there is significant preference of users towards the personalized environment ($p<0.01$).

Furthermore, a Pearson's chi-square test was conducted to examine whether there is a relationship between users' cognitive characteristics (i.e., cognitive styles and Working Memory Span (WMS)) and the usability factors of each environment (i.e., original or personalized). The analysis revealed that 29 users (78.4%), based on the Verbal/Imager class, found the personalized version significantly more attractive (Chi square value=6.540, df=2, p=0.038). Such finding suggests that presenting content in an adaptive format (e.g., diagrammatical representation to Imager users) improves the attractiveness of the Web environment. Another interesting finding was the fact that 27 users (73%), based on the Wholist/Analyst class, could complete their tasks more efficiently and had more control of the environment. The results revealed that there is no significant relationship between the factors; (Wholist/Analyst * Control: Chi square value=4.743, df=2, p=0.093), and (Wholist/Analyst * Efficiency: Chi square value=4.743, df=2, p=0.093). Nevertheless, such finding indicates that the navigation control tools (i.e., tabbed and floating menu) provided to the users in the personalized version improved the usability of the system in terms of user control and task efficiency.

Finally, examining the relationship between the WMS and preference towards a specific environment has revealed that 27 users (73%) found the personalized environment more helpful. The analysis did not reveal significant relationship between the two factors (WMS * Helpfulness: Chi square value=1.936 df=2, p=0.380). Still, such finding is encouraging for further research since the analysis revealed that providing a supportive tool for keeping active information during a task is helpful for the users. As a consequence, no safe conclusion can be drawn at this point whether adapting Web environments based on WMS of users significantly increases the usability of the system. Further studies with a larger sample need to be conducted and various other adaptation effects need to be investigated (e.g., decrease information quantity for users with low WMS) in order to reach more concrete conclusions regarding the influence WMS has on the adaptation of Web environments.

5. Conclusions

This paper presented a semantic Web adaptation framework with the aim to personalize content and functionality of Web environments based on human factors. The adaptation mechanism and effects of the proposed framework have been evaluated with a user study so as to assess users' preference towards an adapted (personalized) and non-adapted (original) version of the same Web environment by utilizing a usability measurement.

Initial findings indicate that incorporating specific cognitive factors in the personalization process of commercial Web environments may positively affect the users' experiences. The most interesting finding was the fact that 73% of the sample significantly preferred the personalized environment indicating that the proposed adaptation framework provides a positive user experience through the adaptation of content and functionality of the Web environment utilized in the study. Another important finding was the fact that presenting the content in a diagrammatical representation (for Imagers) or in verbal representation (for Verbals) has significant main effect on the attractiveness of the Web environment. Furthermore, the analysis revealed that there is a noticeable relationship between the Wholist/Analyst dimension, and the control and efficiency factors of the Web environment, indicating that the adaptive navigation control tools improved the usability of the Web environment.

Even though the evaluation of the proposed framework is encouraging, further investigation needs to be carried out on other types of (commercial) Web environments in order to establish a more rigid connection between human factors and information processing in Web environments.

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