An Individual Differences Approach in Designing Ontologies for Efficient Personalization

Nikos Tsianos[1], Panagiotis Germanakos[2], Marios Belk[2], Zacharias Lekkas[1], George Samaras[2], and Costas Mourlas[1]

[1] Department of Communication and Media Studies, University of Athens
[2] Department of Computer Science, University of Cyprus

Abstract. This article discusses the potential role of cognitive individual differences in the context of designing ontologies for personalization on users' characteristics. The theoretical framework of the proposed approach is derived from the long tradition of psychometric testing, incorporating implications from the field of differential and cognitive psychology. The current state of the identification and systematization of mental abilities is depicted, with additional emphasis on the constructs of working memory and cognitive style, on which a proposed ontology is based upon. Also, a summary of previously conducted relevant empirical work is presented, providing support to the notion of introducing personalization into educational and commercial websites. To that end, the main argument of this work is that the enrichment of ontologies with cognitive factors may lead to efficient personalization and measurable benefits for users.

1 Introduction

The idea of developing adaptive and personalized systems has been mainly supported by arguments focusing on the drawbacks of the "one-size-fits-all" approach (Brusilovsky and Maybury 2002) and essentially the complexity and vagueness of the ever-expanding World Wide Web (De Bra et al. 2004). In parallel, researchers and practitioners in the field of adaptive hypermedia underline the heterogeneity of the user population, while it is often implied that "static", non-personalized systems fail to satisfy the needs and support the goals of different users (Brusilovsky 2001). A certain degree of recognition towards this approach may be deducted from the fact that web services such as Google, Bing, and Amazon are nowadays offering personalized results and recommendations, by employing rule-based and collaborative filtering techniques. Admittedly, though, these popular services could not be classified as adaptive hypermedia, since they are lacking many important features and functionalities; there is no user model, no varying modes of presentation, and no navigational support, to name but a few of the

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elemental attributes of personalized systems (Brusilovsky 1996). Nevertheless, the notion of personalization has finally found its way in users' everyday interactions in a massive, though rather superficial, manner.

Still, a rather obvious question must be addressed: is it worth to develop extensive personalized services, considering that their technical complexity and requirements far surpass that of static systems? During the incubation period of adaptive hypermedia, Dieterich et al. (1993) identified certain criteria in order to analyze and document the usefulness of adopting a personalized approach: the area of application, the characteristics of the users to be taken into account, the aspects of the system that can be manipulated and adapted, and the goals of the personalized approach. E-learning, for instance, qualifies rather easily according to these criteria, since it is a very wide area, the learner population is much diversified (with different goals, needs, and abilities), while the educational content and the instructional method can be manipulated. However, even in this case, the high cost of designing personalized courses for popular and free to use e-learning platforms has resulted in limited appeal outside the research community (Hauger and Köck 2007). Also, Paramythis and Loidl-Reisinger (2004) stress that in many cases educational adaptive hypermedia are not standard compliant. Therefore, the move towards personalized web applications and services is not expected to be an easy one, especially without support from high profile service providers.

More importantly, there is a need for more research on measuring the actual benefit for users, instead of merely developing elaborated personalization and user modeling techniques, along with corresponding semantic schemes; even if personalization is the key to more efficient interactions and satisfying experience on behalf of the users, there is one undeniable issue to be resolved: how and why would users benefit? Individuals are certainly different from each other, but which would be the underlying theories that could guide research endeavors in producing measurable gains? A first approach would be to identify the levels in which individuals demonstrate considerable differences, such as demographics, social, mental abilities, personality, goals, needs, and experience, and to build a cohesive user model by including characteristics that would be proven to be important in affecting behavior and performance. This could be probably achieved only by conducting extensive empirical work, driven by grounded psychological and sociological theories, and by gradually developing an interdisciplinary framework that would bridge technical possibilities with human factors.

To that end, considering in parallel the main functionalities of adaptive hypermedia, effective personalization of Web content involves two important challenges: i) accurately model and represent user information that is deemed as essential and useful for the adaptation process, and ii) 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 provider level, aiming to construct a Web-based adaptation mechanism that will serve as an automatic filter adapting the distributed hypertext/hypermedia content based on the user model. Semantics employ specialized approaches and techniques for alleviating difficulties and constraints imposed by the Web and contribute to the whole adaptation process with machine-understandable representation of user profiles and Web content.

In this context, the work that is presented here constitutes an effort to introduce the notion of individual differences as a core element of the abovementioned research directions, focusing mainly on users' cognitive characteristics. Specifically, we discuss the potential role of cognitive abilities in information processing within Web environments, along with possible ways of providing effective personalization processes, with direct implications on the user model, the Web content, and the semantic structures. This approach has been inspired by individual differences research; in the words of Kyllonen and Stevens (1990, p.130), a person may differ from another in "…fundamental cognitive abilities that affect the overall integrity of the individual's cognitive information processing system". It should be noted, though, that such differences are expected to manifest when a certain amount of information processing load is imposed on the user, which consequently involves hypermedia environments and Web systems that present a certain degree of complexity.

Interestingly, a review by DeStefano and Lefevre (2007) suggests that hypertext reading induces higher cognitive load to users, as compared to other forms of reading, and that proper structuring the content and reducing the number of hyperlinks are both beneficial for users with lower cognitive abilities (namely working memory, though experience is also important). Lee and Tedder (2003) also found that such users are facing higher difficulties in information recall in the case of hyperlinked structures, while McDonald and Stevenson (1996) also suggest that hypermedia navigation increases cognitive load. These studies, along with other research that also focuses on cognitive (or information processing) load, have not dealt with heavily demanding learning or training environments, but with rather simple hyperlinked passages of text. Therefore, it seems that accessing hyperlinked information in the Web may be more demanding for users with lower cognitive abilities, and that personalization on such individual differences could be of importance, with measurable gains.

Thus, the following section of this paper discusses the long history of individual differences, especially at the level of cognition, in an effort to identify factors that could provide useful information about users' behavior, preferences, and abilities; utterly, the aim is to provide adequate theoretical support for a proposed user model and semantic scheme, along with ideas for future empirical research. Section 3 focuses on issues that relate to adaptivity implementation considerations, while section 4 presents certain research efforts that we have conducted in order to support the argument of incorporating individual differences in personalized systems for education and commercial Web-sites. Section 6 concludes the paper with discussion and future trends of our work.

2 Individual Differences as User Modeling Factors

The term individual differences is indeed very broad, since it could include from genetics to personality; thus, it should be mentioned that the way that it is used in our research context derives from the field of Differential Psychology. The term (initially in German, Psychologie der individuellen Differenzen) was proposed by William Stern (1900), in order to summarize the research on mental differences, in coordination to a notion of "general psychology". The emergence and proliferation of the individual differences research is not however directly linked to cognitive research; in fact, researchers from the fields of differential and cognitive psychology have often opposed each other, especially on whether psychometrical approaches are truly related to human cognitive structures (Glaser and Pellegrino 1978). Also, it is rather indisputable that, for the most part, individual differences research was based on (or provided a basis for) the study of intelligence (Dillon and Watson 1996).

2.1 Cognitive Abilities

From the beginning of the 20th century, an impressive number of mental abilities tests have been developed, aiming to measure complex and higher cognitive processes that relate to information processing tasks (Cattell 1987). This research led to the emergence of many theories for intelligence, resulting in a somehow fragmented field; a common however focal point of these theories, originating from the work of Thurstone (1938), is that there are certain distinct basic mental abilities (factors), in which people differ at some extent. All this work was at a large extent summarized by Carroll's very influential meta-analysis, which led to the development of his three stratum theory (1993). Carroll identified a general intelligence factor (g), 8 broad abilities (factors), and 69 narrow abilities which are factorial related (and partially explain) to the former. In our research context, these 8 broad abilities (or those identified by similar theories), could provide a basis for personalization on cognitive abilities as user modeling factors; the general intelligence factor (practically a person's IQ), is considered too broad and (by definition) not directly related to specific information processing tasks that would mostly interest in a Web environment.

Specifically, Carroll identified the following abilities: fluid intelligence, crystallized intelligence, general memory and learning, broad visual perception, broad auditory perception, broad retrieval ability, broad cognitive speediness, and processing speed. A recent further development of the three-stratum theory is the Cattell-Horn-Carroll (CHC) Theory (McGrew 1997), which also includes Cattell and Horn's Gf-Gc theory (Horn and Noll 1997). The CHC model of intelligence modifies and raises the number of broad mental abilities to 10, though this number should not be considered as fixed, since the theory is open to new findings and future developments (McGrew 2009). At a descriptive level, we believe that the CHC model provides a very useful understanding on the organization of intelligence factors (narrow to broad), clearly demonstrating the aspects in which people differ at the level of cognitive abilities (see figure 1).

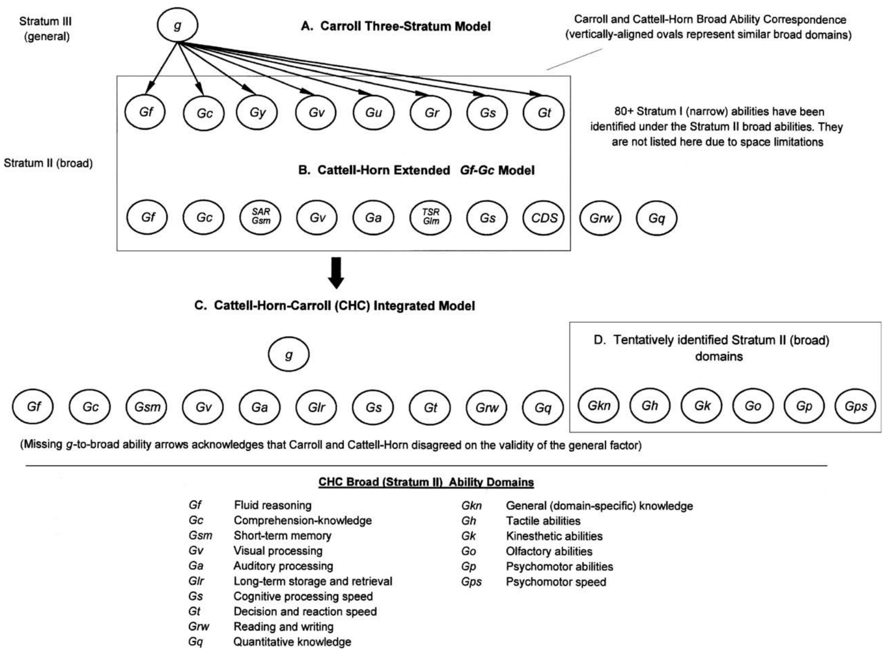

Fig. 1 The Integration of Caroll's Three-Stratum Model and Cattell-Horn's Extended Gf-Gc Model into the CHC Model of Cognitive Abilities (McGrew 2009, p. 4).

As it concerns the 76 narrow abilities that are factorial related to the broad, two examples follow: i) **Comprehension Reasoning** comprises Language Development (LD), Lexical Knowledge (VL), Listening Ability (LS), General (verbal) Information (K0), Information about Culture (K2), Communication Ability (CM), Oral Production and Fluency (OP), Grammatical Sensitivity (MY), Foreign Language Proficiency (KL), Foreign Language Aptitude (LA), and ii) **Short-term Memory** comprises Memory Span (MS) and Working Memory (MW). Obviously, as a result of factor analysis, narrow abilities have different loadings on each broad factor, while they represent performance at corresponding psychometric testing.

It should be clarified at this point that such psychometric theories of individual differences are indeed very elaborate and complex in relation to existing, or even technically viable, approaches in personalization and user modeling. On the other hand, we consider that a broad and thorough understanding of how people differ when required to perform mental tasks is necessary in order to subsequently narrow down the number of possible user attributes that could be used in a personalization scheme. Also, in the context of Web environments, it is very probable that just a few of these factors would suffice in order to predict (at some extent) users' behavior and/or performance; this narrowing down, however, requires both a solid theoretical basis and extensive empirical work. Likewise, our empirical work (see section 4) involves assessing the role of a limited number of factors at a time, with the purpose of gradually enriching and optimizing a user model of cognitive abilities and preferences.

2.2 Incorporating Cognitive Factors into Personalized Web Environments

The effort to introduce cognitive abilities into the design of adaptive Web systems by creating semantic schemes (such as ontologies) and filtering mechanisms is mainly hampered by the fact that there is very limited experience on which factors are the most important in Web interactions. Still, it would be very useful to keep in mind that according to Deary's (2001) review on the relatively recent state of research on intelligence, individuals predominantly differ in the following factors (the definitions are cited from McGrew, 2009, p.5-6):

- **Visual** *(and spatial)* **ability**: "the ability to generate, store, retrieve, and transform visual images and sensations".
- **Verbal ability**: "the breadth and depth of a person's acquired store of declarative and procedural reading and writing skills and knowledge".
- **Memory** *(short-term)*: "The ability to apprehend and maintain awareness of a limited number of elements of information in the immediate situation (events that occurred in the last minute or so)".
- **Processing speed**: "The ability to automatically and fluently perform relatively easy or over-learned elementary cognitive tasks, especially when high mental efficiency (i.e., attention and focused concentration) is required".

Thus, in our opinion, these areas of cognition are a good starting point for the study of their respective effects in Web environments. Deary also points that intelligence factors are highly stable throughout a person's lifetime, though fluid reasoning, memory, and speed tend to deteriorate with high age. Most importantly, according to this survey, performance in psychometric tests is a rather strong predictor of educational and occupational achievement, along off course with numerous other parameters (i.e., social).

The abovementioned factors, with the exception of processing speed, could easily be related to the use of the Web, albeit tentatively; the Web requires both visual and verbal (reading) processing of information, while maintaining awareness of different elements (i.e., hyperlinks) is essential, and as depicted in the introductory section persons with lower levels of working memory may face increased difficulties in hypertext environments. These assumptions do not necessarily imply that more intelligent persons excel at Web interactions – each individual may have different strengths and/or weaknesses, and perhaps the employment of personalization techniques could result in providing tailor-suited environments. Such an approach would be very relevant to the proposed theories of cognitive style, a construct that refers to habitual or preferred modes of problem solving, thinking, perceiving, and remembering (Tennant 1988), or to consistent individual differences in preferred modes of organizing and processing information and experience (Messick 1984).

In fact, Riding and Cheema (1991) identified two independent dimensions of cognitive style, by integrating a large volume of preexisting style research into their theory: Verbalizer – Imager, and Wholist – Analyst. The first dichotomy represents individuals' preference for receiving and processing information in either visual or verbal mode, while the second refers to a corresponding preference for information in whole or in parts; individuals without preferences are classified in each scale as "intermediates". The implications of the verbal – imager dimension are rather clear (imagery vs. textual and auditory information); the wholist – analyst dimension, however, is derived from Witkin's construct of "psychological differentiation" (Witkin et al 1971; Witkin et al 1977), and its implications are somehow more complex. In a nutshell, analysts are better at active analysis and perception differentiation, tend to act independently, are self-oriented and self-reinforced, and develop their own strategies. Wholists prefer social interaction and collaboration, while they require external direction, reinforcement, feedback, defined goals and specific structures. It should be noted that this research has been conducted primarily in the field of learning, but cognitive style has been developed as a broader concept than learning style, which on the contrary focuses on educational strategies and measurement tools in schooling environments (Rayner and Riding 1997).

According to our theoretical analysis, so far, it seems that there is a possibility to link the abovementioned individual differences to certain aspects of Web environments: individuals may excel at or prefer either visual or verbal information (i.e., correspondingly tagged content), while there may be preference for either loosely or highly structured environments (i.e., navigational freedom and level of control). Due to the fact that Riding and Cheema's theory of style (Cognitive Style Analysis – CSA) provides certain rather clear guidelines on how to distribute information to individuals, we opted for adopting CSA as an indicative measure of users' information processing preferences at a preliminary level of exploring individual differences.

Still, the potential role of (short-term/working) memory has not been discussed yet; the following subsection aims to provide some insight on this dominant in the field of cognitive psychology construct. As it concerns processing speed, it could perhaps be related to Web systems that impose time constraints, but in our opinion it would be nearly impossible to increase individuals' performance with current personalization techniques. Also, the role of processing speed may be more important in lower level mental tasks, which is not the case with most Web environments.

2.2.1 The Significance of Working Memory

Working Memory is a central construct in the field of cognitive psychology and neuroscience, as the main mechanism for maintaining information that is required for the performance of mental tasks (Shah and Miyake 1999). Working memory is also closely related to individual differences psychology, since many aspects of this construct have emerged through psychometric procedures (Baddeley 1992). In fact, measuring working (or "immediate") memory has been an important part of intelligence testing since the beginning of the century (Ackerman et al. 2005). Baddeley (1992, p.1) also provides a relevant description: working memory refers to a brain system that provides temporary storage and manipulation of information that is necessary for complex cognitive tasks such as verbal comprehension, learning, and reasoning. It should be mentioned that in relation to the (unitary) concept of short-term memory, working memory usually refers to system that consists of distinct components, including a subsystem for the control of attention.

Moreover, besides being such an important construct for the study of information processing, it has been supported that working memory shares considerable variance with general and/or fluid intelligence (g/Gf) (Kyllonen and Christal 1990; Conway et al. 2003; Heitz et al. 2005). In general, working memory is highly correlated to intelligence, with substantial loadings on the g factor in psychometric testing; thus, it could be hypothesized that the construct of working memory is not only important per se, but also quite (in terms of broadly measuring) representative of an individual's mental abilities. On the other hand, working memory is not isomorphic to intelligence, nor it relates to every dimension of mental abilities.

Operationally, in the context of personalization, it is also very important that this construct has been extensively described by a number of theories, thus allowing a better understanding of individuals' specific capabilities and limitations. In our approach, mostly based on the well-known models of Baddeley (Baddeley and Hitch 1974; Baddeley 2000), Cowan (Cowan 1999; Cowan 2005), and Kane and Engle (Kane and Engle 2000; Kane et al. 2001), the main differences among healthy individuals with varying degrees of working memory span are: a) the ability to control attention, and b) the amount of information that can be manipulated simultaneously (memory span); still, the latter is probably influenced or even caused by the former. The issue of attention control is also central in the rather popular in educational and training hypermedia Cognitive Load Theory (Sweller 2003; Paas et al. 2003), in relation to the form and complexity of learning material.

Accordingly, we consider that Web environments can be manipulated in a way that could compensate for certain individuals' lower levels of attention control and memory span, mainly: i) by restructuring the content, ii) reducing the number of simultaneously presented stimuli, and iii) providing information at a slower pace. These methods are essentially personalization techniques that could be employed in almost every (complex enough) Web system, though their efficiency can only be validated through empirical research. The following section presents a possible way of integrating such functionalities in personalized systems, with cognitive style and working memory as the first areas of individual differences to be explored.

3 Technical and Design Considerations

3.1 Ontology-Based Web Content Annotations

Apart from building a theoretical framework for identifying important information processing parameters, it is also necessary to study and design the structure of meta-data (semantics) coming from the providers' side, aiming to construct a Web-based personalization mechanism that will serve as an automatic filter adapting the hypertext/hypermedia content based on users' profiles. The functionalities of the personalization mechanism are directly derived from the theoretical framework; the assumptions on which methods may assist users' interactions according to their abilities/preferences are in fact the filtering rules. As it concerns the profiling procedure, a large number of corresponding psychometric tools are readily available in either electronic form (i.e., CSA), or could be "ported" online (for instance, we developed an online version (http://adaptiveweb.cs.ucy.ac.cy/profileconstruction) of a common reading span working memory test); however, the presentation of such tools is out of the scope of this paper.

Still, as it was depicted in the introductory section, a main prerequisite for the proliferation of personalized Web services is the establishment of a set of standards that will be supported by high profile providers. Currently, at the level of semantics and ontologies, there have not been proposed any schemes including cognitive individual differences, at least to the authors' knowledge (excluding perhaps certain strictly educational hypermedia research approaches based on learning style). On the other hand, existing systems from other areas could easily be modified in order to map the Web content on users' cognitive profiles.

One such system is OntoSeek (Guarino et al. 1999), which is designed for content-based information retrieval from online yellow pages and product catalogues. OntoSeek uses simple conceptual graphs to represent queries and resource descriptions. The system uses the Sensus ontology (Knight and Luk 1999), which comprises a simple taxonomic structure of about 50,000 nodes. Another similar system developed by Labrou and Finin (1999) uses Yahoo! as an ontology. The system semantically annotates Web-pages via the use of Yahoo! categories as descriptors of their content. The system uses Telltale (Chowder and Nicholas 1996; Chowder and Nicholas 1997; Pearce and Miller 1997) as its classifier. Telltale computes the similarity between documents using n-grams as index terms. The ontologies used in the above examples use simple structured links between concepts.

A richer and more powerful representation is provided by SHOE (Heflin et al. 1999; Luke et al. 1997). SHOE is a set of Simple HTML Ontology Extensions that allow Web authors annotate their pages with semantics expressed in terms of ontologies. SHOE provides the ability to define ontologies, create new ontologies which extend existing ontologies, and classify entities under an "is a" classification scheme. Most importantly, Google has also recently announced that their search engine is going to support enhanced searching in Web-pages, by using RDFa and Microformats embedded in XHTML. Google states that the extra (structured) data will be used in order to get results for Product Reviews (e.g., CNET Reviews), Products (e.g., Amazon product pages), People (e.g., LinkedIn profiles) and any other types of resources will be made public through the data-vocabulary.org.

In our research, these approaches were a starting point for enriching the adaptation process with machine understandable representation of user profiles and Web content; specifically, the corresponding ontologies were taken into consideration for the design and development of our ontological adaptation mechanism.

3.2 *A First Step in Individualizing Ontologies*

In the theoretical section of this paper, a large number of cognitive factors were presented and discussed; however, as mentioned above, after a narrowing down process we opted for using working memory and cognitive style as personalization parameters. In terms of implications on the information space, these two constructs are somehow more relevant and far clearer in comparison to factors such as fluid reasoning or crystallized knowledge, which is rather important at this initial and explorative level of research. For a better understanding of these two adaptivity parameters' implications and their relation with the information space, figure 2 shows the possible content transformations/enhancements, based on the theoretical assumptions.

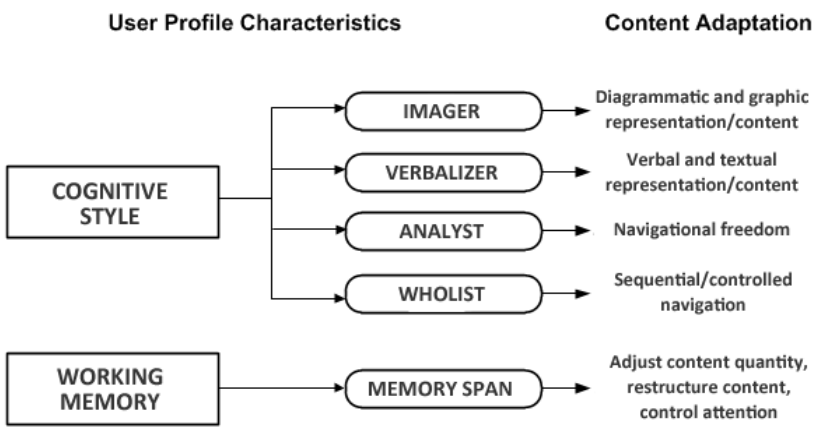

Fig. 2 Web design transformations/enhancements.

Specifically, the cognitive meta-characteristics of a user profile are: imager or verbalizer, analyst or wholist, and working memory span (low/medium/high), and have a particular impact on specific characteristics of the information space: images, text, information quantity and structure, links, control, and navigation support. These transformations represent groups of data affected during the mapping process on the selected cognitive factors. The main rationale is to process and/or alter the same content in different ways (according to a specific user's profile each time), without degrading in any way the message conveyed.

This approach led us to an Ontological Cognitive User Model (OCUM) (Germanakos et al. 2010); an RDFa vocabulary has been designed based on the theoretical framework and can be found online (http://adaptiveweb.cs.ucy.ac.cy/resources/rdf.xml). This vocabulary (User Model) consists of a number of classes and properties which describe a user's profile (table 1). The main class of this vocabulary is

Person, which 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 to cognitive style parameters: i) “imagerverbal” property; imager or verbal, ii) “wholistanalyst” property; wholist or analyst, and iii) “workingmemory” property; the Person’s working memory capacity (i.e., low/medium/high). 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 Working Memory entities. Furthermore, there are three implicitly defined entities: the person's cognitive style, working memory capacity, and his personal details.

Table 1 RDFa Instance of a User’s OCUM

```
<div xmlns:v="http://adaptiveweb.cs.ucy.ac.cy/resources/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>
```

A practical example of this conceptualization would be the following: A user may be identified as verbalizer(V)/wholist(W), in respect to his/her style, with lower levels of working memory capacity (usually one standard deviation below the mean of a group). The content affected for this particular instance, according to the filtering rules, is: images (fewer images displayed), text (predominant mode of information delivery), navigation support (activated and/or enhanced), and info quantity (less quantity, split of competing for attention resources, clear structure with tags and guidelines, or further support with the use of a temporary buffer/notepad holding active particular information during task execution).

This process is rendered possible with the use of a proposed Ontological Adaptation Mechanism (OAM) that is composed of three main layers (figure 3): i) User Profile Layer, ii) Adaptation Mapping Layer, and iii) Web Content Layer.

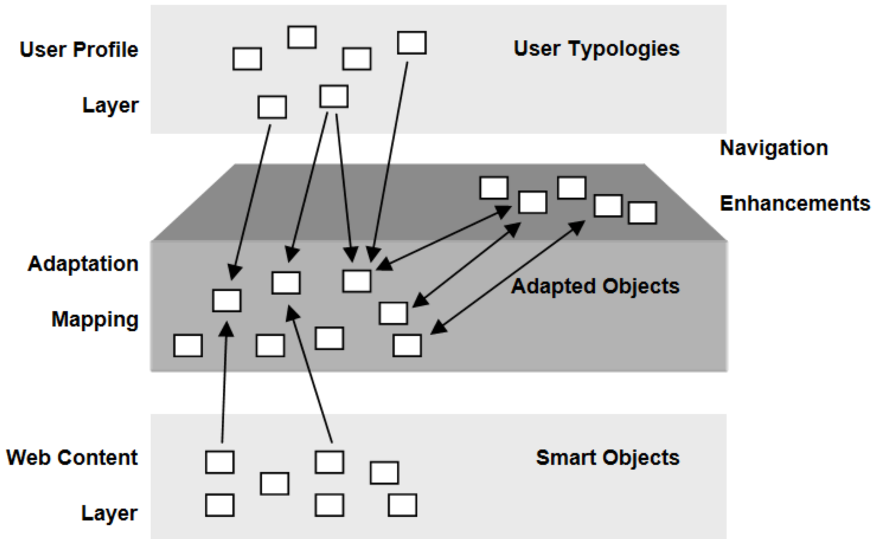

Fig. 3 Ontological Adaptation Mechanism.

The first layer of the OAM is the User Profile Layer, on which users' cognitive parameters are modeled; from a high level point of view, each user profile is a semantically defined object (RDFa object) that contains users' intrinsic characteristics. On the other end of the OAM, the Web Content Layer models hypermedia Web content with specific meta-characteristics, using again an RDFa vocabulary to annotate specific areas of an XHTML document as Adaptable Objects (Belk et al. 2010). In the middle layer, the Adaptation Mapping Layer is responsible for mapping User Profiles with the Adaptable Objects of the Web Content Layer. Based on this mapping, all Adaptable Objects of an XHTML document are manipulated (i.e., show more images and content in a diagrammatical form in case of an Imager), and extra navigation enhancements may be provided to the end-user.

Both the OCUM and OAM can be integrated in various Web-environments, regardless of orientation; still, the usefulness of proposing such an approach lies exclusively on the possibility of providing users with considerable benefits. Since the focus is on information processing, it is anticipated that the field of Web education would provide easily measurable data. However, personalization nowadays is emerging at a broader level, involving everyday interactions; thus, it is of high importance to explore whether an ontological conceptualization of individual differences (admittedly limited at this phase of research) is any useful in non-educational Web-sites. The following section briefly presents our empirical findings in both educational and commercial fields of application, in order to substantiate the usefulness of using OCUM and OAM.

4 Empirical Findings on Mapping Web-Content on Individual Differences

During the process of designing OCUM and developing OAM we conducted a series of empirical experiments in order to assess the positive effects, if any, of personalization on users' performance and/or quality of interactions. In this section, we briefly present the findings of three experiments that have been elsewhere published, elucidating our notion of "benefits for the user". The construct of cognitive style has been used throughout the entirety of this empirical work; on the contrary, the measure of visual short-term memory was replaced in the third experiment by a more robust working memory span and executive control measurement tool.

4.1 Experiment I

The first experiment was conducted in the field of e-learning (Tsianos et al. 2009), and included the following factors as personalization parameters: i) cognitive style, ii) visual short-term memory, iii) processing speed, and iv) self-reported anxiety (as a non-cognitive measure). The experiment was conducted in two phases: in the first phase the effect of personalization on cognitive style was explored (n=138), while the second (and later) phase involved the remaining parameters (n=81), controlling for the effect of style by personalizing the environment on users' style preference. The participants were social sciences university students who volunteered (convenience sampling) to take an online lesson on computer science; they generally considered the course as an additional aid on an academic subject on which they have minimal experience and usually perform poorly.

The procedure, which lasted for about an hour, in both phases was the same: users created their profiles through a series of psychometric tests, logged into the system, took an online course on algorithms and flow charts, and afterwards participated in an on-line exam assessing their level of comprehension of the lesson. In the case of cognitive style (phase I), the filtering process was based on the aforementioned personalization techniques: i) selection of content based on preference for imagery or verbal information, and ii) navigational freedom, level of control, and access to information based on analytic or wholistic preference (with the use of a navigation panel and the manipulation of links). The design of the experiment was between participants, and a match/mismatch methodology was employed: half of the participants were instructed in a matched to their preferences way, while the other half were instructed in a mismatched way. According to the findings of phase I, personalization on cognitive style increased learners' performance by 8.74 points (the mean score was 66.53 out of 100 in the personalized condition, and 57.79 in the mismatched condition, while intermediates scored 58.58): $F(2,137)=4.395$, $p=0.014$. In fact, the difference is statistically significant only between the matched and mismatched condition (post hoc analysis); intermediates perform somewhere in between.

In the second phase of the experiment, the filtering rules were the following: i) visual short-term memory: users that had low levels received segmented content that unfolded gradually, ii) processing speed: different time limits were set for each category of learners, and iii) anxiety: aesthetical enhancement of the environment (font size, colours, and annotations). The match/mismatch methodology was again applied; according to the analysis of the data (2x2x3 Anova), we found a significant effect of matching the instructional style to: a) users' visual short-term memory ($F=_{(1,80)}=4.501$, $p=0.037$), and b) to their levels of anxiety ($F=_{(2,80)}=3.128$, $p=0.05$). The increase in performance was more than 10 points, albeit including the positive effect of matching style. On the other hand, processing speed was not found to have any effect on score or interaction with the other parameters.

4.2 Experiment II

The second experiment involved the commercial Web-site of laptop manufacturer (Belk et al. 2010). In this case, the profiling procedure was the same, but the design was within-participants: each user navigated in both the original and personalized version of the Web-site (n=89 university students). Users were asked to answer certain questions in relation to the available information (tasks), and they were afterwards given a satisfaction questionnaire. Thus, the dependent variables were: i) task accuracy, ii) task completion time, and iii) user satisfaction.

The personalization factors were the following two: i) cognitive style, and ii) visual short-term memory. In the case of style, the filtering rules were the same as in experiment I. In the case of visual memory span, however, an additional support tool was employed: a readily available "notepad", serving as temporary external memory (there was no segmentation of information). According to the results, task accuracy was significantly higher in the personalized condition (1.9 vs. 1 out of three correct answers): Wilcoxon Signed Ranks $Z=-4.755$, $p=0.000$). Also, users required less time to fulfill the tasks: 412 vs. 512 seconds, paired samples $t(88)=4.668$, $p=0.000$. As it concerns the satisfaction questionnaire, 31 users leaned towards the personalized environment, 38 had no preference, and 20 preferred the original version. These differences should probably be attributed to style, since the use of the external memory tool was found to be limited.

4.3 Experiment III

The third experiment was focused on the construct of working memory in an e-learning environment, for the reasons that were depicted in section 2 (Tsianos et al. 2010). The experimental design, the educational course, and the sampling procedure were the same as in experiment I, albeit exploring specifically the effect of personalization on working memory; cognitive style preferences were manipulated as a control and not personalization variable (all preferences were matched), and the sample consisted of 230 university students (voluntary participation). In this case, there were two main personalization techniques that were employed: i) split of attention-demanding objects by segmentation and gradual unfolding of the content, and ii) annotation of certain key pieces of information and concepts. According to the findings, users in the personalized condition outperformed their counterparts by approximately 9 points ($F_{(1,226)}$=8.380, p=0.004).

Generally, in all three experiments we observed a consistent positive effect of personalization, confirming most of our research hypotheses on the role of individual differences in information processing within Web environments (see table 2).

Table 2 Summary of Experimental Results

	Personalization Variables (match/mismatch)	**User Benefit**
Experiment I ***(e-Learning Course)***	Cognitive Style (phase I), Visual Short term Memory and Anxiety (phase II)	Increase of learner performance by 8.74 (phase I) and 10 to 13.43 (phase II) points in post course retention test
Experiment II ***(Commercial Website)***	Cognitive Style and Visual Short-term Memory	Better accuracy (1.9/3 vs. 1/3 correct answers) and task completion time (412 vs. 512 sec.), slightly increased user-reported satisfaction
Experiment III ***(e-Learning Course)***	Working Memory	Increase of learner performance by 9.18 points in post course retention test

It should be noted though that this work involved only a small part of the domain of individual differences, and in a very limited number of Web-environments (namely an educational and a commercial). Therefore, in spite of these positive findings, the benefits of personalization still need to be further researched and consistently demonstrated in various websites and human-computer interactions.

5 Discussion

In this article we made an effort to sum up the theoretical background and the empirical work that has led us to the development of a proposed ontological approach. As such, the focus is not actually on the OCUM and the OAM, but on possible ways of integrating cognitive individual differences in the representation of users' cognitive characteristics. We would expect that by outlining the field of cognitive abilities and by proposing a way for using certain of these factors in applied research, some new ideas could perhaps emerge in exploring elements of human behavior in the Web.

It is evident that it is hard to operationalize cognitive factors in terms of personalization techniques, since such an endeavor would require a continuous trial and error process. However, the significance of individual differences in many areas of cognition and the existing well validated psychometric tools are perhaps too concrete to ignore; thus, the formation of a corresponding ontology and semantic scheme would be very useful in conducting large scale studies on Web behavior, information processing, and personalization. We actually believe that only the bridging of the field of differential and experimental psychology with the field of semantics and Web technologies could produce robust results, for two main reasons: i) the extremely vague area of Web resources and their relation with the numerous cognitive factors would be explored far more efficiently through automated filtering processes, using extendable ontologies, rather than single experimental studies such as ours, and ii) the establishment of standards seems to be a key prerequisite for the adoption of personalization by high profile Web providers.

As it concerns the specific contribution of our theoretical and empirical work, the following arguments may be supported: i) cognitive style preferences seem to relate to how individuals perceive and process information in hypermedia environments, ii) working (and short-term) memory span represents individuals' information processing ability at some extent, and iii) it is possible to produce measurable benefits for users with the use of personalization techniques. Therefore, individual differences seem to have an effect on users' performance in both educational and commercial hypermedia.

It is certainly possible that these factors would not be equally important in different settings, and there is undoubtedly room for more accurate measurements and elaborated personalization techniques. This is actually the reason why we focused on mental abilities and on the current state of research on intelligence in the theoretical section of this paper; we seek new ideas for enriching OCUM (and user ontologies in general), new fields of application, and innovative methods for personalizing Web interactions. More specifically, as it concerns our future research directions, we aim to explore i) the role of verbal abilities in processing textual information in the Web (i.e. news and online encyclopedias), and ii) the role of fluid reasoning in online education, and the relation of the Gf factor with the pace of instruction.

As a closing remark, it should be noted that mental abilities certainly do not define or predict an individuals' behavior; motivation, personality factors, and emotion, to name but a few, are probably equally or even more important. Nevertheless, the long tradition of intelligence testing has produced accurate methods of measurement, and has systemized a large part of human individual differences in a quantitative manner that is quite compatible with the design and development of Web structures and functionalities. In the introductory section we posed the obvious question: is it worth it to personalize the Web, and in particular on the basis of cognitive abilities? Our experience has shown that there may be something of importance in linking abilities and preferences with the perceived by users aspects of the Web; thus, in an era of seeking added value in services, the answer would be positive.

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