The Influence of Screen-Readers on Web Cognition

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This paper reflects on how Web cognition is experienced by blind users employing screen-readers for Web interaction. Many of the differences in Web interaction between sighted users and users of screen-readers arise from the serial way in which Web pages are rendered by screen-readers. We begin by examining the ways in which these differences are brought about through the functionality of current screen-readers. The mismatch between the spatial layout of Web pages and the temporal nature of speech imply a substantially increased cognitive load for Web interactions. The paper reports findings from a survey and a task-based study which provides some practical examples of the way these issues appear in real contexts of use. In particular, the wide differences between the initial impressions and mental models of Web pages gained by sighted and visually impaired users, and the influence that these and other interaction characteristics have on collaborative tasks. We propose a draft taxonomy of errors for cross-modal Web interaction, and examine how non-speech sound might be employed to address the different categories of error in the draft taxonomy.

1. Introduction

Years of development have gone into generic Screen-Reader products such as Jaws [5], Window-Eyes [9] and VoiceOver [1]. In spite of these advances, the way in which information is presented by current screen-readers provides a generally linear representation of Web-based information, militating against the formulation of effective mental models of Web pages, in particular the spatial layout of the page. In this paper we shall analyse the extent to which current

screen-readers support the development of mental models of Web sites. Section two provides a brief overview of current support for Web use in the most popular screen-reader systems. Section three provides an analysis of this functionality, examining the implications for Web cognition for screen-reader users. Section four describes a small scale survey and task-based study we undertook to examine issues that visually impaired Web users currently encounter, particularly to explore issues in collaborative use of the Web by visually impaired and sighted users. Section five examines emerging research in auditory displays and explores what it has to contribute to screen-reader design. Section six concludes.

2 Current Screen-Reader Support for Web Use

2.1 Scope

We have chosen for reasons of brevity and relevance to focus on the currently two most popular Windows-based screen-readers, Jaws and Window-eyes, and VoiceOver for the Apple Mac. VoiceOver is included due to the growing number of visually impaired Mac users since its introduction with the Tiger Operating System [6]. We have also chosen to omit dedicated assistive browser applications, as most visually impaired users choose to use the Web browsing support in their generic screen-readers rather than having to acquire and learn an additional software application. The objective of this section is not to provide a detailed comparison of the chosen screen readers, as this will very rapidly date, but to provide an overview for readers unfamiliar with screen-readers with the general level of functionality available in the most popular systems.

The most widely used Web browser with Jaws and Window-eyes is Internet Explorer, though Firefox is accessible to Jaws and window-eyes users. Currently most Mac screen-reader users use Safari, the browser that comes with OSX. It is worth mentioning that some systems, for example, WebbIE, the browser that comes with the Thunder screen reader [20], greatly simplify the visual presentation of Web pages, for example WebbIE Reduces them to simple numbered lines of text.

2.2 Basic Browsing and Browsing Modes

Jaws and Window-eyes allow navigation through Web pages through the use of cursor keys in the same way users might read and navigate a word processed document. The browsing model used in VoiceOver is rather different. Firstly, on reaching an HTML page, the user needs to issue a keystroke to interact with the html content. VoiceOver supports two browsing modes: Document Object Model (DOM) mode, which is the mode most similar to cursor-based browsing in Jaws or Window-eyes, in which the user moves forwards or backwards through page elements linearly, and Group mode, in which users navigate between groups of elements such as links or text at a time. Group mode looses the detail of DOM navigation but provides a more rapid overview of the page. When in group mode,

the user must specify when it is required to start or finish interacting with the individual elements of a group.

2.3 Navigation Using Hotkeys

All three browsers provide broadly similar and simple mechanisms for navigating common elements of Web pages. This is done by enabling users to request lists of items of a particular type on a page and then selecting the specific item required, or to navigate forwards or backwards between items of a specific type. Item types typically supported include page element, frame, heading, link, table, form, form field, radio button, combo box, text element and place marker.

All three systems support hotkey navigation to the beginning or end of page and element and simple mechanisms for selecting links or browsing forwards or backwards between pages. Place markers in Jaws and Window-eyes are used to locate to a specific point on a page, saving time when one or more specific page locations are frequently required.

2.4 Overviews

Jaws and Window-eyes can provide summaries of page elements. These typically include the current url, the number of each of the major element types (forms, frames, headings, etc.) on the page, and a summary of hotkey strokes for navigating between them. These overviews are limited to the contents of the current page, i.e. they provide no site-wide context or indicators that links may lead to pages on different sites.

2.5 Forms

For a considerable time Jaws and Window-eyes have used a separate mode for the completion of forms. This additional mode is something that novice users can find confusing. VoiceOver does not require a change of mode for form completion and it is likely that the extra mode will be removed from at leased some Windows-based screen-readers in the near future. This is desirable for reasons other than reducing the additional cognitive load implied by the extra mode: while in forms mode typically one is not able to use the hotkey navigation commands described above, and cannot examine text appearing on the form. If the form is well designed to work with screen-readers so that labels for form fields are spoken automatically when the cursor enters the associated edit field this is not a problem, but if not, it can be necessary to exit and re-enter forms mode to check important text relating to fields to be completed. This can be both time consuming and frustrating.

2.6 Non-Speech Sounds

All three screen-readers provide some level of non-speech sound that could be leveraged to improve Web usability. VoiceOver is the most immediately usable of these, providing a range of sound cues as one navigates through different element types. Jaws and Window-eyes provide the ability to link sound files to

Web events, but leave this in the hands of the user or more likely the developer. We shall discuss proposed and potential uses of non-speech sound further in section five.

3 Implications For Web Cognition

In this section we shall examine mechanisms described in section two from the perspective of how well they support the development of effective models of Web pages, whilst balancing this against their overall contribution to Web usability.

3.1 Basic browsing and Browsing Modes

Employing the same mechanism for simple Web browsing as for other applications such as word processing and email can make things easier for users new to the Web who have experience of these other applications. Web documents are often quite different to documents occurring in other applications, however, and so presenting them as if they are the same could be misleading, but perhaps more importantly it potentially misses an opportunity to provide a more accurate and richer representation of how Web pages appear to sighted users. This observation is particularly borne out by our survey findings where we asked visually impaired and sighted users to describe Web pages, see section 4.1. Sequentially cursoring through page elements works best on simple pages without columns, but can be very tedious and confusing where more complex spatial layouts are employed and/or on longer pages.

Requiring an command to begin and end interaction with html documents, as in the VoiceOver approach, incurs an additional overhead, but does not break with the idea of treating HTML documents as other documents as this switching between overview and interaction modes is seen in many situations in the use of VoiceOver.

3.2 Navigation Using Hotkeys

Navigation through hotkeys, either by requesting a list of the instances of a specific type of element, or by navigating forward or backward between them, is one of the most effective ways that current screen-readers enable visually impaired users to build up a mental model of a Web page, or at leased certain aspects of the page, providing the user is aware of these commands and the elements have been used effectively in the design of the page. For example, listing or navigating the page headings can help to provide a partial overview of the page structure. In this way it is possible to build up an understanding of the different subareas of a page and the hierarchical organisation of information. Failure to use headings where they could be employed can equally make it harder to form a mental model of the page, as well as missing an opportunity to support rapid navigation. What may be missed by navigating by element type is an understanding of where the relative density of particular element types occurs

on a page, how much material occurs between adjacent instances of elements of the same type, or in some instances how elements are spatially laid out on the page.

Listing or navigating frames when available, especially when new to a page or task switching, can be of value, providing these have been designed around tasks that the page supports, but this in turn has to be balanced against the additional clutter that a frame-based design presents to the screen-reader. Place markers are a particularly interesting provision from the point of view of balancing the requirements for rapid navigation against support for the development of good mental models of Web pages. Place markers can be extremely helpful, particularly on long, busy or complicated pages, in enabling the user to go directly to the desired place on the page. This is a great time saver, but one thing that is likely to be lost in the process is a sense of context of the page or part of the page around the place marker. The extent to which this matters depends on the task/s to be performed, but as with all issues relating to spatial layout, it is more likely to matter where tasks are to be performed in collaboration with sighted users, who will still have the overall context of the page layout available to them and are likely to use it in referring to information on the page.

The ability to skip to the “next” different element again can save a great deal of time, though again it has a downside in that it provides no indication of the number of “same elements” that have been skipped over. Clearly presented information about single and nested list structures is likely to significantly reduce the cognitive load involved in interacting with these elements, though the cognitive load required is still likely to be higher than performing the same navigation visually.

Table navigation is much more feasible with current levels of support than previously, however the lack of a mechanism to overview subsets or entire tables of data greatly detracts from the value of tabular data for visually impaired users.

3.4 Overviews

The provision of page overviews or summaries in Jaws and Window-eyes can be of substantial value in assessing overall page size and complexity. What is not preserved in these summaries is any sense of the ordering of the different types of elements or their spatial orientation. It is hard to imagine an effective way this could be done concisely in speech, although it certainly provides an interesting candidate for data sonification (see section five).

3.5 Forms

The trend towards removing a specific mode for navigating and entering data into forms is likely to reduce the learning curve for new users and reduce cognitive load when using forms. However a related problem that comes with the increasing use of dynamically updating Web pages is that of making screen-

reader users aware of changes occurring elsewhere on a page in response to changes he/she has made in a form field.

3.6 Non-Speech Sound

In general, non-speech sound is under exploited in screen-reader systems, including access to the Web. Evidence of its potential value can be found in the VoiceOver approach of using different sounds for different Web elements. For example buttons are represented (in the default sound scheme) as relatively hard wooden sounds. These stand out as one quickly browses page elements, and so if from previous experience one knows where buttons or groups of buttons arise on a page they provide feedback on current location as one quickly browses the page. We examine the potential of non-speech sound support for Web browsing in detail in section five.

4 User Study

We conducted a study with sighted and visually impaired Web users in order to identify practical examples of the issues discussed in the previous sections. The study consisted of two parts, each focusing on an area that seems to us to be under represented in the current literature. We firstly examined the initial impressions sighted and visually impaired people formed of Web pages, to identify the features that seemed most prevalent to them and to explore the overall mental models they formulated of Web pages. The second part of the study examined the performance of collaborative tasks involving a sighted and a visually impaired user. In social, educational and work-based settings it is likely that visually impaired and sighted friends or colleagues will find themselves using the Web collaboratively.

4.1 Impressions and mental models of Web pages

We asked a number of sighted and visually impaired Web users to describe to us there initial impressions and more detailed understanding of the layout of a number of popular Web pages. Sites from which pages were drawn included the Guardian, Amazon, Facebook, Virgin Atlantic, MySpace, BTYahoo, Ebay, MSN, gigsandtours.co.uk and the BBC. Each participant was asked to go to the Web page concerned and describe the layout of the site, navigating it as they wished as they gave their description. Responses were audio recorded for later analysis.

4.1.1 Web page descriptions by sighted users

The striking thing about descriptions of Web pages by sighted users was the strong emphasis on visual appearance, how the page was laid out for example in columns, the aesthetics of Web page appearance and the emotional response this engendered. Frequently occurring terms in the first two sentences of Web descriptions included “themes”, “colours”, “pictures”, “style”, “overall layout”, “happy”, “cheerful”, “seasonal, “product centred”. The descriptions tended to be 4-5 sentences in length and provide an overview of the principle visual features

of the Web site and an interpretation of the underlying message implied by the designer of the Web page.

4.1.2 Web page descriptions by visually impaired users

These tended to be longer and much more factual in nature that the sighted users' descriptions, providing a more detailed description of the features of the site as encountered by the screen-reader user. Screen-reader generated overviews were employed to give a feel for overall site size and numbers of elements of different types, and some use was made of navigation between page headings and forms, but the dominant navigation mode was between individual elements. A few comments from screen-reader users related to the style of the site such as the use of frames, headers and overall consistency, but most comments related to functionality and usability. Not surprisingly, comments from screen-reader users on the overall layout of pages came towards the end of their page descriptions as it was only then that sufficient of the overall page structure was clear to make such comments possible.

The implications of the differences in responses to this survey are that sighted and visually impaired users approach tasks on the Web, collaborative or otherwise, with substantially different contexts, focusing on widely different characteristics of the site.

4.2 Task-Based Study

4.2.1 Experimental procedure

The collaborative tasks required pairs of sighted and visually impaired users to complete a Web-based task together. The setup we employed was for one of the pair to tell the other what was required, while the other tried to follow these instructions. When the visually impaired participant was driving the task they had the Web site available to them using their preferred screen-reader. When the sighted person drove the task they could look at the screen of the PC being used by the visually impaired user performing the task. All of the tasks used Window-Eyes or Jaws as the screen-reader and Internet Explorer as the browser. The Web sites employed were the same as those used for the survey of impressions of Web pages. The collaborative tasks were either video or audio recorded as well as direct observations being noted by a researcher not involved in the task. The tasks included simple information searches, comparisons of data, completing forms up to the point of booking flights or concert tickets, checking news and weather information.

4.2.2 Results of collaborative task performance

In general, tasks were performed more quickly and with fewer difficulties when the task was driven by the visually impaired partner. the fact that the sighted user could view more Web content enabled them to compensate for situations where the visually impaired user described Web layout somewhat differently to how it appeared to the sighted partner. The few significant misunderstandings that did

arise were handled by the two participants spending from a few seconds up to a couple of minutes clarifying where on the screen they were working or where they required they other partner to be. A significant barrier to rapid clarification of these discussions was the fact that the sighted user was unable to see the current focus of the screen-reader, something that is handled well in the VoiceOver screen-reader and is being addressed in Windows-based systems. A further source of miscommunication occurred when sighted users referred to spatial layout which was not included in the screen-reader presentation of the page.

Significantly more problems were encountered where the sighted person was driving the task and the visually impaired person was carrying it out. Here the unseen screen-reader focus and gap in spatial presentation also were significant barriers to successful task completion. A detailed description of the numerous other issues encountered is beyond the space available here, but we will be happy to provide more details on request.

4.3 Towards a taxonomy of collaborative error

We collated the errors across the range of collaborative tasks and classified them into what we propose as an initial draft of a taxonomy of collaborative human error for the cross modal tasks described above.

1) *Location disconnects:* Errors due to one of the parties not knowing where the attention of the other is currently focused.

2) *Layout disconnects:* brought about by references to spatial organisation of content by one party that is unavailable to the other (often columns).

3) *Missing objects:* reference to an object such as a text item, image or description by one party that is not unavailable to the other.

4) *Navigation disconnects:* due to differences in how the parties navigate pages, (e.g. mouse v. keystrokes including those provided by screen readers). These may not necessarily bring about errors in tasks but they certainly have an impact on task continuity.

5) *Contextual disconnects:* references to objects or layout around a point of interest by one party that is not readily available to the other.

6) *Affordance disconnects:* when something visually suggests you can perform an action but the affordance is not captured in the Screen-reader representation.

7) *Accessibility gap:* caused by use of something which by its very nature is inaccessible and where no alternative mechanism is provided. Examples of these

include Captchas where no audio is provided and images/maps where it is required to click on the object to navigate to part of the site.

8) *Hollistic disconnect:* refers to one party having a more effective overview of the page or even entire site which provides affordances such as being able to quickly identify the quickest way of performing a task.

9) *Points of focus disconnect:* where one party has the ability to focus simultaneously on more locations on a page than the other party, for example enabling them to deal with dynamic page updating more effectively.

10) *Aesthetics disconnect:* aesthetics are virtually not conveyed at all by screen-reader (only wording and perhaps some feel for density of information). These do not generally lead to errors but do impact on the overall impression of Web sites.

5 Discussion

5.1 The Case for Sound

The case for the use of audio in unseen Web interaction is compelling. In general it is inexpensive, integrated and widely available. Products such as Jaws and Window-eyes support both audio and Braille as output media, but the majority of their users employ audio as the dominant output mode, either because they are unfamiliar with Braille or because Braille, for most users, is slower to use as an output medium. Over a relatively short period of regular use, the speed of audio output can be increased considerably enabling users to review information relatively quickly. Whilst it is acknowledged that for some users and some tasks, Braille is the preferred medium, in general we consider that where possible, improvements to screen reader systems should at a minimum be made available through audio, in order to benefit the majority of users and avoid the extra cost and inconvenience of additional hardware. This is not to decry the development of multimodal approaches to improving screen-readers, as these may make possible or greatly simplify tasks which are inherently difficult using audio alone [15, 16, 18].

5.2 Non-speech Sound

The vast majority of audio output in current screen-readers is in speech. Even though a growing body of research is providing increasing evidence of the potential of using sound to convey information (see www.icad.org) the explicit use of non-speech sounds in commercial assistive technologies remains limited. The release of Jaws version 5 [5] contained the first use of non-speech sound to customise the feedback provided to users about current states of the interface. However, setting these behaviours is not a trivial task, one that requires users to be both aware of the existence of such functionality and to have the will and patience to create sound schemes that suit their needs. In practice this means

that users tend to rely on the existing default speech-only output of their screen-reader, and so continue to encounter many of the problems associated with accessing the Web through speech alone, such as those categorised in the previous section.

Research into Auditory Display (AD) and Sonification [11] is providing a growing body of knowledge describing how to efficiently design and use auditory output in a variety of contexts, including the area of assistive technology. A number of techniques have been developed and thoroughly investigated to convey information using non-verbal sounds by exploiting the characteristics of human auditory perception and the nature of audio as a medium of communication and interpretation. We believe that such techniques are still under-explored in screen-reader technology and can be effectively used to enrich non-visual Web interaction.

5.2.1 Alerts & Monitoring

The dynamic components of Web pages are not easily picked up by screen-readers, which means that users must revisit parts of a page where new information or new objects might have appeared as a result of their interaction and manipulations. Non-speech sounds could be used to convey such dynamism by signalling relevant events as they occur on the page. This can help users developed appropriate awareness of how their interaction with a given Web page is affecting its content, and so allow them to explicitly attend to particular parts of that Web page as required. Auditory display techniques such as Earcons [2, 3] or Auditory Icons [7], which are short musical and environmental audio messages respectively, can form a powerful addition to the speech output of screen-readers to enhance awareness and monitoring of dynamic Web content in this way.

5.2.2 Ambient and Continuous Sound

The use of ambient continuous sound is another auditory presentation technique that has been found to improve interactive experiences and that is currently not supported by commercial screen-reader technologies. Ambient and continuous sound displays to convey contextual information have been effectively used for supporting auditory interaction with diagrammatic representations [14] and for monitoring real-time information such as financial market data [10]. This technique can be exploited to decrease location and point of focus disconnects by, for example, reflecting which mode of interaction a user is in as well as the surrounding content of the current object of focus.

The inclusion of ambient sounds in screen-reader based Web interaction could not only enhance awareness of location and density of elements within a Web page, but could also be exploited to represent the virtually non-existent presentation of aesthetics when accessing Web sites through a screen-reader. For instance, different themes of ambient continuous sounds can be used at different parts of a Web page to best reflect its aesthetical and emotional content. Furthermore, inclusion of such a display technique could enhance referencing in

collaborative interaction because it promotes contextual awareness within the interactive environment.

5.2.3 Rich Auditory Representations

It is clear that the visual appearance of objects on a Web page can convey affordances and indicate possible interactions. This is important information that is completely lost when the same objects are accessed using a screen-reader. The use of non-speech sounds as well as parameterised speech output can decrease affordance disconnects by enabling the perception of affordances of particular components of a Web page by representing the affordance in audio.

5.2.4 Spatial Sound & Multiple views

Another auditory display technique which has been increasingly investigated is the use of 3-dimensional spatial sound to organise auditorally presented information [21, 8]. This can be used to enhance audio-based Web experience by representing different clusters of Web content along a virtual 3-dimensional auditory display. 3D spatial audio could thus be used to convey the holistic impression of Web sites in a similar way that visual appearance does and so reduce potential holistic and layout disconnects. Spatial sound can also be used to enhance features of multiple views of the Web content currently supported by screen-reader technology. For instance, while switching between a links or a headings view usually leads to a loss of spatial information of such components relative to the rest of the page content, a 3-dimensional organisation of the preserved information in each perspective can help maintain the structure of the content while filtering unnecessary information.

Allowing the presentation and interaction with multiple views of the same content has been found to improve user performance when accessing visually represented information through non-visual means [12, 13]. Adding a spatial auditory presentation to organise the information preserved in each view could further improve spatial referencing when sighted and visually impaired users collaborate to complete Web-based tasks by allowing more coherent locus of attention between collaborating parties, this in turn could improve coordination and communication, and thus reduce the potential for location disconnects.

6. Conclusions

We have seen how much of the functionality provided by screen-readers, while providing a range of mechanisms for navigating Web pages, falls short of conveying information relating to spatial layout and assisting users developing good mental models of Web pages. The results of our survey asking sighted and visually impaired users to describe Web pages demonstrated substantial differences between the two user groups in their perception of Web pages: the former emphasising aesthetics, mood and spatial layout, the latter focusing on detailed organisation of pages, the presence of specific element types and usability features. The results of this analysis and survey suggest that sighted

and visually impaired users approach Web collaboration with very different mental models of the environment in which the collaboration is to take place.

The study of collaborative tasks involving pairs of sighted and visually impaired users enabled us to identify a number of different categories of error that arise within a collaborative context, which in turn led us to propose a draft taxonomy for such errors. We finally examined the under-utilised area of non-speech sound as a means of resolving some of the shortcomings identified in current screen-reader systems and proposed an agenda for how elements of non-speech sound might be used to address different categories of the error taxonomy. In future work we propose to develop and evaluate a series of demonstrator applications to examine their effectiveness in addressing the error categories identified, the categories themselves no doubt becoming more clearly defined over time.

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