International Journal of Computer Information Systems and Industrial Management Applications.
ISSN 2150-7988 Volume 4 (2012) pp. 352–357

User Experience Evaluation of WhatsOnWeb: A Sonificated Visual Web Search Clustering Engine

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***Abstract*: The aim of this study was to present a usability evaluation conducted under the User Experience (UX) perspective of a sonificated search engine called WhatsOnWeb, an accessible application based on sophisticated graph visualization algorithms which conveys datasets using graph-drawing methods based on semantically clustered data. Starting with evidence from an amodal system processing spatial representation, the differences between blind and sighted users' interactions whilst surfing WoW was analysed by following the Partial Concurrent Thinking Aloud protocol. Our results demonstrate that the user's ability to perform spatial exploration tasks guided by either visual or acoustic cues seems to be functionally equivalent.**

Keywords: user experience, usability, accessibility, information visualization, sonification.

I. Introduction

Traditionally, the literature on spatial cognition has given considerable attention to the spatial representation guided by only visual exploration, giving less consideration to the analysis of mental representations guided by different sensory inputs. However, a growing number of authors support the amodal hypothesis [1] of spatial representation, highlighted by analyses of the involvement of different sensory ways to convey information in spatial mapping processing [2]. Visual, auditory, haptic, and kinesthetic sensory information seems to be encoded into the same spatial mental image independently from the nature of input source [3, 4], according to many neuroimaging studies highlighting the fact that processed multisensory inputs seem to converge in common brain regions [5, 6].

In agreement with the amodal hypothesis, many studies analysing the performance of blind people in processing spatial auditory inputs have recently been carried out which show that blind people seem to have a motion ability in performing spatial exploration guided by acoustic cues that is functionally equivalent to the visually guided exploration by sighted people [7]; moreover, it has been shown that blind people performing spatial exploration tasks seem to process spatial auditory inputs in a more efficient way than sighted people [8, 9]. Recently, Delogu et al. [10] carried out an experimental analysis on the exploration of georeferenced information by using the software *iSonic* [11], and pointed out that the sonification process, integrated with haptic exploration, allows the transmission of geographical spatial information to blind people. It seems that spatial information processing is guided by strategies related to two different frames of body reference: the egocentric frame and the allocentric frame. The spatial orientation of blind people follows some strategies based on corporal reference points rather than the allocentric strategies used by sighted people in mental rotation and scanning tasks [12]. Therefore, the nature of sound seems to be able to communicate the complexity of static or dynamic data representation, keeping inner relations unchanged [13].

This work aimed to introduce a user experience (UX) evaluation [14, 15] of WhatsOnWeb (WoW), an accessible Web and desktop sonificated visual Web search clustering engine recently implemented at the Department of Computer Engineering (DIEI) of the University of Perugia. WhatsOnWeb is an application based on sophisticated graph visualization algorithms [16] which convey datasets using graph-drawing methods based on semantically clustered data [17]. Unlike the most common search engines (e.g. Google, Yahoo!) which give a top-down, flat representation (i.e., search engines report pages – SERPs) [18, 19], WoW returns a visuo-spatial data output providing a whole information representation within a single browseable page. In this way, WoW overcomes the efficiency limitation of a top-down representation by introducing alternative ways to convey spatial information [19]. Therefore, the WoW graphic output organization allows users to increase the possibility of finding useful information (i.e. increasing access to knowledge on the Web).

In this work, we analysed the differences between totally blind and sighted users' interactions while surfing the WoW search engine in order to compare the visual layouts of WoW with the sonificated ones. This evaluation was conducted by following two procedures – a heuristic evaluation and a usability evaluation with end-users – in order to demonstrate both qualitatively and quantitatively that there are no significant functional differences between the interactions of blind and sighted users [20, 21]. In this way, we wanted to confirm that sonification methods offer an effective tool for designing human-computer interfaces which are able to overcome the digital divide that has arisen by the visuocentric modality in which contents are commonly conveyed.

II. The Visual WhatsOnWeb: An Accessible Web Search Clustering Engine

The visual WhatsOnWeb system prototype [16] was designed in 2007 by the DIEI and redesigned following the User Centered Design approach in compliance with accessibility and usability principles. In particular, the redesign of WoW was conducted in accordance with the accessibility guidelines WCAG *v*1.0 and *v*2.0 as proposed by the World Wide Web Consortium (W3C), the national and international accessibility rules, i.e. the 508 section of the rehabilitation act and the Stanca Act n. 4 – January 9th, 2004 and the ISO 13407 "Human-centered design processes for interactive systems" [22].

The reengineering of the pre-existing code of WhatsOnWeb was carried out by decoupling the algorithm in compliance with Java Foundation Classes and the guidelines provided by Sun and IBM [23, 24], supported by specific extensions for Java accessibility architecture. In order to allow a device-independent interaction with the visual Web search engine, an architecture which allows navigation in at least two conditions controlled by users with the keyboard was implemented by following the characteristics and navigational constraints of the graph. Moreover, a composite architecture was produced in order to allow the vocalization function: this choice grants users access to the information system; indeed, the user might also choose to use a vocalizer when a screen reader has not previously been installed in the platform.

The graphs of the information structure are independent from each layout, i.e. the spatial representation of data, and are structured by different levels of navigation. Navigation is allowed by using different kind of vertices: the cluster nodes, which represent semantic sets of results that can be expanded and collapsed in order to analyse the requested query in depth up to the leaf nodes, which represent the results of the research (Figure 1). Navigation was made possible in two directions, from the *m* peak to the following *m + 1* peak, or vice versa following opposite movements. Moreover, when navigation is focused on the last peak of the list, it is automatically led to continue from the first peak. At an expanded peak, a sub-list of results is available on the graph. Navigation can also be carried out by sliding the expanded sub-nodes one by one, shifting the action starting from the following cluster node.

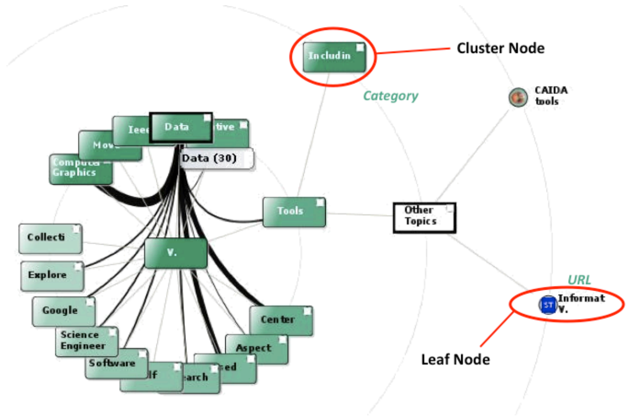

Figure 1. *Radial Layout* - exhaustive expansion of a cluster node

The visual WoW prototype is composed of four kinds of layouts that can be chosen by users: the *TreeMap* layout (Figure 2.A), the *Radial* layout (Figure 2.B), the *Layered* layout (Figure 2.C), and the *Orthogonal* layout (Figure 2.D). In a previous study, the effectiveness and efficiency of each kind of layout was evaluated through a navigation task and a satisfaction questionnaire [16].

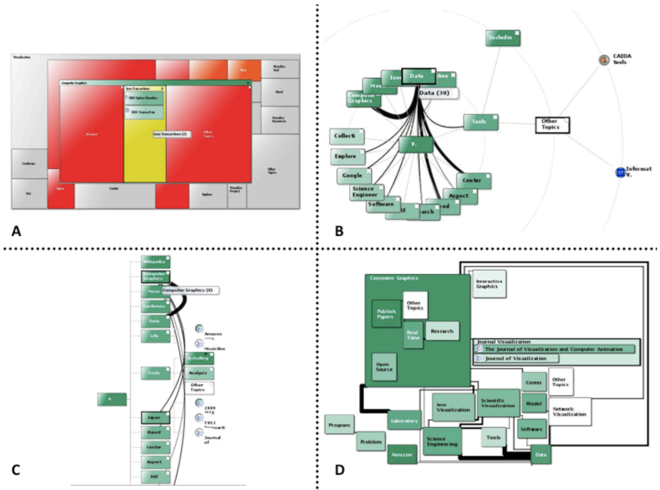

Figure 2. WhatsOnWeb layouts: a) *TreeMap;* b) *Radial*; c) *Layered;* d) *Orthogonal*

The results of the navigation task showed that the *TreeMap* had the best layout, allowing participants to find about 50% of the relevant results for the assigned topics, whereas this percentage was between 33% and 37% for the other layouts. Morever, 56% of subjects judged the *TreeMap* representation as the best layout on the satisfaction questionnaire. Using this evidence, a new layout called the *Spiral TreeMap* (Figure 3) was implemented in order to provide a more effective and efficient spatial representation of data. The new layout was designed so that a spiral navigation of the information is possible: the node with the highest rank on the web and the greatest number of results is set in the centre of the screen, whereas the other, less relevant, clusters/leafs are gradually set around it in a spiral shape. The usability of this new layout was subsequently evaluated on the visual sonificated version of WhatsOnWeb.

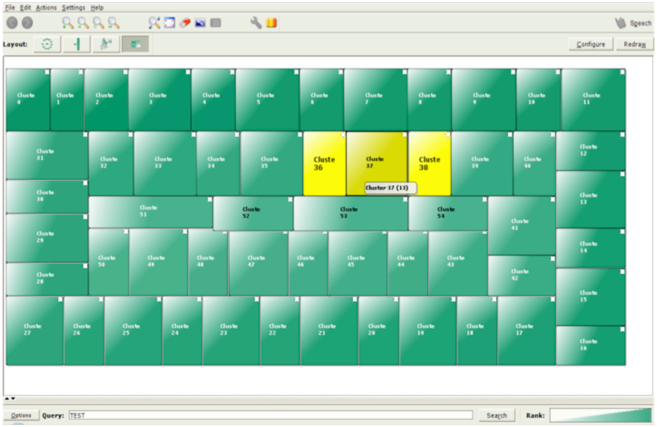

Figure 3. *Spiral TreeMap* layout.

III. The User Experience Design (UXD) Process of the Sonification of WhatsOnWeb

A. The UX sonification of WhatsOnWeb

Over the last twenty years Information Representation research has focused on alternative ways to transmit spatial information via non-visual sensory channels: the challenge was to convey the spatial information data contained in a visual representation by keeping the inner relations unchanged. A widely adopted method for transforming visual spatial representation is the sonification approach, i.e., “the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation” [25].

The literature on sonification pays particular attention to the implementation of aids able to locate spatial information about environments by means of acoustical signals: an electronic travel aid (ETA) is “a device that emits energy waves to detect the environment within a certain range or distance, processes reflected information, and furnishes the user with certain information in an intelligible and useful manner” [26]. Unlike the ETA field, abstract data sonification seems to be a more complex challenge due to the difficulties of granting a functionally equivalent transmission of the spatial relations whilst keeping the features emerging from the user’s dynamic interaction unchanged. In fact, in many systems [27, 28, 29, 30], information is mainly converted into natural sounds and shown to users in a static and non-interactive way (e.g. an audio registration): in this way, users can obtain the information but they cannot interact with the system. Moreover, there is a lack of studies assessing the accessibility and usability of sonification devices by blind users [12].

Interacting with WhatsOnWeb allows the manipulation of abstract data that is information which is not correlated with any physically obvious space. In WhatsOnWeb, indexed data is organized by semantic correlations resulting in abstract information; therefore, as a theoretical background for the sonification of the indexed abstract information, we adopted the sonification framework proposed in 2007 by Zhao, Plaisant, and Shneiderman [11] in order to allow to users dynamic navigation around the interaction environment: the Action by Design Component (ADC) sonification model.

The design of the graph sonification model of WhatsOnWeb was carried out by implementing and testing three types of combinations (Table 1) in a univocal way between visual features and some different features of sound. In particular, we created three sonification layouts – *PanAndPitch Sonification* layout, the *VolumeAndPitch Sonification* layout, and the *BlinkAndPitch Sonification* layout – by differently combining the tone, the pitch, the volume, blinking and the grid reference of sound with the fundamental spatial graphical features of WoW; that is to say, the z axes, the web ranking of each indexed cluster or single data, the level of navigation and the type of vertex (cluster node, leaf node).

	x Axis	y Axis	Ranking	Level
Pan And Pitch	Panning	Pitch	Volume	Timbre
Volume And Pitch	Volume	Pitch	Blinking	Timbre
Blink And Pitch	Blinking	Pitch	Volume	TImbre

Table 1. Comparison of results.

We created the first layout, the *PanAndPitch Sonification,* by using panning to represent the x axis of the Cartesian plane and the pitch of sound for the y axis; moreover, we used the volume to represent the ranking of information, the timbre to show the level of navigation and the double timbre to describe the leaf node. Unlike the first layout, the second one, the *VolumeAndPitch Sonification*, uses the sound volume level in order to represent the x axis by considering the Euclidean distance coding for a node compared to the origin of axes, whereas panning was used to strengthen the node detection as absolute information; furthermore, the node detection on the y axis is transmitted by using the pitch of sound. Finally, the third layout, the *BlinkAndPitch Sonification*, uses the frequency of the sound blinking together with panning to convey spatial relations through the independent mapping of the x axis and, as in the previous layouts, it uses the note pitch for representing nodes on the y axis.

Each sonification layout combines sound and visual events and each is able to describe both global and particular browsing data information: once the user searches for a *query* by selecting the *search* button, first, a global representation of the information is displayed by means of the temporization technique [31], which allows mapping of the information from a non-temporal domain – such as the visual one – to a temporal domain – such as the acoustic one. In this way, the temporization provides a description of the role of each cluster among the whole information representation and it allows to users to process a first mental representation of an overall overview of information. After the first automatic preview the navigation of each graphic node is translated into a complex tone with a latency less than 100 ms to prevent overloading the short term memory [32], representing the corresponding paraverbal information. The orientation of the user's position among the space of navigation is facilitated by a reiterable feedback function which provides the overall preview; moreover, a persistent signal indicating the user’s current position is also provided. Finally, information identification and the memorization of each cluster node are strengthened by verbal feedback voiced by the integrated synthesizer.

B. The evaluation process of the sonificated WhatsOnWeb

The UX evaluation of the reengineered and sonificated WhatsOnWeb (WoW) application was conducted by following two experimental procedures. First, an expert usability evaluation was performed for each sonification layout in order to design a final layout to use in the second evaluation process with end users. Then, we investigated the quality and the satisfaction of users' interactions with both the visual and acoustic sonificated displays of the WoW search engine.

1) The first experimental procedure analysed the usability of the sonification layouts of WoW – the *PanAndPitch Sonification* layout, the *VolumeAndPitch Sonification* layout, and the *BlinkAndPitch Sonification* layout – for each of the graphic layouts – *Radial*, *Layered* and *Spiral TreeMap*. This evaluation was conducted by three UX experts with more than five years of experience, which was carried out in a user scenario by applying a readjustment of Nielsen's heuristic list [33]. In this way, the issues of each layout with medium and high levels of severity were identified: this evaluation phase allowed us to select the best combination of acoustic and visual features and to unify each of them in a single layout that we called *PanAndPitchBlinking* sonification layout. This new layout was able to convey spatial information through the Cartesian plane by using the panning technique to represent the position of data on the x axis and the pitch of the note to represent the position on the y axis. Moreover, it used sound blinking to represent the rank order of each node.

2) The second experimental procedure investigated the UX quality according to two groups of participants – blind and sighted users – involved in a usability evaluation using the Partial Concurrent Thinking Aloud [34, 35] protocol and the System Usability Scale questionnaire [36, 37]. After a description of the task and a preliminary exploration of the layout lasting at least 3 minutes, four totally blind users and four sighted users (mean age 28, equally distributed by sex) were asked to navigate the WoW search engine by following a particular scenario consisting of an exhaustive search for a given query by means of keyboard navigation: both blind and sighted users navigated each of the three types of graphic layouts – *Radial*, *Layered* and *Spiral TreeMap* – by means of either the visual display or the *PanAndPitchBlinking sonification* layout. During navigation, we used the The Partial Concurrent Thinking Aloud (PCTA) technique to identify usability problems found by the user during interactions with the interface. The PCTA is a qualitative usability evaluation technique composed of a phase in which the participants indicate each problem they find during the interaction, i.e. the concurrent protocol, and a phase in which the participants are asked to observe their recorded performance and verbalize their action "aloud", i.e. the retrospective protocol [34, 35]. The PCTA technique is a new evaluation verbal protocol that is able to avoid the possible problems found during the evaluation process using concurrent or the retrospective verbal protocols with blind users [34, 35]. Once the users reached the requested query, they were interviewed about their graphic layout preferences and finally they were asked to complete the System Usability Scale (SUS) survey.

Each problem found during the PCTA protocols was matched with Nielsen's heuristic list as used in the first experimental procedure: the subjects found 19 problems, 9 related to visual performance and 11 related to auditory performance. The statistical analysis carried out by SPSS 18 on the task completion times for each layout showed no significant differences between the two groups and between the different kinds of layout (*Layered* layout, $F_{(1,6)}=4.524$; p=ns; *Spiral TreeMap* layout, $F_{(1,6)}=0.097$; p=ns) except for the *Radial* layout ($F_{(1,6)}=13.690$; $p<0.05$). The analysis of the SUS scores showed no significant differences ($F_{(1,6)}=0.2729$; p=ns) between the two groups of participants. Therefore, since these results highlight similar levels of efficacy, efficiency, and satisfaction for the two groups for both information presentation modalities, the sonificated modality and the visual modality performances seem to be homogeneous [29].

IV. Conclusions

Unless most of the Web search engines (e.g. Google, Yahoo) is marked as "accessible", accessibility seems to be actually not enough: there is a strong need to implement search engines that are both accessible and usable [20, 21]. In fact, many authors highlighted the digital gap that exists between blind people interacting with the Web by using screen readers, and sighted people [38]. In particular, the exploration of SERPs by the most common search engines seems to be more difficult when accessed by blind people using assistive technologies. In 2004, Ivory et al. highlighted the fact that blind users took twice as long as sighted participants to explore search results, and three times as long to explore web pages [39]. Users with visual disabilities cannot access all paraverbal information concerning "not only just the access to text but also to graphics, tables and figures" [40].

In this work, we introduced a visual sonificated Web search engine called WhatsOnWeb, which seems to allow blind and sighted users easier manipulation and findability of information by returning a geometrical spatial representation of the indexed Web data. In order to emulate and facilitate the cognitive mental information processing which organizes human knowledge through semantic categorization [41], the WoW clusters information in semantic nodes, making it easier for all users to find and elaborate on information conveyed by Information and Communication Technologies. The results of our evaluation show a global functional homogeneity between sighted and blind users' experiences of WoW, suggesting that a system which grants accessibility and usability considerably reduces the digital divide. Moreover, WhatsOnWeb is designed in order to provide a device-independent extensible architecture which can lead events through two interaction states. In this way, the reduction in the number of events necessary for searching for a *query* allows navigation through control systems and/or communication systems, such as the Brain Computer Interface (BCI), eye-trackers, tongue controllers and speech/sound interfaces.

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